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Managerial decision-making from the perspectives of behavioral science and neuroscience

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Wuke Zhang, Peter Ping Li, Jie Yu, Liuting Diao and Senqing Qi

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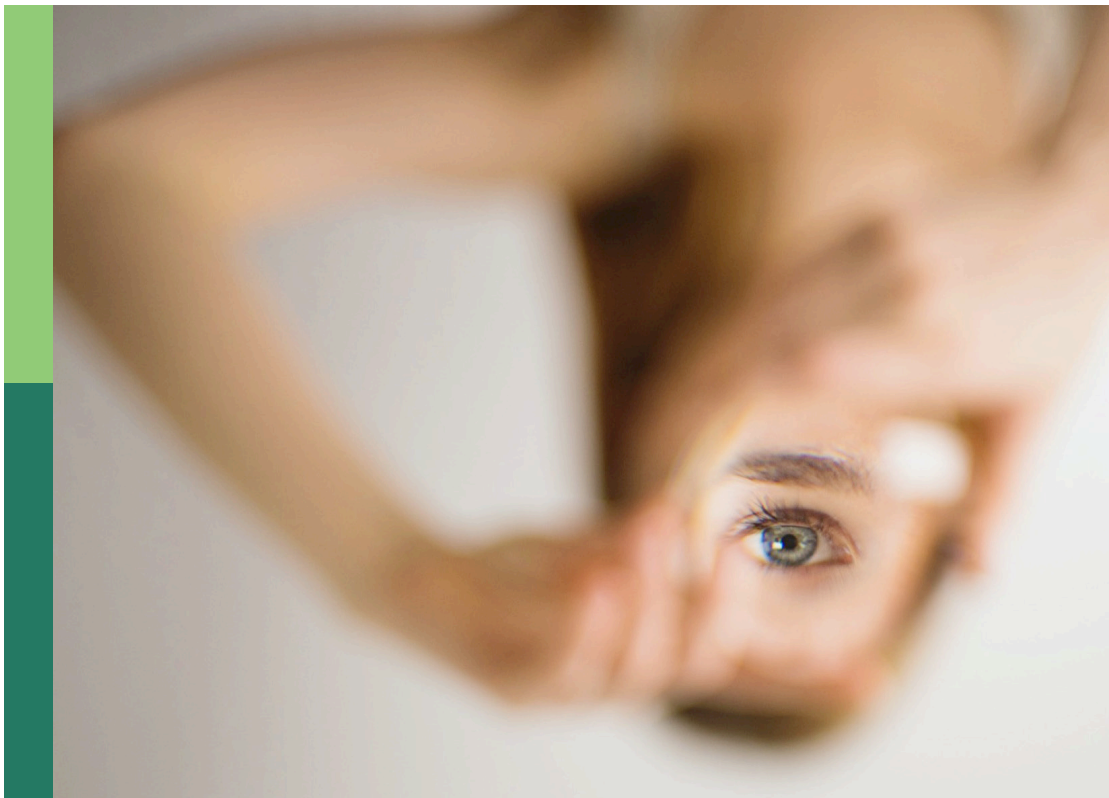

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Managerial decision-making from the perspectives of behavioral science and neuroscience

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Editorial: Managerial decision-making from the perspectives of behavioral science and neuroscience

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Editorial on the Research Topic
Managerial decision-making from the perspectives of behavioral science and neuroscience

Introduction

The past two decades have witnessed the boom of research in exploring managerial decision-making and relevant processes, in which more and more scholars have creatively tried to apply new tools and theories from behavioral science and neuroscience and a series of valuable and remarkable findings have been accomplished in multiple sub-disciplines of management (Camerer and Yoon, 2015; Plassmann et al., 2015; Kirwan et al., 2022; Li et al., 2022). Scholars have used these tools and theories to explore underlying decision-making mechanisms (Ye et al., 2022; Zhang et al., 2022), analyze implicit processes (Plassmann and Weber, 2015; Zhang et al., 2019a), identify individual differences (Plassmann and Weber, 2015; Huang et al., 2021) and produce more accurate predictions of behaviors (Venkatraman et al., 2015; Baldo et al., 2022) in managerial decision-making research areas. Recently, apart from the managerial decision-making periods, researchers are at the same time making more efforts on the fascinating periods preceding and following decision-making behaviors by using behavioral science and neuroscience tools (Karmarkar and Plassmann, 2019).

While acknowledging the development of research in managerial decision-makings, it should also be noticed that most previous studies mainly focused on the research area of marketing especially in consumer behavior, which leaves other managerial decision-making areas, such as investment behavior, operation behavior etc., a void to be filled. Although managerial decisions such as investment and operation are influenced by various factors (e.g., risk, cost, and potential profit), they are finally made by senior executives (Orth, 2002; Zhang et al., 2019b). Thus, tools and theories from behavioral science and neuroscience would also be appliable and accountable for better understanding other managerial decisions mentioned above.

Taking the whole foregoing arguments into consideration, this Research Topic aims to call for a wide range of studies on managerial decision-making using behavioral and/or neuroscience technologies and methods. And it is fortunate to see the Research Topic has attracted a wide range of high-quality submissions from various disciplines. Based on methodologies and research issues, we finally selected 24 exquisite articles in this Research Topic and classified then further into five categories. The main findings and perspectives are summarized as follows.

Consumer behavior research from the perspective of behavioral science

The first part picks 7 published articles, which mainly adopt empirical methods for consumer behavior research from the behavioral science perspective. With rapid advancement of virtual reality technology, Wang L. et al. investigate the thermal comfort and satisfaction of virtual tourists. Based on the data collected from microclimate simulation experiments and subjects' electrocardiogram, their results show that the thermal comfort of virtual tourists is heavily affected by environmental temperature. Their research provides abundant practical implications, especially in promoting the thermal comfort of tourists and reducing the difference between low and peak travel seasons. Gao, Jiang, et al. explore the source of short video customer inspiration and construct the formation path model of customer inspiration. Their research extends short video marketing and has implications for online marketers. Wang takes a new perspective by focusing on the influence of consumer sentiment on assertive advertisement attitudes. Their research reveals that anxious consumers are more likely to choose assertive advertisement. Ding et al. further expand the existing research on the effects of metaphorical advertisements and straightforward adverts. They explore the effects of both types of advertisements on social media and find that the type of social media advertisement had no significant effect on visual attention. By collecting field data on physiological parameters, Rinklin et al. prove that American and Chinese consumers are different in their exposure to novel products. Their findings suggest that new product development and applied marketing should be adapted to local conditions. Chen T. et al. study the underlying mechanism of how online reviews affect consumer purchasing decisions by using eye-tracking. Their findings suggest that consumers are unable to discern fake reviews and pay more attention to negative ones. Gao, Zeng, et al. prove the effect of presence and customer inspiration on impulse purchase intention in short video marketing by using questionnaire survey and three laboratory experiments. Their results provide valuable reference for marketing strategies to shorten consumers' decision-making time in short video purchase.

Empirical studies on consumer neuroscience

The second part selects seven papers, which all use neuroscience tools to empirically explore consumer psychology or behavior. Song et al. explore how individuals with different levels of empathy respond to distant brand extensions under corporate social responsibility and corporate competence associations by using ERPs. They provide potential electrophysiological evidence for the positive impact of brand associations on the evaluation of distant brand extension in the case of subdividing different empathic individuals. In an attempt to address the waste of recycled water use on campus, Liu et al. adopt ERPs to explore the effect of social norms on the willingness to use recycled water and the neural mechanism of cognitive processing. They find that college students pay more attention to social norms in groups with closer social distance and thus suggest that forming the social norms of recycled water usage should begin with the group with close social relations. Peng-Li et al. investigate the combined impact of cognitive regulation and ambient noise on food cravings through neurophysiological activity (i.e., electrodermal activity and electroencephalography). Their findings provide a more comprehensive and objective picture of the factors that influence food-related decision-making. With the rapid development of the take-out industry, Wang C. et al. explore how consumers are affected by taste and hygiene ratings by incorporating behavioral and neural approaches. By focusing attention, cognitive conflict, and decisional confidence that are measured by ERPs, their results uncover the decisional process of online food-ordering when consumers are exposed to taste and hygiene ratings simultaneously. Jing et al. adopt ERPs to explore the effectiveness of price promotions in purchasing affordable luxury products and find that price promotions for a high-priced affordable luxury product are effective, but it is not the case for a low-priced affordable luxury product.

In this part, another two more papers used other neuroscience tools, rather than ERPs, to study consumer psychology and behavior. Kim et al. study the neural mechanism of price and customer ratings affecting consumers' purchase of hedonic products by using functional magnetic resonance imaging (fMRI). Their results suggest that brain regions associated with social cognition are involved in customer ratings, not price, in the process of product selection and evaluation. Fu et al. investigate the influence of consumers' implicit awareness on public service announcements by employing functional near-infrared spectroscopy (fNIRs) and find a correlation between activation of dorsolateral prefrontal cortex (dlPFC) and the effectiveness of public service announcements. Their findings suggest that neuroimaging tool (e.g., fNIRs) can also be used to investigate the effectiveness of public service announcements, not just commercial advertisements.

Business decisions beyond consumer decision-making

In the third part, there are four articles focusing on the business decisions beyond consumer decision-making and various research methods are applied in these articles. Du et al. study the effect of adopting a dual channel supply chain on the performance of a two-level system (manufacturer-retailer) by using a novelty quantitative approach. Their results suggest that the potential market demand for customization affects the price of customized products and the profits of customized channels. From the perspectives of manager cognition and behavior selection, Han et al. discuss the driving mechanism for manufacturer's decision of green innovation. The authors suggest that making green innovation decisions should match the cognition of managers' efficiency logic and their cognition about sustainable development. Wang X. et al. discuss how bank credit willingness is affected by the scale of third-party logistics guaranteeing firms in supply chain finance. They find large-scale 3PL guaranteeing firms receive more positive comments from credit decision makers. Their study reveals the neural processing of credit decisions and expands the theory of credit scale discrimination in the field of decision neuroscience, which is quite rare in previous studies. To address the problem of frequent dishonest transactions by online shopping platform merchants, Chen H. et al. develop monopoly and competitive platform pricing models based on two-sided market theory. They find the impacts of monopoly and consumer information levels on platform pricing, number of bilateral users, and profits.

Basic studies in the field of management psychology

The fourth part contains four papers that explore contemporarily valuable and fundamental issues in the field of management psychology. Zhou et al. explore how incidental affect impact on intertemporal choice. Their results of the two studies indicate that positive incidental affect leads to longer time perception and more attention to the delay attribute of intertemporal choice, which leads individuals to prefer immediate options in the intertemporal choice. Boredom is a common emotion suffered by humans, and Chen and Rau study the relationship between boredom and prospective memory. They use alpha oscillations to examine the relationship between the two factors and indicate the key role of attention management and visual information because they could help prepare for prospective memory. Their findings suggest boredom and prospective memory are linked by parietooccipital oscillations. Sugawara and Katahira explore why people persistently pursue a difficult target. They conduct an online experiment to investigate the hypothesis that choice perseverance leads individuals to repeatedly choose a hard-to-get target. An important finding of this article is that people with high choice perseverance pursue hard-to-get targets. Their results are of great significance to understand the psychological mechanism by which people adhere to long-term goals. Zheng et al. study the relationship between response (in)consistency and the first mover's anticipation. They design a dual-player gambling task to investigate how this inconsistency would influence their anticipation. Their results reveal evaluation of the performance feedback in gambles and suggest the consistency in social information affected the anticipation of outcomes.

Systematic reviews on the research trends of neuroscience in marketing and information system

The fifth part collects two review papers, which analyze the application of neuroscience in the fields of marketing and information system respectively. Zhu et al. conduct a systematic review with a bibliometric analysis on neuromarketing research trend from 2010 to 2021 based on the Web of Science database. The authors explore the mapping of co-citation, bibliographic coupling, and co-occurrence, as well as popular research at different time stages and the research trends of neuromarketing research methods and tools. This study provides an overview of the trends and paths in neuromarketing. As NeuroIS has emerged as a new cutting-edge research field, Lin et al. perform a bibliometric analysis to identify, summarize, and classify existing NeuroIS publications from 2010 to 2021. Their results provide a picture of the development trajectory of NeuroIS studies and reveal potential Research Topics in the future.

Conclusion

In summary, our Research Topic (RT) distills 24 articles that come from various subjects, covering a wide range of research themes. Based on methodologies and research issues, these articles are classified into five sections. The first section, entitled "Consumer behavior research from the perspective of behavioral science," shows the values of behavioral methods in exploring the potential influencing factors and causal relationships in consumer behavior field. The second section, entitled "Empirical studies on consumer neuroscience," indicates the advantages of neuroscience methods in identifying underlying decision-making mechanisms, measuring cognitive and mental processes, and better understanding individual differences. The third section, entitled "Business decisions beyond consumer decision-making," shows that, apart from consumer decision-making, other business decisions can also be studied from the perspectives of behavioral science and neuroscience, which can also provide valuable insights for the decision-making mechanism. The fourth section, entitled "Basic studies in the field of management psychology," discusses some fundamental and interesting issues (e.g., intertemporal choice, reasons of pursuing hard-to-get targets) in the field of management psychology by using various behavioral and neuroscience methods. The fifth section, entitled "Systematic reviews on the research trends of neuroscience in marketing and information system," provides a more holistic picture of current trends and future directions about the application of neuroscience in the fields of marketing and information system.

In the future, we hope to see more international cooperation to generate more up-to-date articles, which can bring us the most cutting-edge managerial decision-making research. More research is also needed to explore different possibilities for the managerial decision-making. At the same time, new research methods and mixed research methods can also be explored in a more creative way to bring us new ideas and insights in our research area. We all sincerely expect that people can learn about interesting knowledge and research of managerial decision-making in our topics.

Author contributions

WZ and JY wrote the whole manuscript. LD collected the references and all published paper in this Research Topic. SQ provided guidance throughout the entire paper and revised the manuscript. All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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ORIGINAL RESEARCH
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The Triggering Mechanism of Short Video Customer Inspiration – Qualitative Analysis Based on the Repertory Grid Technique

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It is believed that stimulating the inspiration of short video consumers might be an effective way to attract and maintain the attention of consumers so that they are willing to respond positively to short video ads. Therefore, in order to explore the source of customer inspiration in short video and its cognitive psychological process, the text and grid data collected from an interview among 25 short video users have been qualitatively analyzed by Kelly Grid Technology in order to construct the formation path model of short video customer inspiration, and find out its source, triggering mechanism, and influencing factors. It is found that the inspiring informational content characteristics include richness, reliability, vividness, and fluency of emotional content characteristics, fun, novelty, and narrative. However, the characteristics of commercial content in short video ads hinder the inspiration of consumers. The study also reveals that an internal mechanism of inspiration stimulation is built on some cognitive processes (i.e., presence, processing fluency, perceived innovation, perceived convenience) generated by informational content, and emotional responses by emotional content (i.e., curiosity, surprise, enjoyment, etc.). In addition, it is shown that personal involvement enhances the relationship between the inspiring content characteristics and consumer inspiration. As a result, customer inspiration and engagement in short video ads are highly enriched. Findings provide implications for short video platforms and online marketers.

Keywords: short video ads, customer inspiration, cognitive processing, emotional process, repertory grid

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INTRODUCTION

With the explosion of information in the era of social media, the limited concentration of consumers is easily distracted or even hardly captured. Despite the vitality and abundance of internet video advertisements, they are also short of effective method to attract the attention of consumers (Teixeira et al., 2012). Therefore, to better engage and maintain the attention of viewers in communication through digital channels, online content producers begin to create short video advertisements (featured by its limited length within 30, 20, or even 10 s) to promote the dissemination of product information and consumer purchase (Liu et al., 2018). A derivative of the Internet age, short video differs from the tradition long video in that filming and editing of

a seconds-long video can be completed on mobile intelligent terminals and shared in real-time on social media platforms. Short video ads, therefore, have become a direct pathway to achieve commercial value of short video platforms such as TikTok and Kwai by raising the transmission and acceptance of short video ads among users who have been gathered in a huge number and precisely directed to certain personalized advertisements. Undoubtedly, when short video becomes one of the most popular recreational forms in the mobile Internet era, short video ads are naturally transformed into a major tool for brands and merchants to promote new products and establish communication and positive relationships with their customers.

While short video ads can be an effective marketing tool, it is far from enough to simply rely on the unique or appealing content to improve its marketing performance. On the one hand, consumers who have been constantly suffering from concentration difficulties may swipe the phone quickly to avoid watching short video ads because of their aversion to the commercials (Nikolinakou and King, 2018). Additionally, given the low purchase conversion rate of short video ads, whether the content that attracts the attention of consumers can motivate purchasing behavior remains an important challenge for current research. For these reasons, the critical issue that should be addressed by online marketers is to find out effective ways to attract and stimulate positive response from consumers. The relevant studies on consumer behavior are, therefore, highly announced and promoted. However, few studies have been found to concern about changes and influencing factors in consumer behavior in relevant context. Although Liu et al. (2018) found that effective editing of short video scenes can enhance the willingness of consumers to watch the video. The findings of which are more applicable to the edition of old videos produced by brand owners, rather than to the creation of new ads, both showing significant difference (Diwanji and Cortese, 2020). Furthermore, prior studies have mainly explored the content characteristics that drive online behaviors such as browsing and sharing in the context of video advertising (Teixeira et al., 2012; Yang and Wang, 2015; Lee and Hong, 2016; Akpinar and Berger, 2017; Nikolinakou and King, 2018; Tellis et al., 2019; Guitart and Stremersch, 2021). It is still questionable whether the theoretical framework based on traditional video ads can be transplanted to the study of short video ads that are fundamentally different in terms of generating and propagating information from the former. For example, TV ads are accused of high expense and low consumer engagement, and online long video ads fail to fit the "staccato" quality of online browsing. Since existing research have difficulty in the solution of effective conversion of consumer attention into real purchase, further research should be developed with a focus on short video advertisements.

Recent research on "customer inspiration" may shed light on the way of capturing and maintaining the attention of short video audiences so as to inspire their positive response. Customer inspiration consists of cognitive activation and intention driver, which describes the internal activation state that encourages the attention of the consumer and new ideas for practice (Thrash and Elliot, 2003, 2004; Böttger et al., 2017). Specifically, customer inspiration will lead to positive emotional experience such as pleasure and surprise. This is an important way to arouse and maintain the attention of the consumer and improve the efficiency of video advertising communication (Teixeira et al., 2012). Customer inspiration will also lead to goal pursuit motivation. Consumers in an inspired state will be motivated to achieve consumption-related goals so that they will impulsively buy some products or services beyond their plan (Böttger et al., 2017). Clearly, inspiration not only encourages the active participation of the consumer in short video ads and voluntary search of inspirational content, but also motivates purchases of products and services within their targets. According to some recent studies, social media, as a new marketing channel, has become an important source of inspiration (Dale et al., 2017; Sheng et al., 2020). Creative short videos should have unique advantages in triggering the inspiration of customers, but no study has been reported to specifically explore the source of the inspiration of customers and its psychological processes. Therefore, this article attempts to address this gap in terms of customer inspiration and relevant theories. Specifically, we aim to answer the following research questions: (1) What are the characteristics of short videos that help to trigger customer inspiration? (2) What is the psychological mechanism of customer inspiration triggered by short video? (3) What are the influencing factors on the triggering mechanism? Resolutions to these problems will enrich the understanding of customer inspiration in short video advertising and help to improve the purchase conversion rate of short video advertising.

LITERATURE REVIEW

Characteristics of Advertising Content

In spite of the significant differences between video advertising and short video advertising in terms of production methods and communication forms, they both essentially reconstruct product attributes, functions, and other business information through audio-visual symbols. In addition, considering that short video research is in the ascendant, it is advisable to refer to the previous studies on video advertising so as to explore the advertising features that can promote communication and consumer purchase. According to the content feature framework of online video advertising shared by consumers (Tellis et al., 2019), informational content, emotional content, and commercial content are the most important driving factors. These factors are controlled by advertisers and have been tested true both theoretically and empirically.

In the classic integrative models of advertising, informational route and emotional route are two main paths to influence consumer attitudes (Macinnis and Jaworski, 1989). They can have a differentiated impact on searching, sharing, rating, and purchasing (Yoo and MacInnis, 2005; Lee and Hong, 2016; Akpinar and Berger, 2017; Tellis et al., 2019; Guitart and Stremersch, 2021). First, information focused content aims to convey information cues related to product attributes, price information, promotional activities, and brand events (Chandrasekaran et al., 2017), which usually involves a propagating argument or factual description (Tellis et al.,

2019; Guitart and Stremersch, 2021). Obviously, by objectively describing the advantages of the brand or product, the informational content of advertisement satisfies the appeal of consumers and improves brand beliefs (Chandy et al., 2001). Some scholars also believe that informational content is crucial in persuasion and communication (Hsieh et al., 2012). Consumers will regard this kind of information as fairer and less manipulative, and the positive inference will increase brand search and purchase intention (Chandrasekaran et al., 2017). However, Tellis et al. (2019) takes the fact-centered informational content as particularly dull and boring, and even irritating unless in such high-risk situations that involves new products or high prices, which results in lower advertising sharing willingness. In response to the above contradictory conclusion, Akpinar and Berger (2017) proposed that if consumers are motivated to actively deal with advertising information, they are to obtain brand and product knowledge that help them to make purchasing decisions, and ultimately improve their evaluation of informational content. Therefore, the informational content of advertisements provides consumers access to awareness of useful or unique features of the product in some special situations (Yoo and MacInnis, 2005), and, as a result, promotes positive consumer attitudes and behaviors.

Secondly, emotion-focused content aims at arousing the emotional response of consumers (Chandrasekaran et al., 2017), which includes positive or negative emotions (Tellis et al., 2019). Different from the complex impact of informative content on consumer response, advertisements with emotional appeal are believed to be more persuasive (Berger and Milkman, 2012; Teixeira et al., 2012; Nelson-Field et al., 2013; Nikolinakou and King, 2018). In fact, emotional content produces many important advertising results, such as viewing time (Teixeira et al., 2012) and advertising sharing (Akpinar and Berger, 2017; Tellis et al., 2019), purchase intention (Lee and Hong, 2016), and sales (Chandy et al., 2001; Guitart and Stremersch, 2021). Furthermore, previous literature explores the advertising characteristics that stimulate the emotional experience of consumers. For example, Tellis et al. (2019) found that drama, plot, characters, and surprise are positive factors that trigger emotions and sharing activities, while mood and music can build emotions and orientations (Yoo and MacInnis, 2005). More importantly, Liu et al. (2018) found that effective editing of rhythm, sequence, and sound in a short video can control the emotional experience of consumers and improve their willingness to watch. Generally speaking, except under some risky conditions, the emotional characteristics displayed in the ads will produce a greater impact on consumer behavior.

In addition, distinct from the content produced by non-marketers, commercial nature and persuasive intention are important characteristics of advertising. Tellis et al. (2019) defined commercial content as the one that influence consumer support to branded product or service, such as a brand logo on an advertising screen. It is worth noting that, the persuasive knowledge activated when the advertisers use commercial content to establish positive brand association for the consumers will also attract the attention of consumers to the features of implanted products, which in return results in the undervaluation or resistance of consumers to persuasive information (Friestad and Wright, 1994), and even unwillingness to share (Akpinar and Berger, 2017). Worse still, the significant commercial motivation of video advertising reduces the effectiveness of content characteristics that originally tend to promote the willingness of consumers to share (Tellis et al., 2019). In summary, the higher the intention of video advertising, the lower the willingness of consumers to share.

Customer Inspiration

Customer inspiration is the specific application of the classical social psychology concept "inspiration" in the marketing situation (Thrash and Elliot, 2003, 2004), i.e., a temporary activation state that prompts the customer to move from a marketing-guided mindset to an internal pursuit of consumption-related goals (Böttger et al., 2017). In this article, the concept of "short video customer inspiration" is used as the specific representation of customer inspiration in the context of short video advertising. Further, Böttger et al. (2017) proposed that customer inspiration is a second-order construct consisting of 'inspired-by' and 'inspired-to' states. The inspired-by activation state relates to the reception of a marketing-induced new idea and the shift in customer awareness toward new possibilities. Comparatively, the inspired-to state relates to the intrinsic pursuit of new ideas and consumption-related goals. Many studies have confirmed that concerns about customer inspiration are valuable in predicting such positive behavior, emotion, and attitude as increased purchasing intention and purchasing behavior (Winterich et al., 2019), pleasure and surprise (Böttger et al., 2017), and customer satisfaction and loyalty (Herhausen et al., 2019).

By combing relevant literature, a large number of empirical analyses have been conducted on the sources of customer inspiration, and their results provide certain implications for research on the triggering mechanism of customer inspiration in short videos. Customer inspiration is not spontaneous but induced by external stimuli of intrinsic value (Thrash and Elliot, 2004). Böttger et al. (2017) proposed that the most inspirational marketing stimulus contains three source features, namely, the provision of inspirational content, appeals to use the imagination, and elicitation of an approach motivation. It is found in some empirical studies that utilitarian and hedonic content have a positive impact on customer inspiration (Izogo and Mpinganjira, 2020). For example, novel and vivid advertising information helps consumers acquire new ideas and imagination, thus triggering customer inspiration (Böttger et al., 2017; Winterich et al., 2019). In addition, advertising information targeted to the specific emotional demands of consumers can also be inspiring. Bischof et al. (2020) observed that the desire of consumers for exploration is contented by the astonishing subscription service, and they are therefore inspired to try new things. Similarly, donation advertisements that evoke strength emotion (Liang et al., 2016) and travel destinations that lead to attachment emotion (Khoi et al., 2019) also have unique enlightenment because they can arouse the inner interest and motivation of consumers to pursue their goals.

Summary of Literature

From the above literature review, it can be seen that: (1) previous studies on advertising are based on the conceptual framework of informative, emotional, and commercial content, deeply exploring the factors that influence the effectiveness of advertising. Most of the discussions focus on advertising attitude, brand evaluation, viewing behavior, purchase intention, sharing intention, sales, and other dependent variables. However, as mentioned above, customer inspiration that includes cognitive activation and intention-driven components is more helpful to resolve the urgent problems in short video advertising, that is, how to attract and maintain the attention of consumers and prompt them to make a positive response. Unfortunately, there is no research taking customer inspiration as the key concept to explore the effectiveness of short video advertising, which should have been a new perspective in the field. (2) A number of advertising features related to information, emotion, and commerce have been identified, and marketing drivers with heuristic traits (informative and emotional) have also been extensively validated. However, the short video, as a new media, is different from other social media applications in terms of content generation, display, browsing and transmission (such as graphic posts, long videos, micro-films, and live broadcasts). Moreover, customer inspiration largely depends on the situation that generates it. The existing characteristics of inspiration may not be applicable to short video advertising. It is therefore necessary to use the current content framework to explore new factors that influence the generation of inspiration of short video customers and its triggering mechanism.

METHODOLOGY

Repertory Grid Technique

This study aims to explore the triggering mechanism of customer inspiration in short videos. In view of the lack of mature theories and studies on this issue, the qualitative research method is given priority. Specifically, the Repertory Grid Technique (RGT) has been adopted in research interviews and data collection. RGT originates from the personal construct theory in cognitive psychology. The constructs accumulated in life are used to explain and predict the events around (Kelly, 1955). Kelly (1955) pointed out that an individual only has a limited number of constructs that are bipolar in nature. For example, the description of consumers of short video advertisements can be 'interesting or boring,' 'novel or plain,' 'lively or bald,' etc. Therefore, RGT is mainly used to extract individual constructs that judge complex things or phenomena (Kelly, 1963). This is especially appropriate for exploring the topics whose answers are indirectly known and implicit knowledge that cannot be conveyed directly (Goffin et al., 2006).

Although customer inspiration is not essentially a mystic experience (Thrash and Elliot, 2004), it is still challenging for consumers to specify the concept of or access to inspiration (Rauschnabel et al., 2019). In addition, compared to other qualitative methods that are easily affected by subjective bias of researchers in data collection, RGT grants respondents the maximum freedom to comment on a topic so as to ensure the authenticity and accuracy of the data (Goffin, 2002), and therefore has been gradually used as an effective qualitative instrument in marketing research (Lemke et al., 2011; Macdonald et al., 2016; Kawaf, 2017). Recent studies also showed that RGT is particularly applicable for the study of the cognitive and emotional experience of digital consumers (Kawaf and Istanbulluoglu, 2019). It is worth mentioning that some novel methods similar to RGT (such as Dynamic EMCUD and VODKA) have recently been developed to obtain dynamic knowledge that is constantly updated and evolving with environmental changes (Lin et al., 2008; Tseng and Lin, 2009). Other methods, like ZMET, were used to resolve important problems in marketing practice by integrating RGT in the method (Coulter et al., 2001). Obviously, in these methods personal construct theory and RGT serve as crucial access to consumers tacit knowledge, which also confirms that RGT allows a better solution to problems on cognitive decision making. In general, RGT helps to uncover the source and cognitive process of inspiration when consumers are exposed to short video advertising.

Sample Selection

As a unique qualitative research method, RGT is characterized by numerous and time-consuming interview steps, which makes it possible to extract enough constructs from 15 to 25 samples to meet the research needs (Tan and Hunter, 2002). With a theoretical sampling method, the interviewees in this study are selected on the basis of judgments of the researchers and research questions. Specifically, the respondents must have high intensity both in browsing short videos and of purchasing relevant products or services on the short video platform. According to the statistical report of "2019 White Paper on Marketing Strategy of China's Short Video Enterprises" released by iResearch, the proportion of male and female users of the short video applications of China in 2019 is close to 1:1 and the user group is mainly under the age of 24. Therefore, this study also balances the gender, age, and other characteristics of respondents according to the portrait characteristics of current short video users. In this study, 25 short video users were interviewed (female 48%, M_{age} = 22.4). The interview was conducted face-to-face, with each interview lasting from 33 to 97 min (M = 56) (**Table 1**). Ultimately, the requirement of theoretical saturation has been reached, that there were no other new ideas from the respondents.

Data Collection

In the formal interview, researchers first explained the meaning of customer inspiration to the respondents to ensure that they can understand the concept properly. The respondents were informed of the two parts in the experience of customer inspiration, namely, to obtain new ideas or possibilities from the external marketing stimuli, thus experiencing a 'flashing' moment of being enlightened as shown in the words like "Aha!," "Eureka!," etc., and to generate motivation to implement new ideas, such as the strong desire to buy or use products. The specific interview steps are as follows. First of all, each respondent needs to watch

TABLE 1 | Information of respondents.

No.	Gender	Age	Browsing frequency/week	Purchasing frequency/Month	Duration of interview/min
1	F	25	4	2	40
2	M	23	7	3	38
3	F	26	3	1	53
4	M	21	8	3	47
5	F	19	6	4	35
6	M	24	12	3	51
7	M	19	7	2	57
8	M	20	5	1	36
9	M	25	9	2	45
10	F	27	10	4	33
11	F	28	8	1	60
12	F	19	6	2	49
13	F	18	7	3	46
14	M	22	20	2	73
15	M	19	14	2	69
16	F	23	10	3	77
17	F	23	8	1	66
18	M	25	7	2	64
19	F	20	12	4	71
20	M	20	9	2	40
21	F	20	7	2	52
22	M	25	10	3	68
23	M	24	21	3	84
24	F	19	6	2	52
25	M	26	15	3	97

the 16 highly inspiring short video advertisements (elements)[1] prepared by the researchers one by one, and to select from them three ads that can stimulate inspiration and three that cannot. The selected six ads are written on a separate card in digital form. Secondly, according to the highly respected triads method (Kelly, 1963), three cards with short video names are randomly presented to the respondents who are then required to answer the following question: "In terms of your choice, which two of the three short video ads are more similar and different from the third one? And what are the similarities?". Answers to this question will lead to a bipolar construct, the positive construct being recorded on the right side of a prepared square and entitled as a novel construct, while the negative one on the left side as a plain one. Next, in order to establish links between elements and constructs, after discussing the specific meaning of the first construct, the respondents need to evaluate all the six short video advertisements selected before with a Likert 7-point scale. In this study, a Likert 7-point scale was adopted because it could give the respondents more freedom to rank elements (Tan and Hunter, 2002). It is worth noting that the constructs extracted by the triple method are more concrete, thus differentiating from the inspiration that is more abstract. To this end, laddering interview technique is applied to elicit higher-order, more abstract constructs that are closer to the target in the personal construct system (Reynolds and Gutman, 1988). In particular, after the respondents answering the initial questions, a series of laddering questions will be raised to establish higher-level constructs, like "Why is this important to you?," "What does that mean to you?," "What do you think about it?". So far, an integrated triple discussion has been completed. A complete grid example is shown in **Table 3**, consisting of elements, construct, and connection (Easterby-Smith, 1980). The process where the constructs have been formulated with the method of triads and laddering is repeatedly applied with the new cards until the respondent fails to produce any new construct. During the whole experiment, no construct that has been mentioned in the previous step is allowed to be repeated. The possibility of creating new construct from each triad encourages the respondents to think deeply about the connotation of customer inspiration in the short video. Reger (1990) disagreed with the necessity of repeating all the triads, for in most of the cases 7–10 groups are enough to exhaust all the constructs of the interviewee. The number of triads in this study ranges from 5 to 13 (M = 8.44, SD = 1.64), which confirms the above conclusions. In the square example of **Table 3**, the first respondent produced five constructs.

[1]Different from the practice of asking respondents to provide interview elements (short video ads), the particularity of customer inspiration requires researchers to guide the selection of elements on the basis of existing theories (Tan and Hunter, 2002). The evocation feature of customer inspiration indicates that it originates from an unconscious thinking or evocative pressure, and is stimulated by new things or new ideas (Thrash and Elliot, 2004). In addition, it is difficult to illustrate the specific sources and characteristics of inspiration (Rauschnabel et al., 2019). As a result, the manipulation of emotions and epiphanies can be realized when the inspiring short video advertisements are selected as external stimuli to the inspiration of the respondents (Oleynick et al., 2014). Before the establishment of the video database, the researchers recruited a wide range of short video ads whose viewers share similar characters to those of the formal respondents. In spite of the similarities of inspirational concept among the respondents (Hart, 1998), the concept of customer inspiration was strictly defined in this study so as to obtain qualified short video ads. In this step, 56 inspirational short video advertisements were collected. These ads were further screened on the principle of inspiring external stimuli (Thrash et al., 2014), namely, (1) whether the selected short video ads are generally persuasive, taking the number of likes, comments, and forwarding as the instructive standard; (2) whether the selected short video ads are endowed with fundamental features of being inspiring; and (3) whether the significant difference in the duration of short video ads would interfere inspiration experience. Through the above steps, a video database composed of 16 short video ads was established (**Table 2**).

DATA ANALYSIS

The recorded audio interview process was transcribed into a written text of more than 60,000 words before data analysis. The analysis of quantitative and qualitative data of transcribed text precisely follows the method adopted by Goffin et al. (2006), which includes three steps: standardization of construct names, categorization of constructs, and identification of key constructs.

Standardization of Construct Names

A small number of constructs in the interview are same in meaning but slightly different in expression. After carefully examining all the text content and grids, two researchers in charge of data collection identified and standardized the duplicate constructs. For example, 15 interviewees admitted that they are inspired when the short video ads provided a sensory experience of audio-visual conformity. But they used

TABLE 2 | Inspiring short video ads.

Product	URL	Length/second	Volume of likes	Volume of comments	Volume of forwarding
Disposable sponge mop	https://v.douyin.com/sfVkYj/	15	136w	2.2w	8.4w
Shadow lamp	https://v.douyin.com/sfV8JR/	15	142.4w	1.2w	1.1w
Collocation of clothes	https://v.douyin.com/RebuF5x/	13	113.2w	4.1w	7.3w
Night table	https://v.douyin.com/sfpgLf/	20	74.1w	1.2w	2.9w
Glass	https://v.douyin.com/sftg9b/	13	187.8w	5.5w	11.6w
Coke inversor	https://v.douyin.com/sfchvQ/	25	189.2w	4.8w	3.1w
Engraving machine	https://v.douyin.com/sfnsxH/	24	60.2w	1.8w	1w
Porphyra rice	https://v.douyin.com/sf4XqU/	25	164.6w	3.0w	6.2w

TABLE 3 | Samples of grids.

Negative construct pole(1)	Short video ads (Elements)						Positive construct pole(7)
	Short video 1	Short video 2	Short video 3	Short video 4	Short video 5	Short video 6	
(1) Plain	5	1	1	7	1	7	Novel
(2) Fail to arouse curiosity	6	1	1	7	1	6	To arouse curiosity
(3) Explicit promotion purpose	6	4	1	2	1	2	Implicit promotion purpose
(4) Irrelevant to personal needs	6	2	1	7	1	5	Relevant to personal needs
(5) Uninspiring	6	1	1	7	1	6	Inspiring

Number 1–5 in each line represents the construct formulated by the respondents. The constructs of all the six short video ads are evaluated in accordance with numbers 1–7, in which 1 represents the negative construct pole (uninspiring), while 7 the positive construct pole (inspiring).

'audio-visual conformity,' 'audio-visual coordination,' 'audio-visual match,' 'audio-visual fit,' and other expressions in the positive construct pole. The inconsistency of this kind was also found in the negative construct pole. To the end, 'audio-visual conformity' was determined as the standard construct name. Through such a process of standardization, 279 initial constructs have been simplified to 50. Furthermore, in order to ensure the significance of the analyzed constructs, the constructs that had been mentioned by at least three interviewees ($\geq$12%) were finally retained, with a total of 39 constructs.

Categorization of Constructs

Based on the inherent meaning of and interaction between constructs, 39 standardized constructs were categorized in accordance with their themes. This categorization strictly followed the four steps recommended by the prior research (Goffin and Koners, 2011), namely, identifying categories, allocating constructs to those categories, tabulating the results, and establishing the reliability of the category system. In the first step, each of the 39 constructs was written on a separate card, including its name, polar position, and typical description of the construct. Next, the preliminary categories composed of names, definitions, and construct distributions were established by discussion between two researchers who were in charge of data collection. At the same time, an independent researcher was invited to classify these cards, and the consistency of the two classification results was calculated accordingly. The reliability index between the coders was 74.36%, which was obtained by dividing the number of the constructs distributed in one category by the total number of constructs. Although higher than the critical level of 70%, it is advisable to modify the definition and distribution of categories to remove ambiguity. Therefore, the second independent researcher classified the constructs based on the modified names and definitions, and got the reliability index of 84.62%, which was much higher than 70%. With the reliable result, 39 constructs were eventually allocated into 18 categories (**Table 4**).

Identification of Key Constructs

Goffin et al. (2006) proposed that frequency and variability are important indicators to the establishment of key constructs. Firstly, the frequency indicator is satisfied when the construct is articulated by at least 25% of respondents. In this part, 14 important constructs met the frequency threshold. Secondly, the variability indicator is used to quantify the relative importance of a construct due to the significant difference in the evaluation of construct, and thus effective in distinguishing highly inspiring short video ads from low inspiring ones. Specifically, the variability of a construct is a measure of the scale of ratings compared to all the other constructs. The higher the variability of a construct is, the greater is its importance to the respondent. The variability of a given construct represents its contribution to the total variance. Additionally, since the measurement of variability depends on the number of constructs contained in each independent square, the variation value of each construct needs to be standardized. In this study, Average Normalized Variability (ANV) of constructs was 8.96%. When the ANV of a construct is greater than this threshold, this construct can be used to distinguish different types of short video ads, i.e., whether they inspire customers. In all, 25 important constructs were found to meet the requirements of the variability threshold. Furthermore, a key construct is defined as the one to satisfy both the threshold of frequency and variability. Accordingly, nine key constructs were identified as the most convincing criterion to distinguish short video ads with varying degrees of inspiration.

RESULTS AND ANALYSIS

As shown in **Table 4**, the constructs derived from RGT are more extensive. Some constructs are related to the informational content characteristics (e.g., richness in scenario, authenticity of content, audio-visual conformity) and emotional content characteristics (e.g., fun, novelty, surprise) of short video ads. Some are likely to be created by cognitive processing (e.g., immersiveness, clarity of the topic, and perceived difference) and emotional response (e.g., curiosity, surprise, and enjoyment) of consumers when they are exposed to short video ads. Some others are affected by the personal characters of consumers (e.g., relevance in interest and demand). In addition, the respondents brought up some constructs connected to the connotation of customer inspiration (e.g., divergent thinking and purchase motive). The analysis of grid and text data proved a significant interaction between these constructs. Therefore, it is necessary to establish relation structures on the basis of the construct category

TABLE 4 | Categorization of constructs and identification of key constructs.

Category	# Concept name	Frequency (%)	ANV (%)	Key constructs
Richness: the ability short video ads to carry data, i.e., to meet consumers' need for quantity of information and to reduce ambiguity.	Richness in scenario	6(24)	10.24	False
	Richness in information	6(24)	7.27	False
Reliability: The authenticity and credibility of short video ads.	Authenticity of content	8(32)	8.21	False
	Professionality of content	6(24)	10.18	False
Vividness: Short video ads enable consumers to create a clear picture of the products, concepts, and situation in their minds.	Display of details	3(12)	5.45	False
	Multi-sensory experience	3(12)	10.58	False
Fluency: Short video ads contains an audio-visual experience that makes it easy for consumers to perceive and identify product features.	Audio-visual conformity	15(60)	5.80	False
	Smooth rhythm	8(32)	7.76	False
	Visual impact	5(20)	9.40	False
	Visual aesthetics	4(16)	11.70	False
	Suitable scenario	3(12)	9.79	False
	Visual fluency	3(12)	10.28	False
Fun: enjoyable, interactive, funny, humorous, and comical short video ads.	Fun	4(16)	9.92	False
Novelty: fresh, surprising, creative, and unique short video ads that produce different experience.	Novelty	15(60)	10.40	True
Narrativity: short video ads that describes outcome in the form of 'storytelling'.	Display of plot	6(24)	8.13	False
	Making of Surprise	4(16)	9.21	False
	Narratives of story	4(16)	0.87	False
Commercial intention: short videos contain a clear marketing label with biased and persuasive intention.	Marketing purpose	10(40)	9.82	True
Presence: consumers perceive the authentic situation by virtual environment.	Immersiveness	9(36)	2.15	False
Processing fluency: subjective perception of the ease with which consumers process information.	Clarity of the topic	6(24)	8.95	False
	Comprehensibility	4(16)	3.99	False
Perceptual innovation: consumers' subjective judgments of novelty in short video ads.	Perceived difference	6(24)	11.56	False
	Perceived novelty	3(12)	10.83	False
	Perceived creativity	3(12)	7.35	False
Perceptual convenience: consumers' perception of practicality and convenience of short video ads.	Perceived influence	11(44)	9.68	True
	Perceived practicality	10(40)	8.26	False
	Perceived convenience	5(20)	9.87	False
Curiosity: the desire to acquire missing information, i.e., consumers' awareness of the "information gap" between what they currently know and what they want to know.	Curiosity	14(56)	11.28	True
Surprise: differences derived from consumers' psychological schema, i.e., perception of the unexpectedness of short video ads.	Surprise	4(16)	10.96	False
Enjoyment: consumers have a pleasant and happy feeling when watching short video ads.	Enjoyment	4(16)	6.48	False
Conceptual inspiration: Consumers are receptive to new ideas and possibilities promoted in short video ads.	Divergent thinking	36	10.15	True
	Cognition challenge	6(24)	10.29	False
	Association initiation	6(24)	10.67	False
	Interest stimulation	4(16)	10.14	False
	Knowledge acquisition	3(12)	7.4	False
Behavioral inspiration: consumers develop intrinsic incentives to achieve consumption-related goals.	Purchase motive	8(32)	12.52	True
	experiential motive	7(28)	10.72	True
Personal involvement: consumers perceive the relevance of short video ads based on their internal needs, values and interests.	Relevance in interest	12(48)	10.94	True
	Relevance in demand	11(44)	9.76	True

and formulate the path model of customer inspiration of short videos (**Figure 1**).

According to the model, customer inspiration is significantly affected by the inspiring informational content characteristics, emotional content characteristics, and commercial content characteristics in which the characteristics of informational content mainly activate the cognition-dominated processing mechanism, that of emotional content which arouse the emotion-dominated processing mechanism, and of commercial content which exert a direct impact on customer inspiration. Besides, the possibility of triggering inspiration in short videos is influenced by customer personality. This part of the article is to illustrate the source, triggering mechanism and influencing factors of customer inspiration in short videos, and draws the corresponding research propositions.

Source of Customer Inspiration in Short Videos

Informational Content Characteristic

Customer inspiration experience is highly correlated with cognition. The key to trigger an inspiration lies in that arousal cognitive events produce new or better possibilities (Thrash and Elliot, 2004). This is reflected in marketing as informational content that can stimulate the imagination of consumers or broaden their mental horizons (Böttger et al., 2017). According to the results of data analysis, inspiring informational content characteristics include richness, reliability, vividness, and fluency. First, short videos with rich content helps to improve the assessment of consumers to the value of advertising content, prompt better understanding of the multiple impacts of products on daily life, and stimulate inspiration, which can be determined by the quantity of product and scenario information. As observed by a respondent, "*Many scenes in the short videos about laser keyboard and engraving machine have been switched, so I think they have a lot of uses. The scenes of the other two videos are relatively unchanged, nothing new*" (Respondent 11). Secondly, the reliability of short video ads refers to the credibility of the informational content, with an intention of helping consumers better understand the product features. This raises their initiatives to accept the new ideas guided by marketing. Reliability depends on the authenticity and professionality of content. As one respondent puts it, "*The short video of smart suitcase reflects the feelings of both the users and the onlookers. This can be called objectivity. But in the video about cookies and milk, only one person and his experience are recorded. That is too subjective. If a short video fails to display every aspect of a product, I will not pay much attention to it*" (Respondent 06). On the other hand, based on dual coding theory, the interpretation of an individual of informational content varies significantly from linguistic to non-linguistic system (Paivio, 1991). It is found in this study that consumers can be better inspired with vivid and fluent presentation of information when there is no great difference in the informational content. For example, vivid content enhances the imagination of consumers about the product due to the exposure to more specific information and activation of a better sensory experience. Similarly, a clear flow of content in advertisement helps to create a coherent viewing experience and better perception of product features, and therefore impulse consumers to try or purchase the product.

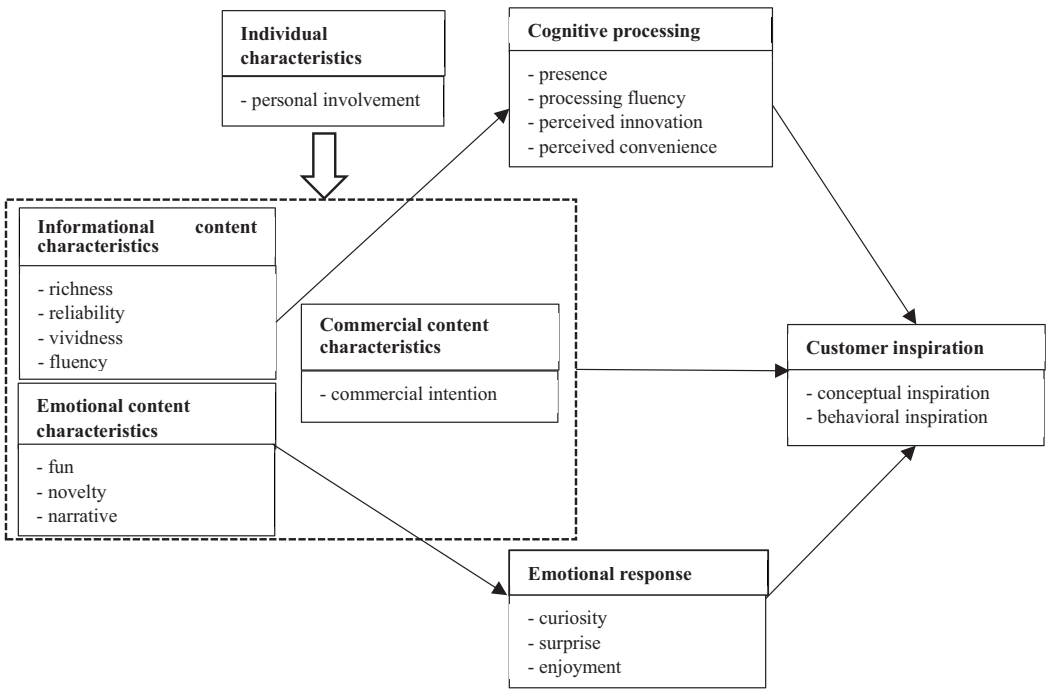

FIGURE 1 | Formation path model of short video customer inspiration.

This is the result of such constructs as audio-visual conformity, smooth rhythm, visual impact, and other perceptual feelings.

In the above constructs, the vividness and fluency of video content have been proved to attract the attention of consumers and stimulate their imagination (Hsieh et al., 2012). Although Böttger et al. (2017) asserted that the vitality of advertising has a positive impact on customer inspiration, this study reveals different findings, i.e., the richness and reliability are also inspiring, and the related constructs exceed the requirements of frequency and variability threshold. Therefore, these constructs should be taken as important triggering factors of inspiration in the design of short video ads. Accordingly, the following proposition is obtained:

P1: The richness, reliability, vividness, and fluency of short video ads promote the generation of customer inspiration.

Emotional Content Characteristic

Different from the informational content characteristic that convince consumers to accept new ideas and possibilities promoted in marketing in the way of persuasion, communication, and knowledge dissemination, the emotional content characteristic of short video ads may generate the intrinsic motivation of consumers to pursue consumption-related goals by stimulating their positive emotional response (Thrash and Elliot, 2003), which is manifested in business environment as a great desire to purchase or use products (Böttger et al., 2017). In short video ads, the characteristics of inspiring emotional content include fun, novelty, and narrativity. First of all, interesting and funny short video ads can attract attention and stimulate surprise and create pleasure so that the intrinsic motivation (hedonic motivation) of consumers is inspired to share interesting advertising content or take actions to buy products. For instance, one respondent emphasized the significance of enjoyment in his answer to the question about two similar inspiring short videos. "*The video of coke inversor is really boring. I didn't see any humor or laughing point in it. But the other two videos are more interesting. I have an impulse to buy the product and get the pleasure as shown in the videos, or just buy it as a gift for my kids*" (Respondent 10). Secondly, novel short video ads have prominent emotional driving effect because of their distinctive content or the way it is presented. It is found in the study that novelty brings about surprise and curiosity that provide consumers strong desires to explore new things. In addition, narrativity depicts an intense emotional experience created by the story in short videos, which also encourages an incentive to the pursuit of consumption-related goals. Narrativity is composed of three elements, namely, plot, surprise, and story, with its intensity increased by the application of these elements. In fact, respondents can accurately identify the organization of content that drives emotional experience: "*The videos of porphyra rice and shadow lamp adopted a way of story telling. They were shot in a very dramatic way. I just couldn't take my eyes away*" (Respondent 18).

In accordance with the findings in the previous research about the novelty in customer inspiration (Böttger et al., 2017; Winterich et al., 2019), this study confirms that novelty, as a key construct, can most effectively distinguish between high and low inspiring short video ads. In the literature on video advertising, Berger and Milkman (2012) found that only videos with enjoyable content can attract attention and bring audience pleasing fulfillment. Tellis et al. (2019) confirmed that dramatic elements (such as plot, character, and surprise) in video advertising can arouse the positive emotions of consumers and enhance engagement of advertisements. Different from willingness to share, fun and narrativity also bring insight and inspiration to customers. Based on this, the following proposition is obtained:

P2: Fun, novelty, and narrativity of short video ads promote the generation of customer inspiration.

Commercial Content Characteristic

Studies on video advertising have shown that high level commercial content negatively affect sharing behavior (Akpinar and Berger, 2017; Tellis et al., 2019). A similar trend is also found in this research that short video ads with distinctive commercial intentions will stimulate the avoidance motivation of consumers that seriously hinders the generation of customer inspiration. During the interview, the respondents usually swiped the screen of the phone quickly at the first sight when browsing the short video ads with strong commercial intent. One of the respondents pointed out the negative impact of commercial intent on inspiration experience: "*As to the yogurt candy videos, the sales pitch is too purposeful. I just want to skip it. The other two videos are not trying to sell anything, they just tell you what it is*" (Respondent 08).

As previous studies have shown, extrinsic incentives (such as low price and discount) in advertisements can stimulate the avoidance motivation of consumers. But approach motivation will arouse the inspiration of consumers (Böttger et al., 2017). It is also confirmed in this finding that the frequency and variability of marketing purpose become the condition of key construct and produce significant negative effects on the obtainment of inspiration through short video ads. Therefore, the following proposition is obtained:

P3: Commercial intention in short video ads hinders customer inspiration.

The Formation Path of Short Video Consumer Inspiration

During the interview, the respondents were often found to spontaneously elaborate their preference to a construct pole, which, in many cases, helps to establish a very clear causal path (Lemke et al., 2011). In the absence of spontaneous interpretation, the laddering interview technique also helped to refine the attribution process (Reynolds and Gutman, 1988). The study results reveal that the cognitive processing caused by inspiring informational content characteristic and the emotional response aroused by the emotional content characteristic are the internal mechanisms for the stimulation of customer inspirations in short videos (**Figure 1**).

Cognitive Processing

Because the informational content focuses on rational description, it mainly activates the cognitive dominated processing mechanism (Yoo and MacInnis, 2005), i.e., thoughts and inferences of consumers when they are exposed to advertising (Cacioppo et al., 1981). This study finds that the informational content of short videos promotes the perceived innovation and perceived convenience of consumers, which is greatly contributing to the formation of customer inspiration. These two cognitive processing paths indicate that consumers understand the competitive advantages of the product, express their understanding and appreciation of the advertising informational content, and in turn create a positive, clear feeling of self-improvement. For example, some respondents perceived the innovative value of short video ads and had an aha experience by saying "*Wow! It can be used like this!*" (Respondent 05). Social psychology shares agreement in that inspiration is closely related to cognition, and the key to its triggering lies in that evocative cognitive event that can promote the understanding of values by people (Thrash and Elliot, 2004). In addition, two important cognitive processing mechanisms, namely, presence and processing fluency, have been found. Firstly, rich, vivid or fluid short video ads can create compelling and authentic experiences for consumers in a virtual environment. This sense of presence greatly stimulates their imagination and inspiration. A respondent illustrates the path through which short videos generate presence and act on customer inspiration: "*Biscuit and power bank videos appeared inauthentic, 'they are displayed in a showroom and everything is well arranged.' By contrast, the video about disposable sponge mop is in the home environment, it is an authentic scene, and bring me a sense of reality, as if I were seeing something really happened around. I will be more focused and attracted to watch the video. I really want to have a try*" (Respondent 13). A recent study also confirmed that the key to inspiring consumers with brand video advertising is to allow them to identify important values through alternative experiences (Chang, 2020). Secondly, the vivid and fluent short video ads reduce the difficulty of processing information, and such smooth processing experience is more conducive to understanding the intrinsic value of new things. Similarly, some respondents elaborated on this cognitive processing path: "*These two videos can inspire me because I could understand their intentions, without any difficulty*" (Respondent 21). Based on this, the following proposition is obtained:

> P4: Presence, processing fluency, perceived innovation, and perceived convenience establish an important path to connect the informational content characteristic to customer inspiration.

Emotional Response

Since emotional content focuses on perceptual description, it mainly arouses the emotion-dominated processing mechanism (Yoo and MacInnis, 2005), i.e., the sensation produced when consumers are exposed to advertising (Macinnis and Jaworski, 1989). The emotional content of short video ads can inspire the emotions of consumers, but only activation pressure and approach motivation (such as curiosity, surprise, and pleasure) can inspire customers. First, some novel short video ads will remind consumers of the existing information gap. A strong desire (curiosity) to obtain the missing information will drive them to search it based on knowledge or information, to strive for the ultimate goal and to spark inspiration. As a respondent said: "*I'm particularly curious about how these amazing and convenient functions of the smart suitcase can be achieved. I'm also curious about how the stickies suck in the dirt. They are quite useful. These two videos make me curious, and I will make it out, see what I can find*" (Respondent 12). In fact, the analysis of grid data suggests that arousing an emotional experience of curiosity is the determinant of identifying potentially high and low inspiring advertisements. Secondly, novel short video ads also create surprise. Therefore, consumers are encouraged to eliminate inconsistencies in their cognitive schema and to try some new things. As one of the respondents mentioned, "*I was amazed at the technological change after watching these two short video ads. That's quite different from another one. I'd never believed it could be used in this way. And this astonishment aroused my strong interest*" (Respondent 19). This statement is also consistent with the view of Bischof et al. (2020), who believe that surprise has a particularly illuminating quality. Finally, pleasant emotions also stimulate the intrinsic approach motivation of consumers and make them inspired. A respondent mentioned the path in which narrative content evoked the pleasant emotions that finally acted on inspiration experience. "*The content in the first two videos is progressing step by step. I can see the process of production, and imagine what it will be. I feel especially happy when I see the final product. I want to do it myself*" (Respondent 13). Accordingly, the following proposition can be obtained:

> P5: Curiosity, surprise, and pleasure form an important path to connect the emotional content characteristic to customer inspiration.

Influencing Factors of Customer Inspiration in Short Videos

Admittedly, inspiring informational content and emotional content stimulate customer inspiration in most cases, there still exist some factors that can affect the frequency and intensity of customer inspiration in short videos (Thrash and Elliot, 2003, 2004). Research on video advertising have found that only when the risk on product or purchase is high will the informational content positively affect the sharing of advertising (Tellis et al., 2019). Similarly, this study identifies an important personal factor in the formation of short video customer inspiration–personal involvement. Personal involvement includes two constructs, namely, relevance in interest and relevance in demand, both of which meet the criteria to be key constructs. According to the theory of involvement, personal involvement reflects not only the degree of association between consumers and informational content, but that between consumers and emotional content (Zaichkowsky, 1994). Therefore, consumers with high involvement have the strongest response to the inspiring informational content and emotional content, which improves the possibility that customer inspiration will be

triggered. On the contrary, consumers with low involvement are impervious to creative new ideas. As one of the respondents said, "*The first two videos are in line with my preferences and interests. I really like the art with lighting effect. I like porphyra rice and I once made it myself. Such content will naturally fill my imagination and make me feel better*" (Respondent 20). Therefore, the following proposition is obtained.

P6: Personal involvement enhances the relationship between content characteristic and customer inspiration.

CONCLUSION AND DISCUSSION

Conclusion

With a focus on the source of customer inspiration of short videos and its cognitive psychological process, 25 short video users were interviewed by RGT qualitative research method. Through the analysis of text and grid data, this article constructs the formation path model of short video customer inspiration, and systematically discusses the source, triggering mechanism and influencing factors of short video customer inspiration. The main conclusions are as follows: the inspiring informational content characteristics in short video ads include richness, reliability, vividness, and fluency, while the emotional content characteristics include fun, novelty, and narrativity. However, the commercial content characteristics of short video ads prevent customers from being inspired. Secondly, cognitive processing such as presence, processing fluency, perceived innovation and perceived convenience caused by informational content characteristics and emotional responses such as curiosity, surprise, and pleasure aroused by emotional content characteristics are the internal mechanism that stimulates customer inspiration in short videos. In addition, personal involvement enhances the relationship between inspiring content characteristic and customer inspiration.

Theoretical Implications

First of all, this article creatively takes customer inspiration as the key construct to explore the effectiveness of short video ads, and provides a new theoretical perspective and methodological instruction for researches and practice on advertising. Specifically, with a different perspective from the previous researches that focused on the key variables such as viewing time (Teixeira et al., 2012), sharing willingness (Berger and Milkman, 2012; Akpinar and Berger, 2017), purchase intention (Lee and Hong, 2016; Liu et al., 2018), sharing behavior (Tellis et al., 2019), sales (Chandy et al., 2001; Guitart and Stremersch, 2021), etc., this article finds that in the current fast-paced and ever-shortening customer journey, customer inspiration helps to explore the importance of short videos in online marketing. Consumers' attention in short video ads is more effectively converted into a positive purchasing behavior.

Secondly, RGT is applied in this article to sort out the content characteristics that influence the generation of customer inspiration in short videos, the cognitive psychological process triggered by customer inspiration, and the key influencing factors. The findings enrich the existing advertising content feature framework and literature on customer inspiration. In specific, the content feature framework of online video advertising constructed by Tellis et al. (2019) provides detailed instruction on how to design advertisements that drive consumers' sharing behavior. In spite of the current fad of short video ads, this article further identifies some new information (richness, reliability, vividness, and fluency), and emotional (novelty, fun, and narrativity) content characteristics in the hot trend of short video advertising. It is also found that personal involvement affects the effectiveness of these content features, which, to some extent, supplements the original conceptual framework. Next, responding to the call on contextual interpretation, application (Thrash et al., 2014), and source exploration of inspiration (Liang et al., 2016; Böttger et al., 2017), this article extensively studies the various sources of customer inspiration in short videos, specifies its cognitive process, and developed insights into its formation process.

Managerial Implications

The research findings may help to resolve some practical problems on how to attract and maintain the attention of consumers and prompt them to make positive response. For online marketers, it is necessary in the design of short videos to have an overall consideration of the inspiring (information, emotion, commerce) content characteristics, increasing richness and reliability of informational content and presenting the information vividly and smoothly. Such practice is conducive to stimulating the cognitive process of customer inspiration. Similarly, emotional content that can arouse consumers positive emotional reactions (curiosity, surprise, pleasure) should also be designed, like adding the funny and novel things to short video ads or displaying presenting the experience of product in a narrative way. In addition, marketers should try to reduce the commercial intention of short-video ads such as sales labels with persuasive bias, thus attracting the attention of consumers to the theme of advertising. Therefore, by increasing the probability of inspiration, consumers can be encouraged to actively participate in short video ads, such as browsing, sharing, purchasing, and other engagement behaviors. The short video platforms can increase the exposure rate of high inspiring short video ads by adjusting the content distribution algorithm so as to attract more consumers for businesses. Furthermore, user portrait algorithm can be improved by collecting data related to user involvement (demands, interests) to increase the frequency and intensity of inspiration, which will greatly improve the rate of purchase conversion of short video ads.

Limitations and Future Research Directions

As an exploratory study, there inevitably exist insufficiencies that need to be further investigated. Firstly, although the selected samples are representative and the number of samples also meets

the requirements of theoretical saturation, the small sample size is not large enough to provide us with sufficient evidence for more convincing conclusions. Future studies should employ a large-scale questionnaire survey to test the reliability of the constructed conceptual model. Second, despite the preciseness of strategies in the selection of short video ads, subjective involvement in the procedure may reduce the validity to some extent. Therefore, attempts can be made to include emotion or sensation analysis of comment text in short video ads in order to sort out the most effective inspiring stimuli for experiment. In addition, the proposed content characteristics (information, emotion, business) that affect the customer inspiration can be well manipulated in the experiment. In future studies, the causal relations in the six research propositions and the impact of each factor on customer inspiration experience should be analyzed and verified by experiments. Finally, while customer inspiration may well explain how short video ads attract attention and motivate positive response, real behavioral indicators are more instructive for marketers and should be applied to the construction of future research framework.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by School of Economics and Management, Northwest University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

PG: conceptualization, methodology, writing – review and editing, supervision, and funding acquisition. HJ: investigation, resources, and writing – original draft. YX: formal analysis and project administration. YC: data curation and visualization. All authors: contributed to the article and approved the submitted version.

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"Carpe Diem?": Disjunction Effect of Incidental Affect on Intertemporal Choice

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Incidental affect has an important impact on intertemporal choice (IC). This research aimed to test how positive incidental affect influences IC and its underlying mechanisms. We assumed that positive incidental affect may have a disjunction effect on IC that includes or excludes immediate time. Moreover, we examined the role of time perception for the effect of affect on IC. In Study 1, after undergoing affect priming by video clips, participants completed the IC task using a multiple staircase paradigm. Using Hierarchical Bayesian Modeling, we estimated the discount rate parameter by distinguishing "immediate" and "non-immediate" conditions of IC. The participants' time perception was also measured. In Study 2, apart from the choice preference of IC, we additionally investigated the differences in the participants' attention to delay and reward attributes before decision making. The results of the two studies indicated that positive incidental affect leads to longer time perception (Study 1) and prior and more attention to the delay attribute of IC (Study 2), which leads individuals to prefer immediate options in the IC (Studies 1 and 2). Moreover, there is a disjunction effect of affect; in other words, the incidental affect did not influence IC excluding immediate time (Studies 1 and 2). This study improves our understanding of the disjunctive effect and its mechanism of inducing a positive incidental affect on IC and thus provides a new perspective on how related decision making can be improved.

Keywords: intertemporal choice, incidental affect, disjunctive effect, time perception, immediacy effect

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INTRODUCTION

Intertemporal choice (IC) refers to the individual trade-offs between costs and benefits at different time points and the corresponding judgments and choices (Frederick et al., 2002). Compared with larger, distant future rewards, people tend to favor smaller, nearer future rewards, thus, temporal discounting is generated (Read, 2004). When rewards occur immediately, individuals tend to discount future rewards more, showing an immediacy effect (Frederick et al., 2002; Weber et al., 2007).

Affect is a central driving force behind decision making, impacting it either positively or negatively. Previous studies have shown that affect influences intertemporal preferences by changing time perception (Ifcher and Zarghamee, 2011; Laube and van den Bos, 2020). According

to the Hot/Cool-System hypothesis, there is a "cool cognitive system" and "hot emotional system," where affect has a greater influence on preferences of immediate reward/loss (Metcalfe and Mischel, 1999; Hirsh et al., 2010). Therefore, affect may have a disjunction effect on IC that includes or excludes immediate time. The current study hypothesized that affect only influences choice preference when IC includes immediate time, and after removing it, its impact on IC weakens. In the current study, taking positive incidental affect as an example, we set different conditions of IC (including or excluding immediate time) to explore the influence of affect on IC and clarify the role of time perception in the effect of affect on IC.

In IC studies, individuals choose between the smaller-sooner (SS) and larger-later (LL) options. Decision makers place a disproportionate weight on immediate outcomes and would change their preference from a smaller monetary outcome to a larger one as both outcomes become more distant in time. This is the so-called immediacy effect. For example:

Program 1. *A. Now, gain $30; B. After 1 d, a gain of $31.*

Program 2. *A′. After 100 d, a gain of $30; B′. After 101 d, a gain of $31.*

People often prefer immediate option A in *Program 1*, but after extending the time for both options, people prefer delayed option B′ in *Program 2* (Kirby and Herrnstein, 1995).

The explanations for the immediacy effect differ among the decision models. *The hyperbolic time discounting model* (Mazur, 1987) assumes that the value of a delayed outcome can be described by an exponential function. Therefore, individuals discount the value of delay at a different rate, and the discount for immediate time is the greatest, leading to a preference for the SS option. Gradually, individuals' discount rate per unit time decreases; therefore, they prefer LL options. However, according to *the perceived time-based model* (Zauberman et al., 2009), such time-variant preferences are due to the perception of delays. Individuals perceive time subjectively rather than objectively, and the relationship between an objective change of time and an individual's subjective time perception conforms to the Weber-Fechner law. For example, the subjective time perception of 3 years may be 1.3 times longer than 1 year (rather than 3 times longer; Zauberman et al., 2009). Therefore, individuals' discount rate per unit of subjective time in IC is constant, and the preference reversal in IC is due to the different time perceptions. Accordingly, in Programs 1 and 2, individuals' subjective time discounting remains unchanged, but the difference in subjective time perception in Program 1 is greater than that in Program 2, thus leading to preference reversal.

The immediacy effect has been widely studied and found to be robust across different situations (Zhou et al., 2019). At the behavioral level, the immediacy effect is an important source of dynamic inconsistency in decision preference (Read et al., 1999); at the neural level, two separate systems are involved in IC: choice pairs that include immediate options will preferentially engage limbic structures compared with those that exclude immediate options. While regions of the lateral prefrontal cortex and posterior parietal cortex are engaged uniformly by intertemporal choices irrespective of delays (McClure et al., 2004). In sum, these studies show the particularities of *immediate time* in IC.

Research on affect and decision making has burgeoned over the last several decades (George and Dane, 2016). These studies mainly investigate the impact of affect based on its valence, time of occurrence, or source. Early research principally focused on the role of valence, that is, how general positive or negative affect, or specific affect, influences IC (Jiang and Sun, 2019). Recently, to comprehensively examine the effect of affect from different sources, researchers divided affect into two categories: integral and incidental (Lerner et al., 2015). Loewenstein and Lerner (2003) defined integral affect as the affective influences that result from evaluating the decision or judgmental target itself, while incidental affect includes all factors that elicit affect but are unrelated to the judgment target. For example, college students on the eve of graduation are faced with two options: "attending a party" or "writing a paper." There are differences not only in the reward magnitude and time dimension but also in their emotional attributes, that is, happiness or frustration. This is an integral effect.

Information unrelated to the task drives incidental affect, which is widespread and has an important influence on behavior. People may inevitably be influenced by these factors (e.g., sunny weather, background music in shopping malls, news about favorite team wins, and traffic jams), and experience incidental effects of pleasure, excitement, or irritability. As background information, incidental affect can be easily ignored. According to the view of "mood-as-information," people often consider affect as a source of information, and make mood-congruent judgments based on asking themselves "*How do I feel about it*?" (Schwarz and Clore, 2007). Moreover, they may mistakenly take an emotion-based reaction as a reaction to the decision target. For example, information unrelated to the decision (e.g., news about a favorite team win) will affect people's subjective well-being ratings. For IC, incidental affect will impact the degree of individual impulsivity, positive behaviors such as saving, or negative behaviors such as addiction.

Research on the impact of incidental effect on IC varies; however, the results, particularly for positive affect, are still controversial. Early research revealed its benefits for IC: Pyone and Isen (2011) found that it promoted cognitive flexibility, fostered a higher level of thinking, and cultivated a more future-oriented view of time, which could lower the time discount rate and thereby facilitate participants' preference for LL options (Wang and Liu, 2009; Ifcher and Zarghamee, 2011; Pyone and Isen, 2011). Contrastingly, recent studies have also shown that its negative impact causes a higher time discount rate, resulting in increased impulsivity (Norouzi, 2011; Kim and Zauberman, 2013; Lempert et al., 2017; Zhou et al., 2021). Similarly, Laube and van den Bos (2020) found that positive integral affect can also cause individuals to perceive the same objective future periods to be subjectively longer, leading people to prefer SS options. One possible reason for such an effect may be that positive affect causes people to shift their focus more on delay rather than rewards in IC; thus, they become less patient.

To study the impact of affect, few studies have distinguished the delay conditions of IC, that is, including or excluding

immediate time. According to the Hot/Cool-System hypothesis (the cool, cognitive "know" and the hot, emotional "go" system), individuals' processing of LL options is mainly driven by the cool system, while the preference for SS options is more likely to be influenced by the hot system (Metcalfe and Mischel, 1999). Similarly, mood management theory posits that individuals arrange internal and external stimulus conditions to minimize bad moods and maximize good moods (Zillmann, 1988a,b). Thus, for IC, when individuals experience stronger positive affect, they prefer immediate rewards, which could be helpful in maintaining their present positive mood (Norouzi, 2011). Correspondingly, most measures to control affect in daily life also involve the effect of immediate time. For example, the US government has set a waiting period law to prevent impulsive acts of gun violence (Giffords, 2021), and the Federal Trade Commission implements the Cooling-Off Rule to protect American consumers (Consumer Information, 2021). Overall, it can be speculated that affect may influence the strength of the immediacy effect in IC, and after removing the immediate time, the impact of affect would be weaker, suggesting a disjunction effect of the incidental affect on IC. Therefore, we postulate the following hypothesis:

H_1: If IC includes immediate time, participants from the affect-positive group are more likely to prefer SS options when making IC compared to the affect-neutral group; when IC excludes immediate time, no significant difference in intertemporal preferences between participants from affect-positive and affect-neutral groups will be observed.

The mechanism underlying the disjunctive impact of affect on intertemporal choice may be related to time perception. The perceived time-based model of IC indicates that individuals' choice preferences for IC reflect their subjective time perceptions (Zauberman et al., 2009). Kim and Zauberman (2009) set two model parameters for decision makers: the overall level of time contraction (α) and time sensitivity (β), to measure individuals' subjective perception of the length of time and their sensitivity to anticipatory time horizons. Related studies found that when the subjective time estimates were accounted for, discount rates were constant but no longer decreased on most time horizons, as hypothesized by the hyperbolic models. These results imply that the nonlinear time discounting assumed by the hyperbolic discount model can be explained by differences in subjective time perception. By incorporating subjective time perception in IC models, simple and linear decision models can better explain individuals' choice preferences.

Manipulating incidental affect can influence IC preferences by changing time perception. Relevant studies have shown that when assessing the time of future pleasant events, people overestimate waiting times, which triggers feelings of impatience and increases impulsivity. When assessing unpleasant events, future time perception is shortened (Geoffard and Luchini, 2010). This may be because it affects changes in time perception by influencing physiological activation and the allocation of attentional resources (Buhusi and Meck, 2006; Wang and He, 2020). That is, attributes of affect, such as source, valence, intensity, and motivation, could change time perception by influencing physiological activation and the allocation of attention resources (Buhusi and Meck, 2006; Gil and Droit-Volet, 2012). Laube and van den Bos (2020) found that integral affect influences impatient behavior because it leads distortions in time perception and thus alters the weighting of choice attributes. In their study, to control for the influence of time perception on decision making, researchers integrated subjective time estimates into a dual-parameter hyperbolic discounting model for IC. The results showed that the difference in time discount rate disappeared, indicating that the difference in time perception led to a change in decision-making preferences. As background information for decision making, manipulation of incidental affect could lead to changes in people's perception and weighting of time, thereby influencing intertemporal preferences. Therefore, we postulate the following hypotheses:

H_2: Participants in the affect-positive group perceived the same objective future durations to be subjectively longer than those in the affect-neutral group.

H_3: There is no significant difference in the subjective time discount rate of participants in the affect-positive and affect-neutral groups.

H_4: Compared with the affect-neutral group, participants from the affect-positive group focus prior and more to the delay rather than the reward attribute of intertemporal options.

The current research distinguished IC as including/excluding immediate time conditions, to reveal the disjunction effect of incidental affect on IC and explored the mechanism underlying time perception. In Study 1, we assessed choice behavior using a staircase IC task. To test the disjunction effect of incidental affect on IC, we subdivided the task conditions into including/excluding immediate time conditions. We used the hierarchical Bayesian modeling (HBM) method to fit participants' responses from different time conditions to the hyperbolic discounting model and calculated the discount rate as the dependent variable. Moreover, to examine whether time perception was prolonged in the affect-positive group, we systematically compared time perception between the affect-positive and affect-neutral groups. Finally, we incorporated time perception into decision models and examined the role of time perception in the disjunctive effect of incidental affect on IC. In Study 2, we tested the robustness of the effects found in Study 1 and further explored whether affect led people to pay asymmetrical weighting to the delay and reward attributes of IC.

STUDY 1

Methods

Participants

GPower software was used to estimate the required sample size for this study. A power analysis indicated that a total of 54 participants were needed for a medium partial $\eta^2(0.25)$

when $\alpha = 0.05$ for a power of 0.95 with two independent groups, using a repeated measures analysis of variance (ANOVA), within-between-subject interactions. The final sample consisted of 62 college students from universities in Guangzhou and Shenzhen, China (32 women, $M_{age} = 20.66$, $SD_{age} = 0.19$). All participants had normal or corrected-to-normal vision. Written informed consent was obtained from all the participants prior to participation. Participants received CNY 20 (CNY 1 ≈ 0.15) in cash for participation. To further incentivize cooperation, participants were informed that at the end of the experiment, one IC pair would be randomly selected from the participants' question set and would receive an extra payment (5% of the reward, CNY 5–10) according to his or her choice in that question. For example, if a participant chose an option with a 15-day delay, then he or she would receive payment 15 days from the day of participation.

Materials and Procedure

Participants were randomly assigned to the affect-positive ($n = 31$) or affect-neutral group ($n = 31$). They completed the tasks in the experiment and the questionnaire in turn, as follows.

At the beginning of the experiment, we aimed to prime participants' affect. The affective priming materials were 5 min video clips. The video of the affect-positive group included well-known variety show clips and a "father-son play" movie. The video of the affect-neutral group included a news interview about the weather and highway snow scenes. The variety show clips for the affect-positive group were determined from pre-experiments,[1] and other materials were all derived from the standardized Asian cultural sentiment database[2] developed by Deng et al. (2017). After watching the video, participants in the affect-positive group were asked to list 3–5 things that made them feel happy in their lives and describe one thing that makes them the happiest, whereas those in the affect-neutral group were asked to list 3–5 common things in life and describe t classroom scenario (Briñol et al., 2007).

After affect priming, participants completed the staircase IC task, making a series of choices between SS and LL options (Hardisty et al., 2013). The task contains two conditions: delay of SS option is *immediate* (today) or *non-immediate* (15 days in the future), and each condition included five blocks (corresponding to five different delays for the LL option). For the "immediate" condition, the delays for LL option time were 7, 15, 30, 80, or 140 days. In the "non-immediate" condition, the delays of SS and LL options were all increased by 15 more days than the "immediate" condition.

In each block, the reward of the LL option was fixed as CNY 200. The SS option began from CNY 100 and was adjusted through trials according to the participant's choice. For example, the first presented option: (a) *15 days, CNY 200*; (b) *Today, CNY 100*. If the participant chose (a), the reward of the SS option presented for the second trial would be changed to the intermediate value of the LL and SS options from the first trial, that is, option (b) became (b') *Today*, *CNY 150*. The range of SS options in the second trial reward was 100–200. However, if participants chose (b) in the first turn, the reward of the SS option in the second trial changed to an intermediate value of 0 and the SS option, that is, option (b) became (b') *Today, CNY 50*. Here, the range of the SS option for the second trial reward was 0–100. The block ended when the range of the SS option reward is no more2+ than five. One practice block was first presented to familiarize the participants with the experimental procedure, and participants could have 1 min of rest between each block and at least 2 min of rest between each condition (see **Figure 1A**).

After the IC task, participants completed a subjective time perception measurement for all delays from the IC task using a non-numerable line scale (Zauberman et al., 2009). In detail, a non-numerable line segment with a length of about 28.5 cm was presented on a computer screen, with a movable cursor in the middle, "extremely short" label on the left end, and "extremely long" label at the right end (see **Figure 1B**). Participants moved the cursor position and set a line segment of a certain length to represent the length of the time horizon. Before starting, participants were informed that they would estimate the length of nine time periods within the interval of 7 to 160 days, and the order of each time period was random. Participants practiced before the experimental session.

Finally, participants completed the Chinese version of the Basic Positive Emotion subscale of the Positive and Negative Affect Schedule (PANAS; Guo and Gan, 2010), and the evaluation questionnaire of affect priming materials (Deng et al., 2017). In this measurement, participants evaluated the familiarity, likability, motivation, valence, and arousal of the affect priming materials on a nine-point scale (1 = extremely low level, 9 = extremely high level; see **Supplementary Material**).

Results

Affect Priming

We tested the difference in the scores of the positive subscale of PANAS and the evaluation of priming materials between the affect-positive and affect-neutral groups. The positive affect score of PANAS in the affect-positive group was significantly higher than that in the affect-neutral group, $t(60) = 4.65$, $p < 0.001$, Cohen's $d = 1.18$, 95% CI = [0.49, 1.23] (see **Figure 2**). For the evaluation of priming materials, there was no significant difference in the familiarity of the video between the affect-positive ($M = 4.94$, $SE = 0.46$) and the affect-neutral group ($M = 4.03$, $SE = 46$), $t(60) = 1.39$, $p = 0.17$, 95% CI = [–0.40, 2.20]. Compared with the affect-neutral group ($M = 3.48$, $SE = 0.27$), participants in the affect-positive group ($M = 6.65$, $SE = 0.36$) liked the video more, $t(60) = 6.94$, $p < 0.001$ Cohen's $d = 1.77$, 95% CI = [2.25, 4.07], and experienced more pleasure, $t(52.58) = 8.10$, $p < 0.001$, Cohen's $d = 2.06$, 95% CI = [2.67, 4.42], and amusement, $t(60) = 5.68$, $p < 0.001$, Cohen's $d = 1.44$, 95% CI = [1.76, 3.66]. Meanwhile, participants in the affect-positive group ($M = 6.65$, $SE = 0.36$) had a significantly higher

[1]In the pre-experiment, we first asked university students from where the experiment was conducted to recommend five videos that they thought most evoke positive emotions. The 20 students were randomly selected from the school to rate the emotional valence of these five videos. The variety show segment that evoked the most positive affect was used as priming material.

[2]The movie clips were all selected from the emotional materials of the "happy" and "neutral" dimensions of the emotion database established by Deng et al. (2017).

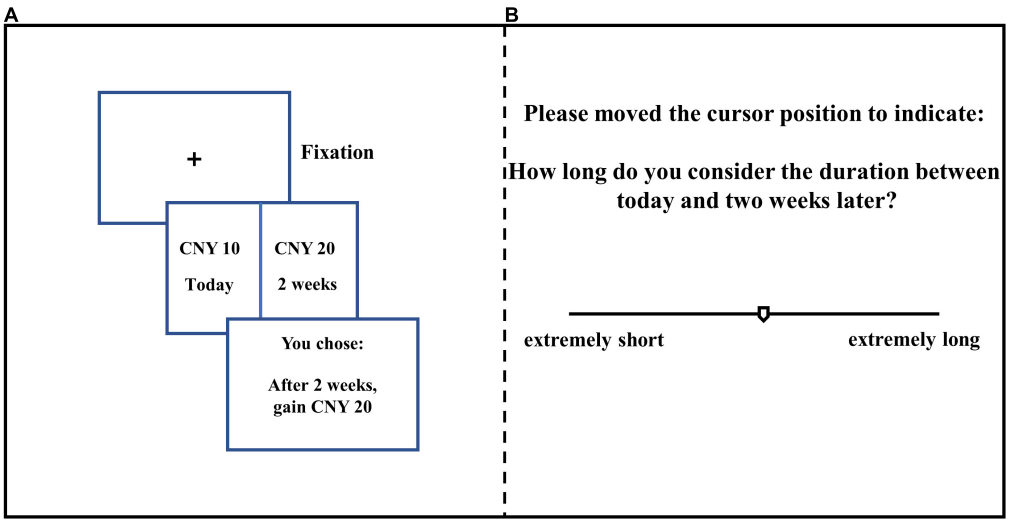

FIGURE 1 | Experimental procedure with example tasks: **(A)** IC task, **(B)** Time perception task.[In both studies, the experimental materials were all presented in Chinese.] For A, the option pair is displayed until participants make a choice.

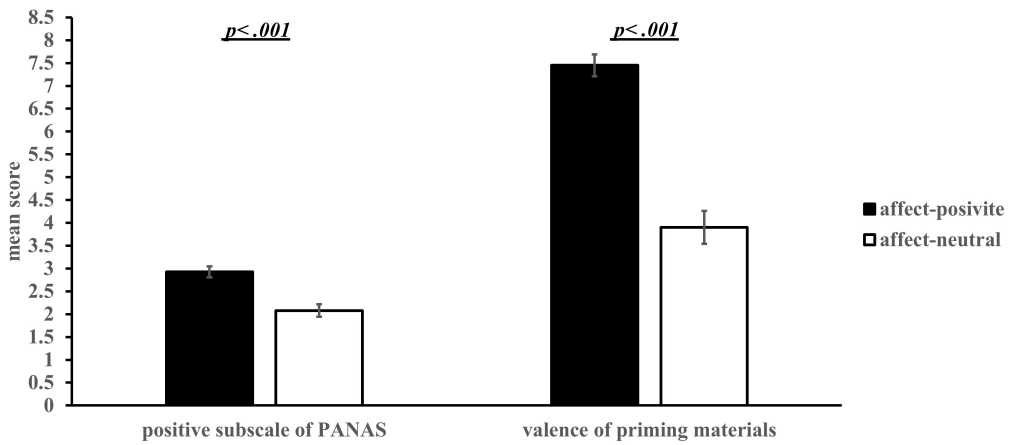

FIGURE 2 | Mean scores of positive subscale of PANAS and the evaluation for the valence of priming materials in different affect groups *(M ± SE)*. The item for valence evaluation was *"Did you feel happy when watching the video"* using a nine-point Likert scale (1 = very unhappy, 9 = very happy).

motivation to enter the video scene than those in the affect-neutral group (M = 3.48, SE = 0.27), $t(60)$ = 4.47, $p < 0.001$, Cohen's d = 9.96, 95% CI = [1.19, 3.12]. Overall, the results indicate that affect priming was effective, and the affect-positive group experienced a significantly higher degree of pleasure than the affect-neutral group.

Objective Time Discounting

We fitted a hyperbolic discounting model (among other candidate models) to participants' choice data to obtain their discount rate, using the HBM method. The analysis was performed using the R software package hBayesDM (hierarchical Bayesian modeling of decision-making task; Ahn et al., 2017; Zhang et al., 2020). All model fittings used four independent Markov chain Monte Carlo (MCMC) chains, and each chain contained 1,000 valid samples after initial tunning of the MCMC algorithm. Therefore, the distribution of all parameters consisted of 4,000 valid posterior samples. A Gelman-Rubin test (Gelman and Rubin, 1992) showed that the $\hat{R}$ of all parameters was less than 1.1, indicating that the four independent MCMCs had converged, and the results of model fitting were stable and reliable.

First, referring to the common method of previous studies, the data were fitted without distinguishing between "immediate" and "non-immediate" conditions. Next, we distinguished the two time conditions to fit the data again. Finally, we used widely applicable information criterion (WAIC; Vehtari et al., 2016) to compare the models obtained by two different fitting methods. The WAIC uses all MCMC posterior samples to calculate the out-of-sample predictive accuracy of the model. To avoid overfitting, it penalizes the model complexity (see **Supplementary Material** for WAIC calculation formulas). A lower WAIC score indicates a

better out-of-sample prediction accuracy of the candidate model. If ΔWAIC > 10, the model is considered to be significantly different (Burnham and Anderson, 2004).

The results showed that when the model was fitted by distinguishing "immediate" and "non-immediate" conditions, whether in the affect-positive (WAIC = 3220) or affect-neutral group (WAIC = 3281), the WAIC was significantly lower than models that jointly fitted data from the "immediate" and "non-immediate" conditions (affect-positive group: WAIC = 2311, ΔWAIC = 909; affect-neutral group: WAIC = 2285, ΔWAIC = 996). The results showed that the experimental data can be better fitted, and a better model can be obtained after distinguishing "immediate" and "non-immediate" conditions. Thus, we adopted a decision model that distinguished the time conditions for further analysis.

Taking the discount rate estimated above as the dependent variable, 2 (affect) × 2 (task conditions) analysis of variance (ANOVA) showed that the main effect of affect was significant, $F(1, 60) = 3.34$, $p = 0.07$, $\eta^2 = 0.05$, 95% CI = [−0.004, 0.08]. The time discount rate of the affect-positive group ($M = 0.08$, $SE = 0.02$) was larger than that of the affect-neutral group ($M = 0.04$, $SE = 0.02$). The main effect for task conditions was significant, $F(1, 60) = 4.81$, $p = 0.03$, $\eta^2 = 0.07$, 95% CI = [0.002, 0.03]. The discount rate of the "immediate" condition ($M = 0.07$, $SE = 0.01$) was significantly greater than that of the "non-immediate" condition ($M = 0.05$, $SE = 0.01$), indicating an immediacy effect. The interaction between affect and task conditions was significant, $F(1, 60) = 8.84$, $p = 0.004$, $\eta^2 = 0.13$. Bonferroni adjustments were used for post-hoc pairwise comparisons. Post-hoc analysis showed that in the condition of "immediate," the time discount rate of the affect-positive group was significantly larger than that of the affect-neutral group, $p = 0.02$, 95% CI = [0.01, 0.12]; in the condition of "non-immediate," the time discount rate of the affect-positive group was not significantly different from that of the affect-neutral group, $p = 0.42$ (see **Figure 3**).

Overall, these results support the hypothesis that the influence of incidental affect on IC has a disjunction effect; when including "immediate time," positive incidental affect causes individuals to prefer smaller-sooner options in IC, and the strength of immediacy effect is stronger when IC excludes "immediate time." Positive incidental affect has no effect on choice preferences (Hypothesis 1).

Time Perception

We calculated and compared the subjective time perceptions of the two affect groups (Kim and Zauberman, 2009). In detail, the measured length of the line scale was transformed into day units by setting the overall mean distance for the one-week duration as the baseline unit (e.g., $M_{\text{one week}} = 7.42$ cm; 7.42 cm represents the subjective time of a week) for the time judgment by each individual. Then, the subjective time perception "T" for each delay was calculated. Furthermore, in order to compare different lengths of time perception from a unified dimension and examine the overall level and sensitivity of time perception, a power function model of time perception was used to fit their time perception data into "immediate" and "non-immediate" conditions and estimate the time perception model parameters of each participant (Kim and Zauberman, 2009; Cruz Rambaud and Ventre, 2017; Cruz Rambaud et al., 2018; Laube and van den Bos, 2020)[3]:

$$T = \alpha t^{\beta_3} \tag{1}$$

where α is a scaling parameter that captures the overall degree of time contraction (how long or short individuals perceive time to be overall), and β is a nonlinear scaling parameter representing diminishing sensitivity to time.

[3]We modeled the data using Steven's power law and Weber-Fechner law, and used Bayesian Information Criterion (BIC) to measure the performance of two models. The results indicated that the power function (Steven's power law) fitted the data better than Weber-Fechner law ($BIC_{Steven'spowerlaw} = 3960$, $BIC_{Weber-Fechnerlaw} = 4142$, a lower BIC score indicates a better fitting of data). We therefore used the power model in all subsequent analyses.

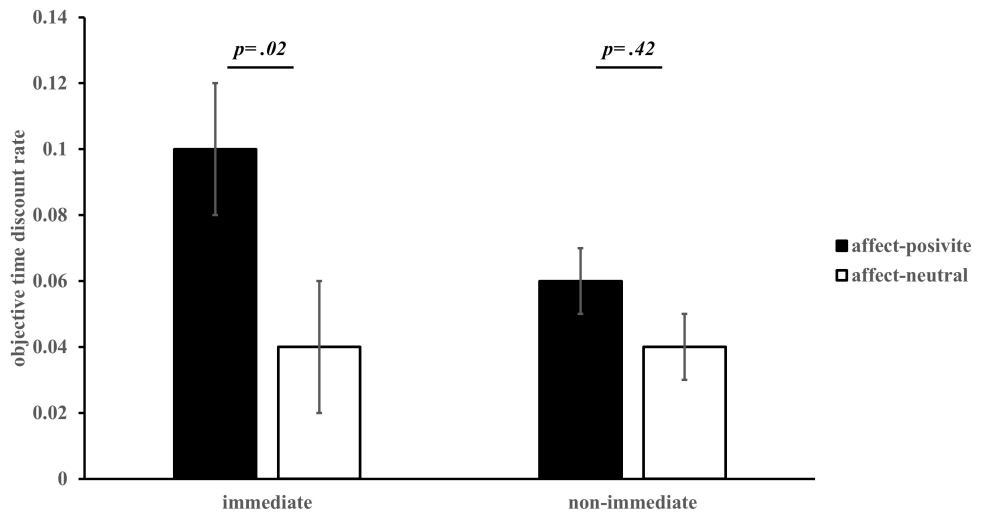

FIGURE 3 | Objective time discount rate for different affect groups *(M ± SE)*.

The results of a 2 (affect) × 2 (task conditions) ANOVA revealed that, for the overall perception of time (α parameter), the main effect of affect was significant, $F(1, 60) = 4.36$, $p = 0.04$, 95% CI = [0.12, 5.52]). However, neither the main effect of task conditions, $F(1, 60) = 0.31$, $p = 0.58$, nor the interaction between the two, $F(1, 60) = 0.22$, $p = 0.64$ (see **Figure 4**) were significant. For sensitivity to time (β parameter), none of the main effects of affect, task conditions, and their interaction were significant, affect: $F(1, 60) = 2.17$, $p = 0.15$; task conditions: $F(1, 60) = 0.48$, $p = 0.49$; interaction: $F(1, 60) = 0.004$, $p = 0.95$. These results support the hypothesis that compared with the affect-neutral group, participants in the affect-positive group had a longer subjective perception of time, but there was no difference in the time sensitivity between the two conditions (Hypothesis 2).

Subjective Time Discounting

To control for the impact of time perception differences on decision-making results, we integrated the subjective time estimate into the intertemporal decision model and replaced the time parameter t in the intertemporal decision model with the corresponding subjective time Perception T and estimated and compared the model parameters of the different participant conditions (Laube and van den Bos, 2020).

Results of a 2 (affect) × 2 (task conditions) ANOVA showed that the main effect of affect was marginally significant, $F(1,60) = 3.03$, $p = 0.09$, 95% CI = [−0.01, 0.14]. However, neither the main effect of conditions, $F(1, 60) = 1.27$, $p = 0.27$, nor the interaction between the two were significant, $F(1, 60) = 2.24$, $p = 0.14$ (see **Figure 5**). The above results support the hypothesis that after integrating subjective time perception into the IC model, no differences were found in discount rates, indicating that the subjective difference in time perception impacted choice preference in IC (Hypothesis 3).

In sum, Study 1 revealed the disjunctive effect of incidental affect on IC and the underlying mechanism of time perception. After priming positive incidental affect, individuals perceived time as a longer and preferred the SS option when making choices of IC, including immediate time. Incidental affect has no impact on individuals' choice preferences for IC, excluding immediate time.

STUDY 2

Study 1 showed the disjunctive effect of incidental affect on IC, and time perception was an important mechanism. However, we did not examine how people processed the delay and reward attributes of IC after priming positive affect. Therefore, in order to further clarify the mechanism of effect on IC, we adopted an attribute attention test to investigate whether incidental affect led to asymmetrical attention toward the delay and reward attributes of IC.

Methods

Participants

A power analysis indicated that a total of 118 participants were needed for a medium partial $\eta^2(0.4)$ when $\alpha = 0.05$ for a power of 0.95, using a χ^2 test. The final sample consisted of 120 college students from a university in Guangzhou, China (59 women, $M_{age} = 20.2$, $SD_{age} = 7.49$). All participants had normal or corrected-to-normal vision. Written informed consent was obtained from all the participants prior to participation. They received credit for their course grades and CNY 5 payments for participating.

Materials and Procedure

Participants were randomly assigned to affect-positive ($n = 60$) or affect-neutral ($n = 60$) groups. They completed the experimental tasks and the questionnaire. At the beginning of the experiment, participants were primed with affect, as in Study 1.

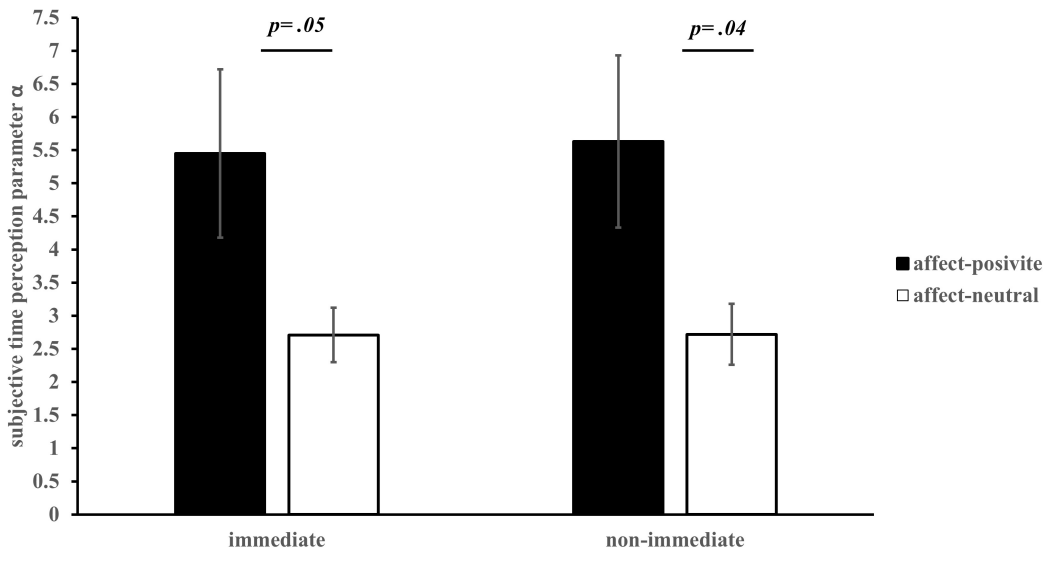

FIGURE 4 | Subjective time perception parameter α in different affect groups *(M ± SE)*.

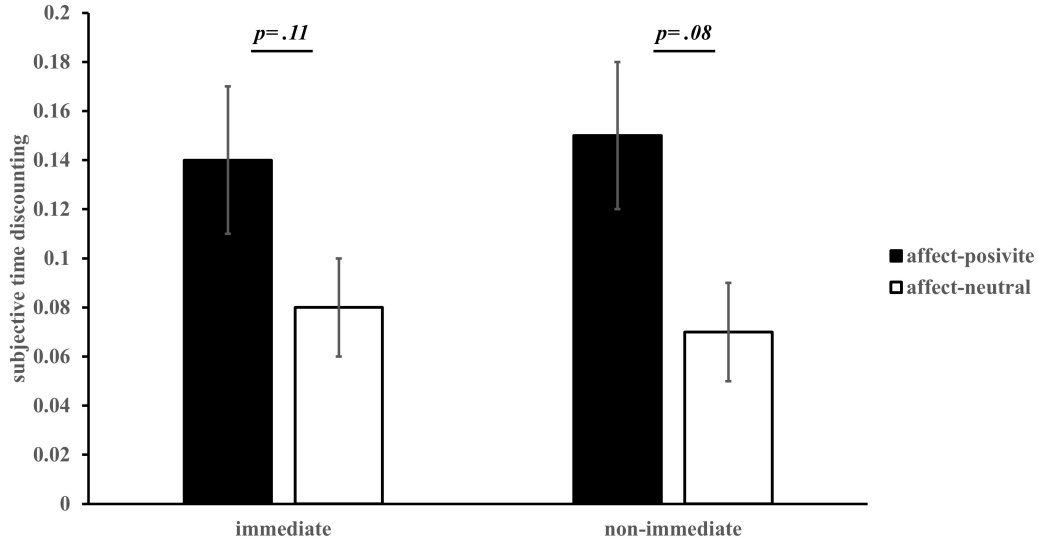

FIGURE 5 | Subjective time discount rate in different groups *(M ± SE)*.

After affect priming, participants completed the attribute attention test. The purpose of this test was to investigate whether the primed positive affect led to differences in individuals' attention weight to reward and delay attributes in IC (Laube and van den Bos, 2020). The experiment was designed according to the principles of query theory (Weber et al., 2007). First, participants were introduced to the meaning of IC through examples and an attribute combination of each option (SS option: "shorter delay," "smaller reward"; LL option: "longer delay," "larger reward") and completed a question to test whether they understood the meaning of each attribute as a manipulation check. Next, participants were presented with a set of IC options; however, the attributes of the options were all obscured, and there were only four boxes marked with "shorter delay," "longer delay," "smaller reward," and "larger reward." Participants could open a box to acquire information to make a choice. There were two conditions in this test: the "full choice condition" and "constrained choice condition." In the "full choice condition," participants could choose to open all the boxes in turn to acquire information about all attributes of a choice to investigate which attribute participants would look for first. In the "constrained choice condition," participants could select only three of the four pieces of information to investigate which attribute participants to focus on more (i.e., "two delay attributes, one reward attribute" or "two reward attributes, one delay attribute"; see **Supplementary Material** for the experiment materials).

The participants then performed the IC task. The experimental material was obtained by simplifying it from Study 1. The task contains two conditions: the delay of the SS option is *immediate* (today) or *non-immediate* (15 days in the future), and each condition included 10 trials (corresponding to 10 different rewards for the SS option). For the "immediate" condition, the delay for the LL option time was fixed as 85 days in the future, and in the "non-immediate" condition, the delay of the LL option was fixed as 105 days in the future. The reward of the LL option was fixed as CNY 200, and the SS option for each condition ranged from CNY 100 to CNY 194. Finally, the participants completed the same questionnaire as in Study 1.

Results

Manipulation Check

Five participants did not pass the manipulation check for the attribute attention task and were excluded from further analysis. Therefore, the final number of people included in the analysis was 115 ($N_{positive} = 57$, $N_{neutral} = 58$).

Affect Priming

The test results of the difference in the PANAS positive subscale scores between the affect-positive and affect-neutral groups showed that the positive affect score of PANAS in the affect-positive group was marginally significantly higher than that in the affect-neutral group, $t(113) = 1.69$, $p = 0.09$, 95% CI = [−0.05, 0.59] (see **Figure 6**). The results of analysis of the five subscale items showed that there were no significant differences between the two conditions in the dimensions of "cheerful," "delighted," "excited," "lively," and "enthusiastic" ($0.24 < p < 0.58$); however, the "happy" and "joyful" degrees of the affect-positive group were significantly higher than those of he affect-neutral group, "happy": $t(113) = 2.59$, $p = 0.01$, Cohen's $d = 0.48$, 95% CI = [0.11, 0.86]; "joyful": $t(113) = 2.04$, $p = 0.04$, Cohen's $d = 0.38$, 95% CI = [0.01, 0.79].

For the evaluation of the priming materials, no significant difference in the familiarity of the video between the two groups was observed ($M_{positive} = 5.39$, $SE_{positive} = 1.71$; $M_{neutral} = 3.97$, $SE_{neutral} = 0.29$), $t(113) = 0.83$, $p = 0.41$, Cohen's $d = 0.15$, 95% CI = [−1.99, 4.83]. Compared with the affect-neutral group ($M = 3.84$, $SE = 0.23$), participants from the affect-positive group ($M = 7.47$, $SE = 1.66$) liked the video more, $t(113) = 2.18$, $p = 0.03$, Cohen's $d = 0.41$, 95% CI = [0.34, 6.92], and experienced more pleasure, $t(113) = 2.53$, $p = 0.01$, Cohen's $d = 0.47$, 95%

CI = [0.90, 7.42], and amusement, $t(113) = 1.96$, $p = 0.05$, Cohen's $d = 0.37$, 95% CI = [−0.03, 6.63]. Meanwhile, participants in the affect-positive group ($M = 7.79$, $SE = 1.66$) had a significantly higher motivation to enter the video scene than the affect-neutral group ($M = 4.60$, $SE = 0.27$), $t(113) = 1.92$, $p = 0.06$, Cohen's $d = 0.36$, 95% CI = [-0.11, 6.48]. Overall, the results indicate that affect priming was effective, and the affect-positive group experienced a significantly higher degree of pleasure than the affect-neutral group.

Intertemporal Choice

Taking the proportion of SS option as a dependent variable (Zhou et al., 2019), a 2 (affect) × 2 (task conditions) ANOVA showed that the main effect of affect was marginally significant, $F(1, 113) = 3.68$, $p = 0.06$, 95% CI = [−0.004, 0.22]. Participants in the affect-positive group ($M = 0.77$, $SE = 0.04$) preferred the SS option more than those in the affect-neutral group ($M = 0.66$, $SE = 0.04$). The main effect of task condition was significant, $F(1, 113) = 10.80$, $p = 0.001$, $\eta^2 = 0.09$, 95% CI = [0.03, 0.10]. The proportion of SS options in the "immediate" condition ($M = 0.75$, $SE = 0.03$) was significantly higher than that in the "non-immediate" condition ($M = 0.68$, $SE = 0.03$), indicating an immediacy effect. Their interaction was not significant, $F(1, 113) = 0.22$, $p = 0.64$. The Bonferroni post-hoc analysis showed that in the "immediate" condition, the proportion of choosing SS options in the affect-positive group was significantly higher than that in the affect-neutral group, $p = 0.04$, $\eta^2 = 0.04$, 95% CI = [0.003, 0.24]. In the "non-immediate" condition, there was no significant difference between the affect-positive and affect-neutral groups ($p = 0.11$; see **Figure 7**).

Overall, these results replicate the main findings of Study 1 and support our hypothesis (Hypothesis 1), indicating that incidental affect has a disjunction effect on IC.

Attention Toward Attributes

In the "full choice condition," participants could choose to open all the boxes to acquire information about all attributes. The results showed that participants were more likely to first open the box representing the delay attribute ("shorter delay" and "longer delay") in the affect-positive group than the affect-neutral group, χ^2 (1) = 19.47, $p < 0.001$, $r = 0.41$ (see **Figure 8A**). In the "constrained choice condition," participants could only choose "two delay attributes, one reward attribute" or "two reward attributes, one delay attribute." The results indicated that participants in the affect-positive group were likely to open more boxes representing the delay attribute than those in the affect-neutral group, χ^2 (1) = 5.44, $p = 0.02$, $r = 0.22$ (see **Figure 8B**). The results indicate that compared with the affect-neutral group, the affect-positive group prioritized and paid the most attention to the delay attribute of IC, rather than the reward attribute.

Altogether, these results support the hypothesis that affect can lead to differences in processing IC in terms of delay and reward attribute. Compared with the affect-neutral group, after priming positive affect, individuals will prioritize and pay more attention to the delay attribute before making an IC (Hypothesis 4).

DISCUSSION

The current research revealed the disjunction effect of incidental affect in IC; it also revealed that a shift in subjective time perception is the underlying mechanism of this effect. Across two studies, we consistently found that positive incidental affect was associated with an increased impatient decision for IC that includes immediate time. However, no change in choice preference for IC that excludes immediate time was observed. Moreover, positive incidental affect changes intertemporal preferences by causing the individual to perceive the same objective future durations to be subjectively longer. Before making a decision, individuals paid more attention to time and were more inclined to know about the delay of intertemporal options, rather than reward attributes.

Disjunction Effect of Affect on Intertemporal Choice

The finding that positive incidental affect can cause individuals to show stronger an immediacy effect in IC is consistent with previous studies (Norouzi, 2011; Kim and Zauberman, 2013;

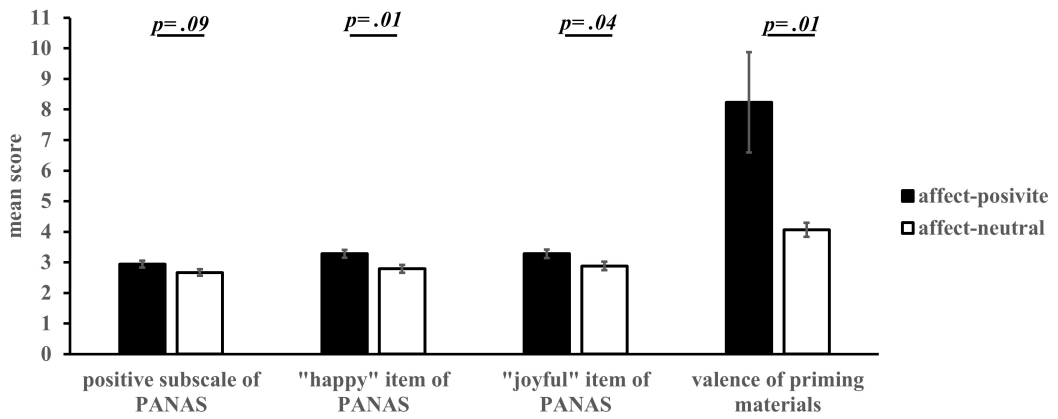

FIGURE 6 | Scores of positive subscale of PANAS and the evaluation of priming materials in different affect groups *(M ± SE)*.

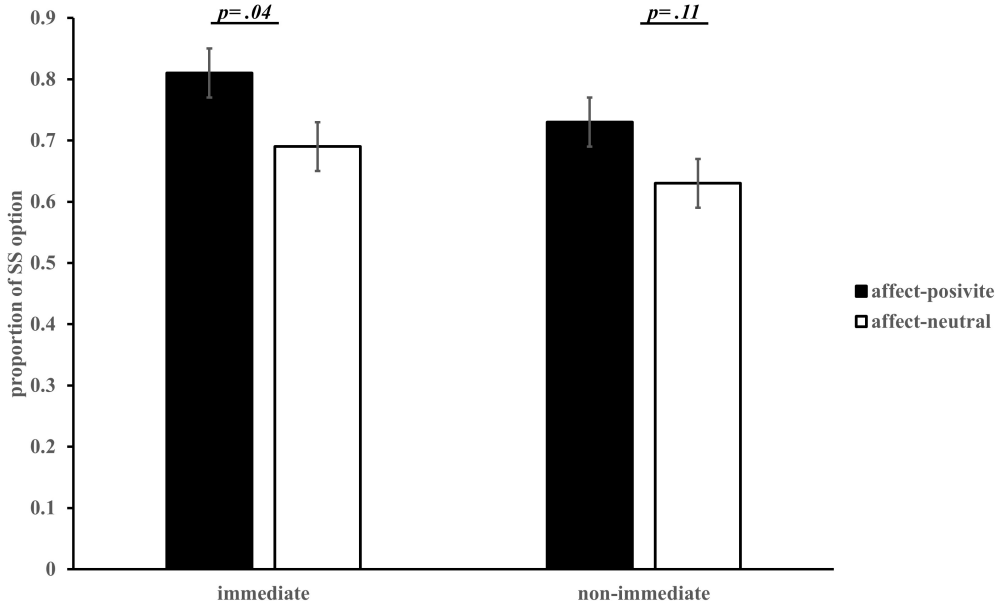

FIGURE 7 | Proportion of SS option in different groups *(M ± SE)*.

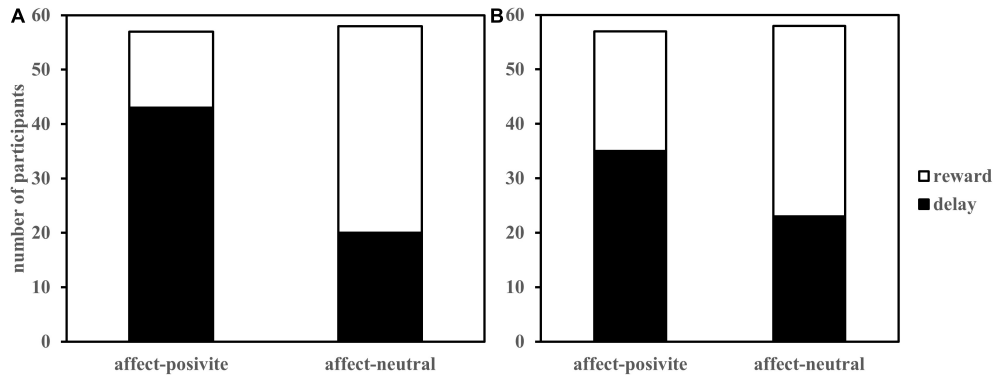

FIGURE 8 | Attributes that participants pay attention to in attributes attention test: **(A)** attribute of first attention, **(B)** attribute of most attention.

Lempert et al., 2017). These results are also consistent with the findings of Laube and van den Bos (2020), which indicated that integral affect leads to increased impatience in intertemporal choice. However, in contrast to these studies, using HBM, we distinguished IC including/excluding immediate time when estimating model parameters and obtaining a better model to reveal the disjunction effect of incidental affect. Studies 1 and 2 consistently showed that affect only influences IC, which includes immediate time, while individuals' choice preferences remain the same when excluding immediate time.

Our finding, however, is different from that of other studies, which found that positive affect corresponds to long-term preferences for IC (Wang and Liu, 2009; Ifcher and Zarghamee, 2011; Pyone and Isen, 2011). Considering the difference in evaluation of affect materials between affect-positive and neutral groups, this divergence of influence on IC may be related to the fact that although the valence of the emotional priming materials is identical, there were differences in other dimensions, such as emotional intensity, self-involvement, and motivation. This speculation is supported by Lempert et al. (2017), who showed that when imagining positive experiences and recalling positive memories, although both can prime positive affect, they have opposite effects on the degree of individual impulsivity. Therefore, incidental affect has a complicated influence on decision making. Future research should focus not only on common dimensions, such as valence and arousal, but also on other dimensions of affect, such as motivation and involvement.

Mechanisms Underlying the Impact of Incidental Affect in Impatient Choice: Time Perception

Similar to the findings of integral affect and other related studies (Geoffard and Luchini, 2010; Laube and van den Bos, 2020),

the current research also found that after the priming of positive affect, individuals subjective time perception was longer. Moreover, in Study 2, we also revealed that incidental affect will also lead individuals to pay more attention to the delay attribute of IC. These studies showed that positive affect influences intertemporal preferences by making individuals overestimate time and increasing their attention to time. Overall, the above studies consistently demonstrate that time perception is the mechanism by which it influences IC; when an individual has a long-term perception, the waiting time could be perceived as a cost, which reduces the attractiveness of future options and causes higher impulsivity in IC (Wittmann et al., 2007; Wittmann and Paulus, 2008; Norouzi, 2011; Kim and Zauberman, 2013).

According to the assumption of the classic time discounting models, compared with the immediate rewards, distant rewards are afforded a smaller weight (Read, 2004). According to these models, time interval is like a "ruler," and its length determines the degree which the individual will lose value in the future. The scale of this "ruler" is not uniform; thus, the discount rate varies at different time intervals. According to the hypothesis of the perceived time-based model, changing the delay time of IC leads to the reversal of decision preferences, not a change in discount rate, but a change in subjective time perception (Kim and Zauberman, 2009). Therefore, when people weigh options that occur at different times, the "ruler" they use is highly dependent on individual differences in their time judgments. Combined with the results of this research, factors such as affect can change behavioral decision making by influencing subjective time perception. It should be noted that in Study 1, there was no difference in the subjective time discounting between IC conditions (including/excluding immediate time), suggesting that compared with the results of objective time discounting, after controlling for the impact of time perception on decision-making results, the immediacy effect disappeared. This result indicated that time perception is an important mechanism for affect in IC, and future studies are necessary to examine whether it has such a consistent and strong role in other behavioral effects of IC.

Implications

Theoretically, this research distinguishes the time conditions of IC and reveals the disjunction effect of incidental affect on IC. That is, incidental affect only influences information about immediate time of IC. Computationally, using HBM, we estimated the discount rate parameter by distinguishing "immediate" and "non-immediate" conditions of IC and obtained a better model than that jointly fitting data from different conditions. Moreover, the research reveals that incidental affect leads to differences in levels of individual attention paid to the delay and reward attributes of IC. Based on the perceived time-based model, through the test of subjective time discounting, this research shows that affect influences intertemporal preferences by changing time perception. In sum, this research provides more accurate answers to how incidental affect impacts IC.

This research also provides a new perspective on how to improve related decision-making behaviors. Based on the findings, positive incidental affect would lead to a stronger immediacy effect by influencing time perception. In the investment field of China, the sales of financial products have a "24-hour cooling-off period" rule, that is, consumers have the right to unilaterally and unconditionally cancel the contract within a reasonable time (China Banking and Insurance Regulatory Commission, 2019). This rule is consistent with our findings. Thus, from the perspective of regulators, shielding immediate time in IC can reduce consumers' irrational decision-making behavior and protect their rights; from the perspective of consumers or decision makers, recognizing the important relationship between affect and the immediacy effect can reduce short-sighted impulsive behaviors in life and improve IC.

Limitations and Perspective

First, this research is based on incidental affect, distinguishing only according to emotional valence and comparing positive and neutral affect. However, according to the results of Study 1, there are differences in the dimensions of excitement and motivation between the two conditions. Combined with other studies that examine the effect of positive affect on IC (Wang and Liu, 2009; Ifcher and Zarghamee, 2011; Pyone and Isen, 2011), and finding that imagining positive experiences and recalling positive memories have differential effects on behavior (Lempert et al., 2017), we can infer that even with the same valence, differences in emotional strength, self-involvement, motivation, and other dimensions will have differential effects on behavior. In addition to distinguishing affect according to common dimensions such as salience, valence and arousal, future related research should also investigate other dimensions of affect, such as motivation and involvement. In addition, according to the two-system analysis, which can be applied to positive and negative affect, negative affect may be similar to positive affect, which influences the immediacy effect of IC by affecting time perception. Future research can investigate the mechanism and boundary effect of negative affect in order to make useful attempts to resolve related research disputes.

Additionally, this research only adopted behavioral experiments and model fitting methods and did not directly verify the influence mechanism of affect from the perspective of the decision-making process. According to the assumptions of the attribute-wise model of IC, an individual's impulse level stems from differences in the weighting of delay and reward attributes (Dai and Busemeyer, 2014). Similarly, our research also finds that after decision makers are stimulated with positive affect, they pay more attention to delay attributes and hope to learn more about time before making a decision. Future research may utilize process tracing methods, such as eye tracking and mouse tracing, to directly test the attentional mechanisms underlying incidental affect on decision making. It would also aid in investigating the neural mechanisms facilitating the impact of affect on IC utilizing model-based neuroimaging.

CONCLUSION

This research explores the disjunction effect of incidental affect on IC under different time conditions and the mechanism underlying time perception. It found that positive affect makes

individuals pay more attention to the delay attribute of IC before decision making, perceive subjective time as longer, and lead to a stronger immediacy effect in IC.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB) Committees at the Chinese Academy of Sciences. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

LZO: conceptualization, methodology, software, validation, formal analysis, data curation, writing—original draft preparation, review, and editing, supervision, project administration, funding acquisition. TZ: formal analysis, investigation, software, visualization, writing—original draft preparation, review, and editing. LZA: formal analysis, writing—review and editing. J-ML: writing—review and editing. Y-YZ: funding acquisition, writing—review and editing. Z-YL: conceptualization, methodology, validation, resources, data curation, writing—original draft preparation, review, and editing, supervision, project administration, funding acquisition. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.782472/full#supplementary-material

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Environmental Temperature in Thermal Comfort Under Different Virtual Tourism Activity Intensities: Based on Microclimate Simulation Experiment

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Although COVID-19 lockdowns and travel regulations have restricted the spatial area for human activities, tourists can still use virtual devices and applications for travel purposes. This study aimed to explore the thermal comfort and satisfaction of tourists under various tourist activity intensities, using experimental and semi-structured interview methods, combined with microclimate simulation experiments and electrocardiogram data to monitor physiological indicators. The results showed that: (1) The thermal comfort of virtual tourists had a significant correlation with the environmental temperature. (2) The thermal comfort of virtual tourists differed under various activity intensities. The virtual tourism activity intensity moderated the relation between environmental temperature and tourists' thermal comfort. (3) In the state of exercise (slow walking, fast walking), the environmental temperature affected tourists' physiological indicators. (4) Virtual tourism that integrates realistic visual, audio, and tactile sensations can improve tourists' perception and satisfaction. The results provide a new perspective for the study of the virtual tourism experience and thermal comfort. In addition, it provides theoretical and practical support for the development of virtual tourism scenes in the environmental temperature context.

Keywords: virtual tourism, thermal comfort, activity intensity, experimental research, semi-structural interview

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INTRODUCTION

The COVID-19 pandemic has dramatically reduced the number of tourists worldwide. In 2020, the numbers of international arrivals fell by 74% from the previous year with financial losses of 1.3 trillion US dollars, becoming "the worst in the history of tourism years". In the post-lockdown period of the pandemic, although the tourism industry has shown the ability to quickly recover and return to normality, the uncertainty shock of pandemics still poses danger to the industry. The tourism industry needs transformation and upgrading. Due to improvements in technology, virtual reality (VR) has addressed the limitations posed by simulating the environment through pictures and videos (Carmigniani et al., 2011; Choi et al., 2015; Bogicevic et al., 2019), providing a better "immersion" experience (Bohil et al., 2011). Virtual tourism has sparked a surge of related products and services (Burdea and Coiffet, 2003; Serino et al., 2014). Virtual tourism not only solves the problem of boredom at home during the pandemic but also meets the huge social and market needs of the Internet era.

The following questions can be posed: Is virtual tourism just for tourists to obtain audiovisual experiences through technical means? How can the perfect virtual tourism experience be obtained? The experience needs to be integrated with microclimate conditions to enhance tourists' sense of presence and activity comfort, enabling them to have an immersive tourism experience (Zheng et al., 2010). The biggest advantage of virtual tourism is the high degree of tourist participation and interaction with the virtual travel experience (Huang et al., 2020). However, its realization depends on the tourists' Internet-connected devices; it cannot replace an on-site tour, let alone replicate the various atmospheres and sense of fun (Minderer et al., 2016). Therefore, it is essential to strengthen the sense of experience and simulation of virtual tourism (Riva et al., 2011), especially to meet the need for tourists to have an immersive experience based on the development of temperature-related environmental virtual tourism scenes.

Climate is one of the biggest factors affecting human comfort (Nicol and Humphreys, 1973; de Dear and Brager, 1998), and temperature has been utilized as an important tourism resource (Clements-Croome, 2013). Some tourism activities developed according to the climate have become popular choices for tourists, for example, migratory bird tourism, residence tourism, and retirement tourism (Hao et al., 2020). To date, few studies in the literature have researched the climate comfort of tourism activities, let alone the climate comfort of virtual tourism activities. Developing climate and temperature-related virtual tourism products without theoretical guidance means that tourists will not have pleasant and high-quality travel experiences in their virtual tourism activity (Bell et al., 2003). Therefore, it is necessary to explore virtual tourists' thermal comfort and their satisfaction with virtual travel experiences.

The study used both qualitative and quantitative methods, conducting a 3 × 3 experiment and semi-structured interview to explore two important areas: (1) A microclimate simulation experiment was used to simulate the environmental temperature under different types of virtual tourism activity intensity; virtual tourists' thermal comfort were analyzed by quantitative research. (2) Tourists' satisfaction was further explored under various virtual tourism activity intensities through semi-structured interviews, revealing the new characteristics of virtual tourism thermal comfort, thus promoting the sustainable development of the virtual tourism industry.

LITERATURE REVIEW

Virtual Tourism and Virtual Tourism Experience

Virtual tourism emerged in the 1990s; Perry and Williams (1995) first defined virtual tourism as a new format resulting from the combination of VR technology and tourism. Virtual tourism refers to the use of computer simulation technology, VR technology, and augmented reality (AR) technology to dynamically present real or non-existent tourism landscapes to tourists (Heeter, 2000; Wrzesien et al., 2013). Tourists can obtain an immersive travel experience without leaving home (Lin et al., 2020). With the continuous development of GIS (Geographic Information System), three-dimensional visualization, virtual reality, 3D Internet, and other technologies (Wrzesien et al., 2013; Brown and Green, 2016), virtual tourism can not only use computers to process graphics, images, videos, sound, and animation, but also present three-dimensional entities and the three-dimensional environment in a virtual form, realizing interactive three-dimensional animation and dynamic simulation (Choi et al., 2015; Botella et al., 2017; Loureiro et al., 2020).

On-site tourism brings tourists on site, giving them a real experience, while virtual tourism is a mirror-image simulation of a travel experience, which is the core of the entire virtual tourism activity (Williams and Hobson, 1995). Xu et al. (2001) compared the interactive mechanisms of virtual tourism and real tourism, finding a strong correlation between acquisition path and perception effect. The virtual tourism experience is not designed simply to meet the needs of audiovisual senses; its ultimate goal is to provide a full sensory immersive experience that integrates interaction, immersion, and artistic conception (Kaptelinin and Nardi, 2006; Jung et al., 2016; Calogiuri et al., 2018). In the future, virtual tourism will not be limited to fixed public places such as 9D virtual reality experience halls, VR experience centers, or VR theme parks. It could even control audiovisual systems, lighting systems, door and window systems, and other indoor smart home control systems to create private smart virtual tourism projects (Liu, 2020).

Virtual Tourism Activity Types

In a virtual tourism experience, tourists enter a set virtual tourism scene through VR technology and use a variety of interactive devices such as helmets, data gloves, or sensory feedback devices to meet the needs of the scene and tasks and to control the environment (Tatzgern et al., 2015). Virtual tourists can "go through" to the scenic spots, communicate with other tourists, take part in exercise such as hiking or adventure, and even manipulate "objects" (such as plants and animals) in the virtual scenes (Martinez-Grana et al., 2013). According to the different interactions between tourists, there are four types of virtual tourism: desktop virtual tourism, cabin-style virtual tourism, immersive virtual tourism, and naked-eye 3D virtual tourism (García-Crespo et al., 2016; Myung et al., 2020).

In desktop virtual tourism, tourists experience virtual world landscapes through computer monitors or mobile terminal devices. These landscapes are mainly rendered by 360° three-dimensional real-world technology (Liu and Deng, 2017), which can be operated in a 360° direction and watched on any terminal (Choi et al., 2015). Chinese famous tourist attractions and cities can be browsed from all angles on virtual tourism websites such as "China Panorama Network" and "Panorama Virtual Travel Network." In cabin-style virtual tourism, tourists are sited in a special cabin equipped with a screen that can watch the virtual world. The virtual world can be observed from different angles by rotating the cabin. The users don't need to wear other special devices to engage in interactive activities in the virtual world, which they can do so in a burden-free manner (Huang et al., 2020). In immersive virtual

tourism, tourists need to be equipped with helmet-mounted displays or wrap-around monitors to experience the virtual travel world (Burdea et al., 1996; Mattila et al., 2020) and take part in various virtual tourism activities. The scene is stronger and more realistic. In naked-eye 3D virtual tourism, AI, eye tracking, and 3D rendering is used to track the tourists' eyeballs through an integrated camera. The system performs AI calculations based on the captured eye movements and dynamically presents realistic beaches, forests and fields, and other landscapes, aiming to provide tourists with an immersive naked-eye 3D viewing experience (Wrzesien et al., 2013).

Tourism Thermal Comfort

Changes in climatic conditions such as temperature and humidity comprehensively affect the comfort of the human body, which in turn has, to varying degrees, health and physiological effects on the human body. Therefore, climate comfort is a very important factor in human activities. Climate comfort evaluation models and indicators have been extensively studied in the fields of architectural design (Hellwig, 2015), urban planning (Parkinson and de Dear, 2015), human health, and tourism development (Zhou et al., 2014). Tourism climate was first introduced by Hibbs (1966), who pointed out that tourism climate is a tourism resource with beneficial or adverse effects within a certain time and space, which can be used for tourism development and can be quantitatively evaluated. Tourism climate has gradually become a new research field; some indicators specifically aimed at measuring tourism climate comfort have been proposed, such as CI (Climatic-tourist Index), TCI (Tourism Climate Index), and CIT (Climate Index for Tourism) (Fang and Yin, 2015; Nalau et al., 2017). Climate comfort has gradually become an important determinant in the tourism decision-making process (Brager and de Dear, 1998).

Temperature is a key factor that impacts human comfort and is an important indicator for climate comfort. Research on thermal comfort includes significant guidance on helping tourists to make travel decisions and select tourist destinations (Mieczkowski, 2010). The existing research on thermal comfort mainly focuses on the influence mechanism, and the temporal and spatial distribution of the thermal comfort zone. However, in thermal comfort evaluation research, the body temperature classification standard varies in different conditions and cannot be simply applied to other contexts. For example, the "pleasant climate" varies from region to region, according to the effective temperature; the "pleasant climate" ranges from 15–19°C in the United Kingdom, 20–26°C in Europe and Indonesia, 21–26°C in India, and 21–29°C in Malaysia (Lise and Tol, 2002; Hamilton, 2004). The thermal comfort of tourism not only affects the length of the comfortable period of tourism and the choice of tourist destination, but also affects the changes in tourism activities and the function of tourism resources (Lu et al., 2016).

Hypotheses

The study examined the effect of environmental temperature and virtual tourism intensity on tourists' thermal comfort, and whether the environmental temperature has an impact on tourists' physiological indicators under various virtual tourism intensities. The conceptual model is shown in **Figure 1**.

With the extensive development of indoor tourism activities such as museum tours, temperature has become the environmental factor that is the easiest to change. In outdoor tourism activities, the temperature of destinations can be changed by increasing vegetation coverage and water areas, providing tourists with a healthy and comfortable tourism environment. According to the human body thermal balance theory, there is heat exchange between the human body and the environment. When the heat generated by the human body is equal to the heat emitted, the human body is in a thermally comfortable state. Numerous studies have also shown that environmental temperature affects the thermal comfort of tourists (Schellen et al., 2013).

According to exercise physiology, metabolic rate is a representative indicator of human energy metabolism and has an important influence on thermal sensation and comfort. During exercise, the human body has a high metabolic rate, with the low thermal resistance of clothes, a large amount of perspiration, and shortness of breath. There is a significant difference in the thermal comfort perceived by the human body in the exercise state compared to the quiet sitting state (Ji et al., 2015). A recent study conducted by Zhang et al. (2020) found that under different weather conditions, exercise intensity has a significant impact on the thermal comfort of the human body. In addition, in different exercise states, the human body will reach a state of equilibrium through the contraction and relaxation of blood vessels, perspiration, and shivering. Compared with the sitting posture, the human body has a greater range of temperature acceptance and adaptation during exercise. People who are in a thermally comfortable state during exercise have lower skin temperature, higher sweating rate, and higher core body temperature (Revel and Arnesano, 2014). The physiological functions of the human body change greatly under different exercise levels; the acceptance and adaption range of temperature is not always the same, which affects the thermal comfort of the human body (Yin et al., 2017). Therefore, the study considered the effect of activity intensity which is closer to the actual virtual tourism activity and enhances the stimulating effect. Thus, it was meaningful to consider the influence of activity intensity that is close to the actual virtual tourism experience, as proposed in the following hypotheses:

H1: Environmental temperature and activity intensity influence virtual tourists' perceived thermal comfort.

H1a: Environmental temperature influences virtual tourists' perceived thermal comfort.

H1b: Activity intensity influences virtual tourists' perceived thermal comfort.

H1c: Activity intensity moderates the relationship between environmental temperature and virtual tourist's perceived thermal comfort.

According to tourism embodied theory, tourists' experience is the result of the interaction of a series of related elements such as perception, the body, and the environment in the travel process. Thermal comfort during tourism activities is impacted by both physiological and psychological factors. Physiological

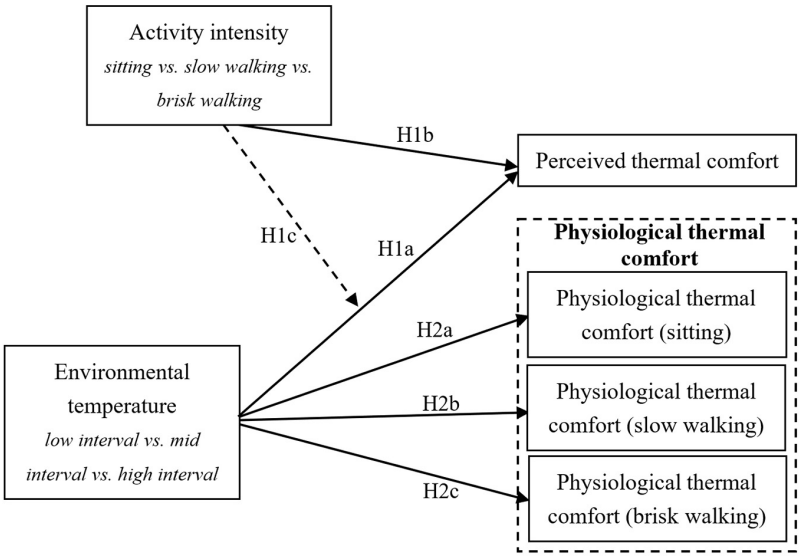

FIGURE 1 | Conceptual model and hypotheses.

indicators are important in studies of thermal comfort. Previous studies have shown that tourists, as warm-blooded mammals, can maintain a relatively constant body temperature when the environmental temperature changes. Under the control of the temperature regulation center (hypothalamus), the human body's heat production and heat dissipation processes are changed by physiological adjustment responses such as blood flow to the skin, vasoconstriction, and sweating rate. In addition, the thermal environment can also cause changes in water and salt metabolism, the cardiovascular system, and the nervous system. Studies have indicated that the higher the environmental temperature, the greater the labor intensity and the faster the heart rate (Boo-Chai, 1978). Kanosue et al. (2002) argued that the more uncomfortable people are, the higher the blood oxygen-dependent level of the tonsils on the sides of the brain. A study conducted by Xiong et al. (2016) has shown that indicators such as serum IL-6, oral temperature, skin temperature, heart rate, and heart rate variability are sensitive to temperature changes; thus, these indicators can potentially reflect the effect of temperature on human health and thermal comfort. This study used the seven indicators of HR (heart rate), PR (pulse rate), SPO_2 (blood oxygen), NIBP-Dia (diastolic blood pressure), NIBP-Sys (systolic blood pressure), NIBP-Mean (average blood pressure), and RR (respiratory rate) as proxies for the human physiological function change process, exploring how the environmental temperature influenced virtual tourists' physiological data under different activity intensities. Based on previous research, this study posits the following hypothesis:

H2: Under different tourism activity intensities, environmental temperature influences virtual tourists' physiological thermal comfort.

H2a: In the state of stability (sitting), environmental temperature influences virtual tourists' physiological indicators.

H2b: In the state of slow walking exercise, environmental temperature influences virtual tourists' physiological indicators.

H2c: In the state of brisk walking exercise, environmental temperature influences virtual tourists' physiological indicators.

MATERIALS AND METHODS

Experiment Instruments

The experiment was conducted in a tourism microclimate simulation laboratory in an eastern Chinese university. A window on the cabin door enabled the researcher to observe the experimental situation. There are temperature sensors, air humidifiers, LED lamps, and blowing ports in the cabin; thus, the temperature, humidity, wind speed, light, and other environmental factors can be controlled through the control panel outside the cabin. It can be heated and cooled in a short period, and the convenient operation makes it easy to simulate different virtual tourism environments in research on tourism comfort. The experimental instruments included a running platform, LED display screens (used to play documentaries of tourism scenes and to simulate the virtual tourism environment, which is the essential difference between this experiment and other thermal comfort experiments), and an electrocardiograph (testing the subjects' physiological indicators). The experimental instruments and pictures of them are shown in **Table 1** and **Figure 2**.

Virtual Tourism Scenarios

Travel is the process of interaction between tourists and the travel time and space environment. Tourism experimental research starts with the establishment of tourism scenes. This is also the biggest difference between tourism experimental research and exercise physiology experiments in other disciplines. In

TABLE 1 | Experimental instruments.

Instruments	Simulation/test content	Units
Microclimate warehouse	Air temperature	°C
	Relative humidity	%
	Wind speed	m/s
	Illuminance	Lux
ECG measuring instrument	PR (pulse rate)	Bmp
	HR (heart rate)	Bmp
	SpO_2 (pulse oxygen saturation)	%
	NIBP (blood pressure)	mmHg
	RR (respiratory rate)	rpm
Running platform	Activity speed	m/s

the experiment, climate environment parameters consistent with the outdoor environment were set and controlled by the microclimate cabin, including temperature, humidity, solar illumination, and wind speed. The LED display screen was used to play tourism documentaries to simulate different travel scenes, and the speed and slope were adjusted through the treadmill to simulate the three activity forms of sitting, walking slowly, and walking quickly, thus simulating different tourism activities in the virtual tourism situation. According to previous studies on tourism climate comfort (Qian and Ye, 1996; Dahai and Rong, 2000), the optimum value of humidity is 70%, wind speed is 2 m/s, and illuminance is 4200 lux.

Experimental Design

The study examined whether environmental temperature and activity intensity can influence tourists' thermal comfort. To simulate the climate environment in different activity intensities and obtain both physiological and psychological data, each respondent participated in two factorial (temperature and activity intensity) repeated experiments. This also helped to avoid the errors caused by individual differences. Therefore, this study employed a 3 (environmental temperature: low interval, mid-interval, and high interval)° × 3 (activity intensities: sitting, slow walking, and brisk walking) between-within subjects experimental design.

Based on the suggestion that the environment has an impact on the human body (Büttner, 1938), an increasing number of research studies have used the human body thermal balance model in thermal comfort assessment. The change of the human body's thermal balance is an important factor that influences human physiological parameters. The human body thermal balance equation is:

$$Q_m = Q_C + Q_r + Q_{res} + Q_{es} + Q_{st}$$

Q_m is the heat production of human body metabolism, unit: W/m^2; Q_c is the heat that the human body emits to the surrounding environment through convection, unit: W/m^2; Q_r is the heat emitted from the human body surface to the surrounding environment through radiation, unit: W/m^2; Q_{res} is the heat taken away by exhaled water vapor, unit: W/m^2; Q_{es} is the heat taken away by sweat evaporation, unit: W/m^2; Q_{st} is the heat storage of the human body, unit: W/m^2.

When Q_{st} = 0, the human body is in a state of thermal equilibrium. In a low-temperature environment, the heat storage of the human body declines and leads to Q_{st}<0, and people feel cold and uncomfortable. In a high-temperature environment,

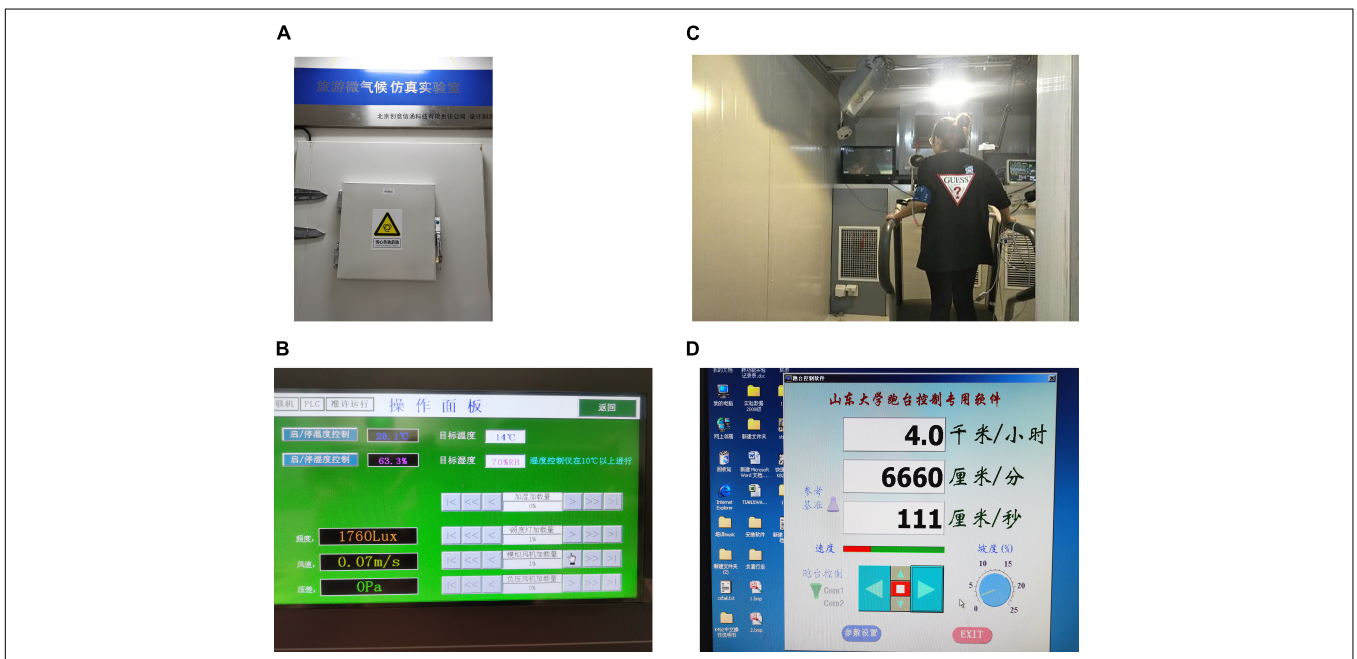

FIGURE 2 | Experimental instruments. **(A)** The appearance of microclimate warehouse. **(B)** The operation panel of microclimate warehouse. **(C)** Running platform, LED screen, ECG measuring instrument. **(D)** Running platform control center.

heat accumulates in the body, resulting in $Q_{st} > 0$, and people feel hot and uncomfortable. Fanger's (1970) equation is established under the conditions of normal temperature and low activity level, and it is difficult to accurately predict the thermal comfort of the human body in the state of exercise. Thus, it is more suitable to conduct tourist exercise studies from the perspectives of exercise physiology and environmental psychology (Merla et al., 2010). Under different levels of exercise, the human body maintains a balanced state through the contraction and dilation of blood vessels, perspiration, and shivering. In addition, the body's physiological functions and comfort change significantly under various activity intensities (Ji et al., 2015).

The physiological equivalent temperature index (PET index) refers to the climate temperature in which the human skin temperature and in-body temperature reach the same thermal state in a certain indoor or outdoor environment. Qiu et al. (2005) explored the human sweat regulation mechanism under different temperature circumstances and different exercise intensities in human experiments, revealing the relationship between environmental temperature and different types of human activity intensities. Considering the health of respondents, the study adopted three mild temperature intervals in the PET index: 13.1–18.0°C (slightly cool, light cold pressure), 18.1–23.0°C (comfortable, no heat pressure), and 23.1–29.0°C (slightly warm, light heat pressure). These three temperature intervals have been used in application examples of PET indicators (Höppe, 1999; Matzarakis et al., 1999; Shang et al., 2020), and each large temperature interval was subdivided into three small ranges to obtain a more accurate thermal comfort result. With a slight modification to the existing research (Qiu et al., 2005), the current study used the following common virtual tourism activity intensities: sitting, slow walking, and brisk walking (**Table 2**).

The specific experimental requirements are casual and comfortable posture when sitting quietly; the pace of slow walking is 0.7 m/s, and the pace of brisk walking for men is 1.3 m/s and for women is 1.1 m/s (Delp et al., 2007). The nine temperature sub-intervals and three activity intensities constitute 27 experimental conditions (**Table 3**). The physiological data were collected using electrocardiographs while the experiment was being conducted.

TABLE 2 | Examples of tourism scenarios under different activity intensities.

Activity intensities of the experimental design	Common scenarios in virtual tourism activities	Literature sources
Sitting	360° 3D panoramic desktop display browsing of tourism cities, tourism scenes, and virtual attractions.	Griffon et al., 2011, Chen, 2013
	Preview the hotel accommodation conditions by moving the screen and pointer.	Lee and Oh, 2007
Slow walking	A panoramic walking tour of VR theme park scenic spots through helmet-mounted displays or omni-directional monitors.	Lin and Zhang, 2017; Yu, 2017; Sutherland, 1968
	Watch the set underwater world, volcanoes, etc., through the mobile screen in the special cabin.	Huang et al., 2020
Brisk walking	Interactive sports such as running or climbing in naked-eye 3D virtual tourism scenes.	Lewis and Rosie, 2012
	Perform virtual game operations as a pilot, astronaut, etc., on the advanced simulator.	Jiang et al., 2007

TABLE 3 | Experimental design.

Activity intensity	Temperature (°C)	Sitting	Slow walking	Brisk walking
A: 13.1–18.0	A1: 13.1–14.7	A11	A12	A13
	A2: 14.8–16.3	A21	A22	A23
	A3: 16.4–18.0	A31	A32	A33
B: 18.1–23.0	B1: 18.1–19.7	B11	B12	B13
	B2: 19.8–21.3	B21	B22	B23
	B3: 21.4–23.0	B31	B32	B33
C: 23.1–29.0	C1: 23.1–25.0	C11	C12	C13
	C2: 25.0–27.0	C21	C22	C23
	C3: 27.1–29.0	C31	C32	C33

Controlled conditions: relative humidity (70%), wind speed (2 m/s), illuminance (4200 lux).

Data Collection and Sample

The experiment was conducted from February 2019 to August 2020. Sixty respondents were recruited through the TBL WeChat public platform; only respondents older than 18 years old with no history of heart disease or other health problems were eligible to participate in the experiment. The sample comprised 30 males and 30 females. The majority of respondents were between 18 and 30 years old; the average age was 21.72 years old. BMI was an important criterion for selecting respondents; the BMI of respondents was between 20 and 23, with an average of 21.26.

All the respondents had to uniformly wear short-sleeved T-shirts and trousers to mitigate the effect of the thermal-resistant clothes. At the same time, respondents needed to have a good night's sleep and not to exercise strenuously or diet before the experiment.

The respondents were randomly divided into three groups, each of which contained ten males and ten females. In the three activity states, the first group experienced the temperature range A1+B1+C1, the second group experienced the temperature range A2+B2+C2, while the third group experienced the temperature range A3+B3+C3. This helped to eliminate measurement errors caused by individual differences. Each respondent carried out nine sets of the experiment, and each experiment lasted 10 min. To avoid the influence of the previous experiment, the subject returned to their resting state after each experiment.

Measuring Tourist Response Variables

Environmental climatic data and activity intensity are posited as antecedents. Climatic variables such as humidity, wind speed, and illumination were controlled within a comfortable range. Temperature was the only climatic variable in the study and was

divided into nine intervals. Activity intensity was divided into three states: sitting quietly, walking slowly, and brisk walking.

The physiological indicators and perceived thermal comfort were set as outcomes. Considering the mobile nature of tourism, the experiment mainly collected data on seven basic indicators that can reflect the changing process of human physiological functions during exercise, including HR, PR, SPO_2, NIBP-Dia, NIBP-Sys, NIBP-Mean, and RR.

Thermal comfort is the subjective feelings of virtual tourists. Psychophysiologists use numerical scales to quantify these feelings. In order to express the relationship between scores and comfort intuitively, the study adopted the human thermal comfort scale (four-level index, 0 = "very uncomfortable," 1 = "uncomfortable," 2 = "a little comfortable," 3 = "comfortable") (Deb and Ramachandraiah, 2011).

Interview Outline

To gain a comprehensive understanding of tourists' thermal comfort under different virtual tourism intensities and complement the quantitative research, qualitative data collection was also conducted. Semi-structured interviews were conducted with the 60 subjects who participated in the experiment; they had a good understanding of the virtual tourism experience. An in-depth interview lasting around 20 min was conducted with each of these subjects. The interview outline mainly included travel preferences, feelings about the experiment, suggestions, and open questions. The interviews began in May 2019 and ended in October 2020.

At the beginning of the interview, each interviewee was assured that the recording would only be used for the purpose of this research. After obtaining their consent, the conversation was recorded using recording device. During the interviews, researcher briefly recorded the respondents' answers, reactions, and problems that arose, and adjusted the interview strategy according to the actual situation. After the interview, referring to the interview notes, researchers transcribed the interview content verbatim into a recording script, listened to the recording repeatedly and proofread it, finally producing an interview transcript for subsequent analysis.

The study employed a variety of measures to ensure the validity and reliability of the interview data. First, three test interviews were conducted to help the researcher gain skills prior to the formal interview, and some questions were modified based on participants' feedback. Second, to build rapport and establish comfortable interactions between the researcher and interviewees, measures were taken in advance of the interview and also during the interview itself. A summary of the project and interview outline were sent to the participants before the interview either via e-mail or text message, and the interview time was mutually agreed upon. During the interview, the researcher aimed to create a relaxed atmosphere and adjust the opening question according to the actual situation, recording the important content at the same time. Third, if the content of the interview data was found to be unclear, the researchers would conduct a second interview via e-mail or telephone call to ensure that the qualitative data truly reflected the participants' experiences. Finally, a panel of two researchers combined to analyze and theoretically label participants' responses: one researcher conducted the initial analysis, while another researcher who was well acquainted with the study checked this independently.

The socio-demographic profile of the respondents is presented in **Table 4**.

Experiment Steps

The experiment steps were as follows.

Step 1: A health survey of registered respondents was conducted to ensure that they did not have a history of heart disease or other health problems. Respondents were reminded to prepare clothing to wear for the experiment. After the respondents arrived in the laboratory, they were informed of the specific content of the experiment, precautions, and emergency response measures. Respondents were asked to sign the experimental informed consent form and to provide basic information and complete a pre-test questionnaire. The subjects' pulse and blood pressure indicators needed to be within the normal range; if not, they had to sit still until their heart rate and pulse returned to a resting state.

Step 2: A virtual tourism microclimate experimental scenario was set up. Tourism is a process of interaction between tourists and the tourism environment; the simulation of the tourism situation is the essential difference between this experiment and other thermal comfort experiments. In the experiment, the microclimate cabin set and controlled the simulated climate environment consistent with the outdoor environment, including temperature, humidity, solar illumination, and wind speed. The LED display screen was used to play tourism documentaries, while the speed and slope angle were adjusted through the treadmill to simulate three activity intensities (sitting, slow

TABLE 4 | Socio-demographic profile of the interviewees.

Demographic		Frequency	Percentage
Gender	Male	30	50.00
	Female	30	50.00
Age	<18	13	21.67
	18–30	32	53.33
	30–40	13	21.67
	>40	2	3.33
Education	Bachelor's degree or under	25	41.67
	Master's degree	24	40.00
	Doctor's degree	11	18.33
Climate zone of residential place	Tropical	11	18.33
	Subtropical	21	35.00
	Temperate	28	46.67
Virtual tourism experience times	0	6	10.00
	1–5	30	50.00
	6–10	18	30.00
	More than 10	6	10.00

walking, and brisk walking). This enabled the simulation of different tourism activities in virtual tourism situations.

Step 3: Every respondent took off metal accessories, wore an electrocardiograph, entered the tourism microclimate cabin, and completed nine sets of virtual tourism experiments. After respondents finished each experiment, they were asked to evaluate their perceived thermal comfort using a four-point scale ranging from 0 to 3. Before starting the next set of experiments, respondents had to wait until their pulse, heart rate, and other physiological indicators returned to a resting state. Researchers also adjusted the climate parameters in the microclimate cabin to stabilize within the proper range.

Step 4: Semi-structured interviews were conducted after the respondents finished all experiments, which helped to fully understand their thermal comfort experience under different virtual tourism activity intensities. All the conversations were recorded and summarized.

EXPERIMENT ANALYSIS

Relation With Perceived Thermal Comfort

The study used SPSS 24.0 software to analyze the interactive relationships between environmental temperature, activity intensities, perceived thermal comfort, and physiological thermal comfort.

It was proposed that when tourists experience virtual tourism activity, they are influenced by environmental temperature and activity intensity (sitting, slow walking, brisk walking), which affects their perceived thermal comfort (H1). The ANOVA results (**Table 5**) provided partial support for H1 as environmental temperature showed significant differences regarding perceived thermal comfort. The *P*-value is lower than 0.05, revealing significant differences between the low, mid, and high intervals. Thus, H1a was supported. The *P*-value of activity intensity is greater than 0.05, revealing no significant differences between sitting, slow walking, and brisk walking. Therefore, H1b was rejected. H1c predicted that there will be a significant interaction between environmental temperature and activity intensities. The ANOVA also tested the interaction between these two variables; the results (**Table 5**) showed that the *P*-value of interaction is lower than 0.05, which indicated that activity intensity had a moderate effect on the relationship between environmental temperature and perceived thermal comfort. Therefore, H1c was supported.

In the state of sitting, the lowest value of perceived thermal comfort was between 13.1 and 16.3°C. Tourists' sensations changed from uncomfortable to a little comfortable in the interval 16.4–18.0°C; thus, the inflection point was in this interval. The comfort value reaches the highest point in the interval 21.4–25.0°C. When the temperature was higher than 25°C, the comfort value dropped slightly. In summary, in the sitting state, the majority of virtual tourists had a good acceptance of the temperature at 16.4–29.0°C. In the interval 13.1–16.3°C, the temperature was cold and the experience was relatively poor for tourists.

In the state of slow walking, the lowest value of perceived thermal comfort was again between 13.1 and 16.3°C, but higher than the counterpart in the state of sitting quietly. The turning point was also in the interval 16.4–18.0°C. In this state, no virtual tourists gave the highest scores for perceived thermal comfort, which means that there was no comfortable temperature range when tourists were walking slowly. In the interval 19.8–21.3°C, perceived thermal comfort reached the highest value. When the temperature was higher than 21.3°C, the perceived thermal comfort of virtual tourists dropped a little. Overall, in the interval 16.4–29°C, all virtual tourists accepted the temperature well, while tourists felt cold and found the experience poor in the interval 13.1–16.3°C.

In the state of brisk walking, the perceived thermal comfort values between 13.7 and 27.0°C were all greater than 2, indicating that most tourists felt comfortable within this temperature range. When the temperature was higher than 27.0°C, the comfort level dropped quickly and tourists felt a little hot. In summary, in the state of brisk walking, no temperature range made all respondents feel comfortable. Compared with other intervals, tourists felt more comfortable between 19.8 and 21.3°C.

In summary, as the temperature increased, the virtual tourists' comfort level first increased and then decreased; under different activity intensities, the subjects' comfort levels also differed within the same temperature interval. **Figure 3** shows the detailed relations among perceived thermal comfort, environmental temperature, and activity intensity in the virtual tourism context.

According to **Figure 3**, the perceived thermal comfort under different virtual tourism activity intensities all increased first and then decreased. In the lower temperature range, the comfort level gradually increased with the increase in temperature, and in the middle-temperature range, it reached a higher comfort level and was relatively stable. In the higher temperature range, the comfort level gradually decreased as the temperature increased. The overall change pattern centered on the interval of 19.8–21.3°C: the higher the activity intensity, the higher the comfort level. When the temperature was higher than 19.8–21.3°C, the higher the activity intensity, the lower the comfort level. Compared with slow walking and sitting quietly, the respondents' comfort value during brisk walking decreased at a faster rate.

Therefore, the results also showed that the intensity of virtual tourism activities cannot directly affect the perceived thermal comfort of tourists. However, activity intensity can be used as a moderator to adjust the relationship between environmental temperature and perceived thermal comfort. Thus, H1a and H1c were supported, while H1b was rejected. **Figure 4** illustrates the

TABLE 5 | ANOVA: environmental temperature, activity intensity, and perceived thermal comfort.

	Temperature	Activity intensity	Temperature*activity intensity
F	25.74***	1.91	6.96***
P	0.000	0.126	0.000

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

FIGURE 3 | Virtual tourist's comfort level-temperature under different activity intensity.

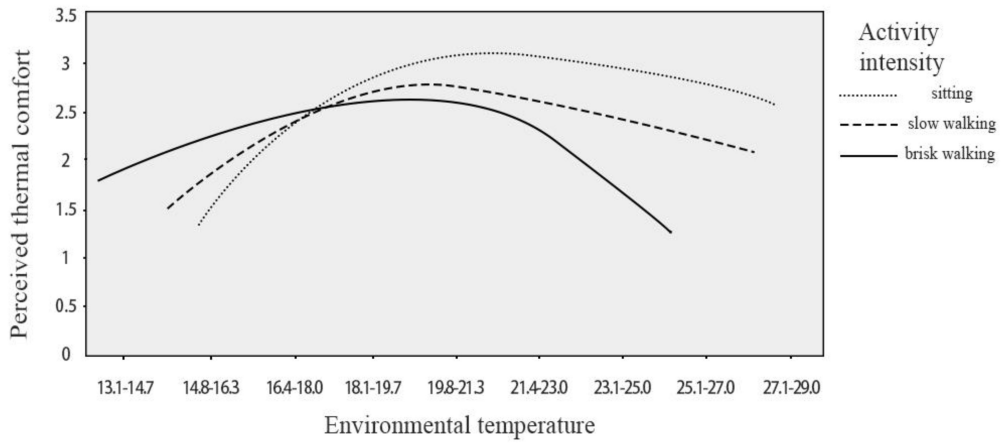

FIGURE 4 | Moderating effect of activity intensity on the relationship between environmental temperature and perceived thermal comfort.

moderating effect of activity intensity on the relationship between environmental temperature and perceived thermal comfort.

Relation With Physiological Thermal Comfort

The respondents' resting physiological indicators were tested and recorded before the experiment. As previously mentioned, 60 subjects were randomly divided into three groups: the subjects in group 1 experienced the temperature range A1+B1+C1 in the three activity states, group 2 experienced the temperature range A2+B2+C2 in the three activity states, while group 3 experienced the temperature range A3+B3+C3 in the three activity states. The ANOVA revealed significant differences in natural blood pressure between group 1, group 2, and group 3 (**Table 6**). It cannot be concluded that the difference was caused by the change in experimental factors, so the blood pressure-related indicators were excluded in the further analysis. The *P*-values corresponding to HR, PR, SPO_2, and RR are all greater than 0.05, indicating that there is no significant difference in the physiological indicators of the three groups in the natural state, meaning that these indicators could be included in the further analysis (**Table 6**).

A homogeneity test was conducted before the ANCOVA (**Table 7**). The results showed that: in the state of sitting quietly, only the RR passed the homogeneity test ($F = 2.406$, $P = 0.123$);

TABLE 6 | ANOVA: The resting physiological indexes in the pre-test.

Groups	HR	PR	SPO_2	NIBP-Dia	NIBP-Sys	NIBP-Mean	RR
Group 1	77.88	75.83	98.00	107.94	68.06	76.24	17.24
Group 2	78.02	76.00	98.15	110.50	72.75	83.95	16.55
Group 3	78.00	76.15	98.24	113.29	74.53	83.65	16.82
F	1.381	1.824	0.849	7.874***	33.081***	51.089***	2.004
P	0.219	0.191	0.428	0.000	0.000	0.000	0.136

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 7 | Homogeneity test of interaction under different activity intensities.

Activity intensity	Statistics	$HR_{resting*temperature}$	$PR_{resting*temperature}$	$SPO2_{resting*temperature}$	$RR_{resting*temperature}$
Sitting	*F*	80.13***	254.96***	629.30***	2.41
	P	0.000	0.000	0.000	0.123
Slow Walking	*F*	54.73***	0.21	0.17	1.88
	P	0.000	0.657	0.683	0.172
Brisk walking	*F*	67.50***	11.28***	0.51	0.22
	P	0.000	0.001	0.475	0.642

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

thus, RR and temperature were included in the covariance analysis. In the state of slow walking, PR ($F = 0.213$, $P = 0.657$), SPO_2 ($F = 0.168$, $P = 0.683$), and RR ($F = 1.879$, $P = 0.172$) passed the homogeneity test; thus, PR, SPO_2, RR, and temperature were included in the covariance analysis. In the state of brisk walking, SPO_2 ($F = 0.512$, $P = 0.475$) and RR ($F = 0.217$, $P = 0.642$) passed the homogeneity test; thus SPO_2, RR, and temperature were included in the covariance analysis.

The ANCOVA revealed that in the state of sitting, temperature did not have a significant effect on the virtual tourists' physiological indicators (**Table 8**). In the state of sitting, the temperature does not significantly affect RR, due to the *P*-value being greater than 0.05. In the state of slow walking ($F = 3.337$, $P = 0.001$) and brisk walking ($F = 2.390$, $P = 0.018$), the temperature has a significant effect on tourists' SPO_2. In addition, in the state of slow walking, the temperature has a significant effect on PR ($F = 2.272$, $P = 0.025$). Therefore, in the stable state, the environmental temperature did not influence virtual tourists' physiological indicators. In the state of exercise (slow walking, brisk walking), the environmental temperature influenced virtual tourists' physiological indicators. Thus, H2 was partially supported, H2a was rejected, while H2b was supported.

In any state, the environmental temperature did not affect the RR significantly. The reason for this may be that temperature mainly affects the RR by affecting the activity of enzymes related to respiration. Due to the internal temperature regulation mechanism of the human body, the short experiment time and non-extreme environmental temperature, the subject can maintain a body temperature that fluctuates within the normal range. Therefore, in this experiment, the subjects' respiratory enzyme activity did not change greatly; the environmental temperature had no significant effect on the RR.

TABLE 8 | Results of the analysis of covariance.

Activity intensity	Statistics	*HR*	*PR*	SPO_2	*RR*
Sitting	*F*	–	–	–	0.120
	P	–	–	–	0.998
Slow walking	*F*	–	2.272*	3.337**	0.16
	P	–	0.025	0.001	0.996
Brisk walking	*F*	–	–	2.390*	0.59
	P	–	–	0.018	0.787

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

INTERVIEW ANALYSIS

To supplement the quantitative study, we conducted qualitative research after the experiment to help understand respondents' views with regard to their perceptions of virtual tourism and thermal comfort. The interview process consisted of interview initiation, question design, data collection, data analysis, theory establishment, and forming conclusions. Questions about travel preferences, travel activity intensity, virtual travel intentions, perceptions in the microclimate cabin, and experimental suggestions were asked to the 60 respondents who had previously participated in the experiment. The respondents were sequentially coded as W1–W60.

Thematic analysis was used to analyze the qualitative data (Braun and Clarke, 2006). The authors identified the key content from interviewees' narratives, and it was found that the conclusions obtained from the interview data were consistent with the results in the experiment. The specific interview results are as follows.

The interview analysis showed that 56 of the 60 respondents were very interested in the temperature virtual tourism activity, 35 respondents indicated that the virtual tourism experience was similar to real travel, and they felt different levels of thermal comfort under the three types of activity states. Eighteen respondents thought that the activity intensity in virtual tourism can affect their perceptions of temperature, and 52 respondents were willing to participate in more realistic temperature virtual tourism activities in the future. Some respondents commented as follows: "I feel that the temperature virtual tourism experience is very realistic; it seems like I was in a real travel environment"; "It's fun to watch the travel scenes while feeling the temperature changes and exercising." Nevertheless, others showed their dislike of the temperature virtual travel experience: "The activity intensity is not accurate and not realistic enough"; "I would become distracted easily if the time was long." Based on this, respondents put forward three suggestions: improving the simulation degree of the virtual tourism environment and temperature, adding a more realistic tourism experience and enriching the visual and auditory feedback content, and temperature virtual tourism should be more intelligent and life-oriented, being closer to the real travel experience.

It can be seen from the interview data that respondents' virtual tourism experience could be improved by adjusting the perceived temperature under different activity intensities and simulating the virtual tourism situation to the maximum extent,

thereby stimulating their interest and enthusiasm for the travel experience. The study also found that the respondents hope to interact with objects in the virtual tourism world naturally through necessary equipment, and to experience a more realistic virtual tourism environment that integrates visual, auditory, and tactile sensations. Therefore, exploring the combination of temperature, posture, sound and eye tracking, and other new interactive methods could provide a diversified and satisfying immersive interactive experience for virtual tourists.

CONCLUSION

Conclusion and Discussion

Previous studies have shown that under different temperatures, tourists perceive different microclimate comfort levels and their recreational behaviors also differ (Chen and Dong, 2015). Microclimate simulation experiments are popular in environmental psychology research, but few studies have introduced these to virtual tourism, and there has not yet been research on thermal comfort in the context of virtual tourism. The current study contributes to fill this gap. The results of this study demonstrated the relationships between environmental temperature, activity intensity, and perceived and physiological thermal comfort in the context of virtual tourism by using experimental and interview methods. The study aimed to understand the role of environmental temperature in how virtual tourists assess their thermal comfort under three types of activity intensities (sitting, slow walking, brisk walking). The findings indicated the following.

First of all, the environmental temperature affected the perceived thermal comfort of virtual tourists, and there was a significant relationship between perceived thermal comfort and environmental temperature in the virtual tourism experience. Activity intensity can moderate the relationship between environmental temperature and perceived thermal comfort, which is consistent with the findings of an existing study (Qiu et al., 2005). The current study confirmed that activity intensity did not directly affect perceived thermal comfort, but instead influenced tourists' thermal comfort by moderating the relation between temperature and thermal comfort. Under the same activity intensity, as the temperature increased, the comfort level of tourists first increased and then decreased; under different activity intensities, the thermal comfort level of tourists also differed within the same temperature range. In addition, the results indicated that tourists' comfortable temperature range for all activity types was 19.8–25.0°C, which is within the most acceptable outdoor environmental temperature range of 19.6–29.5°C (Shang et al., 2020).

Second, under different intensities of virtual tourism activity, the environmental temperature will affect the physiological thermal comfort of tourists. Both the tourism environment and tourists' self-adaption will lead to changes in physiological comfort indicators (Ji et al., 2015). Therefore, it is necessary to discuss the mechanism of thermal comfort in virtual tourism from a physiological perspective. Physiological indicators provide an objective evaluation of thermal comfort and the basis for subjective thermal comfort. The study introduced activity intensity into the model and discussed the influence relationship under different activity states. From the results of covariance analysis, it can be seen that in the sitting state, the environmental temperature did not significantly affect virtual tourists' physiological indicators. In both slow and brisk walking states, the environmental temperature had a significant effect on tourists' blood oxygen (SPO_2). In addition, the environmental temperature can also affect tourists' PR significantly in the slow walking state. This study responds to the initiatives of Tussyadiah et al. (2018), who called to "include objective measurements like using sensors and psychophysiological analysis in the virtual tourism study."

Furthermore, this research evaluated thermal comfort through both subjective and objective procedures in the microclimate simulation experiment, enriching the analysis method and expanding the studies in the relevant field (de Dear et al., 2013; Zare et al., 2018; Bogicevic et al., 2019).

Theoretical and Practical Implications

This study has shown that the experimental method is applicable to research on virtual tourism thermal comfort to a certain extent, and this study may be one of only a few attempts to empirically assess the impacts of environmental temperature and activity intensity on tourist thermal comfort in a virtual tourism context. The current study contributes to the extension of relevant studies in two ways. First, we added analysis of tourist thermal comfort to virtual tourism research, which addressed the call to further broaden and extend virtual tourism research studies (Bogicevic et al., 2019). Previous studies mainly explored the concept and prospects of virtual tourism (Guttentag, 2010), and conducted empirical studies to assess whether or not tourists supported virtual tourism experiences (Tavakoli and Mura, 2015; Bogicevic et al., 2019). The current study analyzed virtual tourism experiences in different activity intensities, which is quite rare in previous studies.

Second, this study employed a microclimate simulation experiment in the context of virtual tourism. Tourism microclimate simulation experiments are mostly used to study tourist perceptions and behaviors in specific tourist attractions (Galagoda et al., 2018). The current study combined physiological parameters and a microclimate simulation experiment within virtual tourism research, conducting a fine-grained analysis of the influence of temperature on the comfort of tourists. It provides a new perspective to explore the virtual tourism space situation and enriches the content of virtual tourism (Tussyadiah et al., 2018).

From a practical standpoint, the findings also provide significant implications for tourism managers. First, in this study, we have demonstrated that environmental temperature was significantly related not only to tourists' perceived thermal comfort but that it also contributed to their physiological indicators of thermal comfort. These findings extend our understanding of tourists' virtual tourism experience and offer a novel view on providing a successful service to virtual tourists. Thus, destination managers should utilize temperature to improve the immersion and satisfaction of the virtual tourism

experience, which are the biggest drawbacks of virtual tourism (Cheong, 1995). Tourists' psychological and physiological responses result from interaction between tourists and the travel time and space. The simulation of the travel situation from the aspects of climate environment, activity scenes, and visual effects can improve the simulation degree of virtual tourism, enhancing the sense of interaction and immersion of the experiment.

Second, we have also confirmed the moderating effect of activity intensities on the relationship between ambient temperature and thermal comfort. Therefore, future construction of virtual tourism scenes should control tourists' activity intensity and help to relieve visitors' fatigue. Based on the theoretical evidence of the human–environment relation, through the creation and design of virtual tourism scenarios, realizing the control and design of tourists' activity intensity helps to provide a better experience.

Third, as suggested by our results, high levels of realistic visual, audio, and tactile sensations in virtual tourism promoted tourists' positive perceptions and satisfaction. Thus, tourism managers should recognize the development trend and important role of virtual tourism in the post-COVID-19 period (in non-crisis situations). Virtual tourism is not a comprehensive replacement of the traditional tourism industry, but assists in promoting the sustainability of tourism destination brands (Rácz and Zilizi, 2019). Tourism destinations may consider designing and developing virtual tourism programs based on the environmental temperature. Through a reasonable combination of virtual tourism and environmental temperature, the thermal comfort of tourists can be promoted, and the difference between low and peak travel seasons can be reduced.

Limitations and Future Research

Like other research studies, this study also has limitations. First, future studies could try to improve tourists' sense of immersion in virtual tourism. The tourism experience is an interactive process between tourists and travel time and space. This study uses videos to replace the virtual tourism experience, which is not accurate enough. Future research could combine AR, VR, MR, and other equipment to improve the simulation degree of virtual tourism and construct a more realistic tourism scenario, resulting in a more rigorous experiment. Second, this study only considers thermal comfort as the outcome; human body comfort evaluation is a psychological state of feeling satisfied with the environmental temperature. Future research studies could integrate tourism fatigue and time sensation in the model to conduct a comprehensive tourism experiment. Third, the temperature intervals selected in the study were mainly in a milder range, and most of the respondents were young. Future researchers could conduct comparative experiments based on age, physical condition, and region to obtain more extensive and universal results.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by School of Management, Shandong University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work, and approved it for publication.

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Is Distant Extension Always Upset? Neural Evidence of Empathy and Brand Association Affect Distant Extension Evaluation

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Distant brand extension as an essential strategy of obtaining benefits was highly focused on the normal marketing practice and academic research. In the current study, we aim to recognize that how individuals with different levels of empathy respond to distant extensions under corporate social responsibility (CSR) and corporate competence (CC) associations to explore the corresponding neural mechanisms using event-related potentials (ERPs). We divided subjects into two groups involving a high empathy (HE) group and a low empathy (LE) group according to an empathy measure questionnaire. The subjects first faced a brand name following the CSR or CC association descriptions, and then, they were asked to evaluate the new product of brand by a five-point scale. Current results revealed that the participants of the HE group were more apt to accept the distant extension products than those of the LE group. Additionally, in the HE group, products from a brand with CSR associations were more acceptable than CC associations. Moreover, a larger N2 amplitude was elicited in the LE group than in the HE group. For the LE group, an augment N2 was found under CSR than CC associations, reflecting that LE consumers might perceive conflict when evaluating distant extensions and allocate more cognitive resources to deal with CSR information. At the later stage, the HE group showed a greater P3 than the LE group. For the HE group, an increased P3 was elicited under CSR than CC associations, suggesting that empathic individuals might show motivational salience and helping willingness toward distant extension products, especially under the CSR scenario. These results provide potential electrophysiological evidence for the positive impact of brand associations on the evaluation of distant brand extension in the case of subdividing different empathic individuals.

Keywords: distant extension, brand association, empathy, event-related potentials, corporate social responsibility, competence

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INTRODUCTION

Brand extension, whereby a well-established brand uses its name to launch new products not offered ever before, is a beneficial and popular branding strategy (Keller and Aaker, 1992; Swaminathan, 2003). It is frequently used by modern enterprises in a realistic marketplace. To expand corporate market share, multiple established brands endeavor to extend their products into new categories

relatively dissimilar with their core business range, namely, distant brand extension (Su et al., 2021). For instance, Apple successfully extended from phones to watches, Ferrari went beyond sports cars to introduce perfume, and Nestle went from human's coffee, tea, and milk powder to pets' food and drinks. Reflecting this trend, a growing stream of literature has focused on adopting appropriate strategies to introduce incongruent new products for benefiting from the parental brand equity, mostly (Jhang et al., 2012; Zhong et al., 2020; Gerrath and Biraglia, 2021). Several scholars identified some factors, such as strong brand reputation (Chun et al., 2015), products displayed placement (Zheng et al., 2019), and life-role transition of consumers (Su et al., 2021) to promote distant brand extensions success. In fact, despite the strategy of distant extensions having a degree of risk (Loken et al., 2002), from a long-term profit perspective, it can also gain much more potential benefits, such as expanding the financial revenue stream, dispersing sales pressure, and grabbing market resources (Parker et al., 2017). As a result, it is critical to understand how to enhance the positive evaluation of consumers toward distant extensions to reduce the risk of increasing enterprise costs.

Brand association, which is usually considered as the perception, cognitive, affect, and else information grasping of a person toward a company (Brown and Dacin, 1997), plays a significant role in a new product evaluation (Berens et al., 2005; Rubio and Marin, 2015). A strong and unique brand association benefits the brand extension evaluation (Keller, 1993). Generally, two essential types of brand associations were highly mentioned by previous researchers, that is, corporate competence (CC) association and corporate social responsibility (CSR) association. Specifically, CC association is commonly seen as perceptions of consumers about the ability of parent brand, such as superior technology, innovational competence, whereas the construction of CSR association is often characterized by a brand with high efforts to critical societal issues, such as engaging in social welfare, donation, and support activities (Brown and Dacin, 1997). For the two types of brand associations, previous scholars held different insights about its effect on brand extension evaluation. For example, Johnson et al. (2019) considered that CSR associations are generally seen as more valuable when consumers evaluate distant extensions than CC associations because they provide warm perceptions for consumers, while CC associations are not thought to. Inversely, Wang and Liu (2020) deemed that CC associations, providing direct evidence of product qualities, can help consumers deliver competence-related attributes of the parent brand to an extension product and further give a better extension evaluation. Notably, previous neuroimaging evidence has provided an insight that different types of brand association messages are processed diversely in brain activities of consumers, reflecting different mental processes among various consumer segments (Chen et al., 2015). In particular, a recent functional MRI (fMRI) study conducted by Medina et al. (2021) demonstrated that the brain response to the processing of CSR messages between low and high social awareness consumers was distinct. Accordingly, although the two types of associations positively influence product evaluations of brands, we suspect that individuals with different prosocial levels do not respond equally toward all CC and CSR associations (Lee and Cho, 2018; Xue et al., 2020). Further, it may be that the individual prosocial differences may result in distinctions in distant extension evaluations in the context of CC and CSR associations.

Empathy, as an essential prosocial capability, pertains to the human ability to understand and experience other emotions, reliably measured by psychometric scales, such as the Empathy Quotient (EQ) scale (Davis, 1983; Lawrence et al., 2004). It encompasses two components of affective (closely related to sympathetic emotions) and cognitive (focused on the attributed mental states of others) (Davis, 1994). The empathy-altruism hypothesis implies that the empathic response is tightly linked with prosocial behaviors (Batson and Shaw, 1991; Pelligra and Vásquez, 2020). Based on the hypothesis, the emotional mechanism and altruistic attributes of empathy obtained great attention from previous studies. For instance, prior evidence has shown that individuals with high empathy levels can be easily evoked empathy responses. They can perform a series of social support behavior, such as donating to charity (Lee et al., 2014), assisting unfortunate persons (Tangney et al., 2007), and caring for others' pain (Flasbeck and Brüne, 2019). Furthermore, this kind of support behavior takes place not only among human beings but also can be motivated when consumers evaluate brands or products. To be specific, subjects with high empathy showed more preference for vulnerable brands (Kraus et al., 2012) or increased willingness to pay for fair-trade products (Zerbini et al., 2019). Contrarily, individuals with low empathy are self-interest orientation and usually care for their own well-being (Cialdini et al., 1997). From the perspective of neuroscience, Lee (2016) adopted electroencephalogram (EEG) measurement to uncover the neural mechanism of consumer empathy in response to corporate social responsibility messages and found that high empathy individuals are more inclined to pay for prosocial brand products than low empathy ones. Recently, He et al. (2021b) employed the functional near-infrared spectroscopy (fNIRS) technique to capture brain activations of subjects when they viewed advertising and demonstrated that empathic connections could increase positive attitudes of consumers toward advertising evaluation. However, in terms of brand extension evaluation, how individuals with varying levels of empathy respond to distant extensions under diverse brand associations, in particular, their neural mechanism, is unknown.

Neuroscientific tools, as novel and efficient measurement, can help capture automatic and implicit processing of subjects to solve these issues (Solnais et al., 2013). These approaches can overcome the limitations of traditional methods (e.g., questionnaire surveys and face-to-face interviews) that are short of objectivity and rarely better understand cognitive and affective processes of subjects (He et al., 2021a; Pei and Li, 2021). In the consumer neuroscience realm, multiple neurological techniques were used by previous scholars to explore the neural mechanisms underlying the brand extension evaluation processing. For example, an fMRI approach was employed to reveal the connection between the corresponding brain regions and emotional processing during the extension evaluation (Yang et al., 2021). By contrast, event-related potentials (ERPs), owing

to the characters of low cost and high temporal resolution (milliseconds), have been extensively applied (Ma et al., 2007, 2008, 2014, 2020, 2021; Wang et al., 2012; Fudali-Czyz et al., 2016; Shang et al., 2017; Yang et al., 2018; Song et al., 2020). By using this method, some of the studies have identified a variety of valuable components to investigate the cognitive process of consumers during brand extension evaluation, such as the perceived conflict (N270) (Ma et al., 2007), categorization process (P300 and N400) (Ma et al., 2008; Wang et al., 2012), or affect transfer effect (LPP) (Song et al., 2020).

Specifically, the typical N2 component is a negative-going potential with a time window of approximately 200–400 ms at the frontal areas (Donkers and Van Boxtel, 2004; Folstein and Petten, 2008; Yoder and Decety, 2014). Multiple previous evidence has shown that N2 is sensitive to mismatch and conflict-related monitoring toward the stimuli (Veen and Carter, 2002; Larson et al., 2014; Han et al., 2015). For instance, Shang et al. (2017) indicated that a greater N2 amplitude was responded to products presented with social risk sentences than the control condition, reflecting stronger cognitive and emotional conflict under social interactions. The authors explained that consumers might need to regulate the cognitive conflict between their own purchase desire and the incongruence information from social communications, which was reflected by the larger N2 amplitude. Moreover, in brand extension research, higher N2 amplitudes were recorded for distant extensions rather than near extensions, reflecting perceived risk and conflict between the original brand and extensions (Ma et al., 2007, 2020; Song et al., 2020). Compared with previous studies, the stimuli of extension products were all relatively far from the original brands in this study. Although the given brands have good associations, the conflict effect of the brand extension might emerge in the current study. Furthermore, it has been suggested that positive emotions of consumers could reduce the cognitive conflict, in which case a decreased N2 amplitude was observed (Jin et al., 2018). Compared with low empathy individuals, empathic consumers were more apt to be elicited positive affect responses by good brand performance (Lee, 2016). Meanwhile, consumers with different prosocial traits respond in a dissimilar way toward CSR and CC brand association messages (Chen et al., 2015; Medina et al., 2021). Accordingly, we hypothesize that different N2 amplitude would be evoked between high empathy and low empathy groups.

A P3 component is a positive-going wave over the central to parietal regions with a peak latency range of 300–500 ms after stimulus onset (Polich and Kok, 1995). It has been indicated that the P3 component was linked to processes of stimuli categorization evaluation (Azizian et al., 2006). Previous studies investigating the neural mechanism of brand extension evaluation have demonstrated that an enhanced P3 was observed by category congruence between the original brands and extension products (Ma et al., 2008; Shang et al., 2017). In addition, the P3 component can also be elicited by affective/motivational stimuli with higher amplitudes (Nieuwenhuis et al., 2005; Jin et al., 2020). More importantly, neuromarketing research has found that P3 was sensitive to the prosocial motivation and helping behaviors (Chiu Loke et al., 2011; Carlson et al., 2016; Teng et al., 2018). For example, Chiu Loke et al. (2011) indicated that women who scored higher in the Prosocialness Scale were more inclined to make helping decisions than men, which was reflected by larger P3 amplitude. Carlson et al. (2016) revealed that the P3 component could predict prosocial motivation and behaviors of participants, and a notable P3 amplitude was found for evaluating high-empathy targets than low-empathy targets. Recently, Liu et al. (2021) examined the different brain activities when evaluating the distant extension products with different brand reputations, which found the CSR condition elicited larger LPP (P3 family) amplitude than the ability reputation condition. Based on the abovementioned research, because CSR messages are more prosocial and empathetic, we posit that larger P3 amplitudes would be observed in CSR than CC associations and in HE than the LE group.

In total, the N2 and P3 components were applied to investigate the neural distinctions among different empathy individuals toward distant extension products under two types of brand associations. In the experiment, participants were first divided into two groups according to individual scores of an empathy questionnaire used by previous studies. During the ERP measurement, each of them was successively presented to a series of procedures: a brand name following an association activity (CSR or CC), after that, EEG was recorded while participants evaluated the new product of brands. Following recent research by Liao et al. (2019) and Liu et al. (2021), to better understand, two fixed verbs were applied for connecting the above target stimuli (brand, association activity, and product name). Finally, a five-item scale ranging from 1 to 5 was applied to investigate the consumers' acceptance of distant extensions.

MATERIALS AND METHODS

Participants

In the current experiment, 42 Chinese native speakers, including undergraduate and graduate students from Yanshan University, were recruited. All the participants did not have any psychiatric illness or mental disorders. They were all healthy, right-handed, and had a normal or corrected-to-normal vision. Prior to the EEG recording, a written informed consent was obtained from every participant. This study was approved by the institutional review board. Data from two participants were excluded due to technical problems and excessive EEG artifacts. Therefore, the final sample included data for a total of 40 participants (19 women). The age of them ranged from 18 to 33 years (M = 24.36 years, SD = 3.74 years). They were paid 30 yuan (around USD 13) for taking part in the experiment.

Stimulus Design

The dairy brand was viewed as an appropriate choice, as most Chinese consumers, the subject group type used in the experiment, mostly drink milk daily, with a high focus on brand development (Ozdemir et al., 2020). Accordingly, five well-known national Chinese dairy brands (Yili, Mengniu, Wangzai, Sanyuan, and Guangming) were selected as the brand stimuli

materials according to the ranking list on chinapp.com. The five brands mainly run business in dairy products, such as milk beverages, with no difference on social responsibility and competence performed in daily life. Besides, none of them has been exposed to scandal in terms of lacking social responsibilities or capabilities recently. Prior to the experiment, all the participants self-reported that they were all familiar with the given five brands, such as the brand name and product attribute information. In addition, the clothes category is not belonging to the main business scale of dairy brands, which was considered a relatively distant extension category from the original beverage brands by previous studies (Ma et al., 2007). Thus, five clothes products (e.g., t-shirts) were selected to the present product stimuli. Significantly, to date, these dairy brands have not been extended to the clothes industries in the Chinese marketplace.

For the brand association activity construct, according to Johnson et al. (2017), in which the CC association highlighted the characteristics of enterprises through high product quality communications, as well as the CSR association mainly emphasized its social welfare. Thus, a total of 12 brand association descriptions of CC (n = 6) and CSR (n = 6) were generated by a discussion group consisting of four marketing doctors. Every description of brand association was limited to the four Chinese characters. Next, a group of subjects (n = 60) who did not engage in the formal experiment and the former discussion group was invited to rate the appropriateness of brand association descriptions through an online survey. A 5-point Likert scale ranging from 1 to 5 ("1 = strongly disagree" and "5 = strongly agree.") was used for all item responses. Finally, eight brand association descriptions were determined. For the four CC descriptions: technology development (M = 6.112, SD = 1.024), technological innovation (M = 6.022, SD = 1.112), technical communication (M = 5.634, SD = 1.014), and quality improvement (M = 5.600, SD = 1.001); for the four CSR descriptions: targeted poverty alleviation (M = 6.532, SD = 1.201), education of children (M = 6.201, SD = 1.021), charitable donation (M = 5.955, SD = 1.029), and rural vitalization (M = 5.543, SD = 1.002).

Procedure

A 2 (empathy level: high, low) × 2 (brand association: corporate social responsibility and corporate competence) between-subjects design was conducted in the experiment. For the empathy level measurement, the present study referenced Lee (2016) and Yen and Yang (2018) to design a 7-point Likert scale containing six items. To ensure the effectiveness of the scale, we followed the cross-cultural adaptation procedure (Beaton et al., 2000). First, the English empathy scale was initially translated into a Chinese version by two Chinese doctors majoring in neuromarketing. Then, another translator translated it back into English and compared the consistency between the two versions. Next, two professors proofread the descriptions of all measurement items to ensure the construct validity. Finally, the scale was tested again on the basis of a pilot study toward 10 Chinese consumers. All above participants reported that the Chinese version of the empathy scale was clear and suitable.

To categorize participant groups, a sample of 120 students (60 men mean age = 21.5 years, SD = 3.5 years) majoring in marketing were invited to fill in the empathy scale approximately 2 weeks before the ERPs experiment. We selected the participants according to the average scores of the five items falling above 82.5% or below 17.5% of the whole sample. In the end, a total of 42 students with the extreme average scores in the empathy scale (Chronbach's alpha = 0.90) were divided into the HE group (N = 21, 13 women) and LE group (N = 21, 14 men). They were all willing to take part in the EEG measures of our experiment.

The participants were performed to sit in a dim and sound-attenuated room at a viewing distance of 70 cm from a computer screen. All the stimuli were presented in the center of a computer-controlled monitor (1,024 × 768 pixels, 60 Hz). Based on a recent work by Liu et al. (2021), each group of stimuli in the current study employed the formation of a sentence. Specifically, two fixed verbs were adopted to connect among the brand name, activity, and product name, consisting of the five parts: brand (1) + pushed (2) + association activity (3) + launched (4) + product (5) (e.g., "Yili pushed technological innovation and launched T-shirt" or "Yili pushed charitable donation and launched T-shirt"). And each part of the stimuli group was successively presented in Chinese characters (white and bold song font, size 30). They were all controlled with a range of two to four characters with a visual angle of 2.1–4.5 degrees × 0.8 degrees and positioned at the center of the black screen. As shown in **Figure 1**, a fixation cross displayed at the beginning of each trial for 500 ms on a blank screen, prompting the start of a target trial. Next, 1–4 parts of the target stimulus appeared for 700 ms, followed by a blank screen for 500 ms. In addition, there was a random interval, respectively, lasting for 500–800 ms among them, following a product name (the 5 part) was subsequently shown for 1,000 ms. Finally, after a black screen appeared for 500 ms, a five-point Likert scale was presented for participants to rate the acceptance degree toward the brand extension from 1 "very unacceptable" to 5 "very acceptable" by pressing a button on a mini keypad. The rating scale disappeared immediately on the screen when they gave feedback. Before the formal experiment, all participants were provided six stimulus groups to practice. Totally, 200 stimuli groups (each consisting of 1–5 parts) were involved in the experiment and pseudo-randomly assigned into four blocks, with each block holding 50 trials. The E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA, United States) was used for the stimuli presented and behavioral button recordings. The experiment totally lasted for approximately 35 min.

Electroencephalography Recordings and Analyses

The electroencephalography data were collected from 64 Ag/AgCl electrodes placed on an electrode cap arranged in the international 10–20 system with a Brain actiCHamp amplifier (Brain Products GmbH, Munich, Germany). The electrode impendence during the recording was maintained below 10 kΩ. The sampling rate was 500 Hz, and the online bandpass filter was between 0.05 and 100 Hz. The vertical and horizontal electrooculogram was measured by two electrodes placed

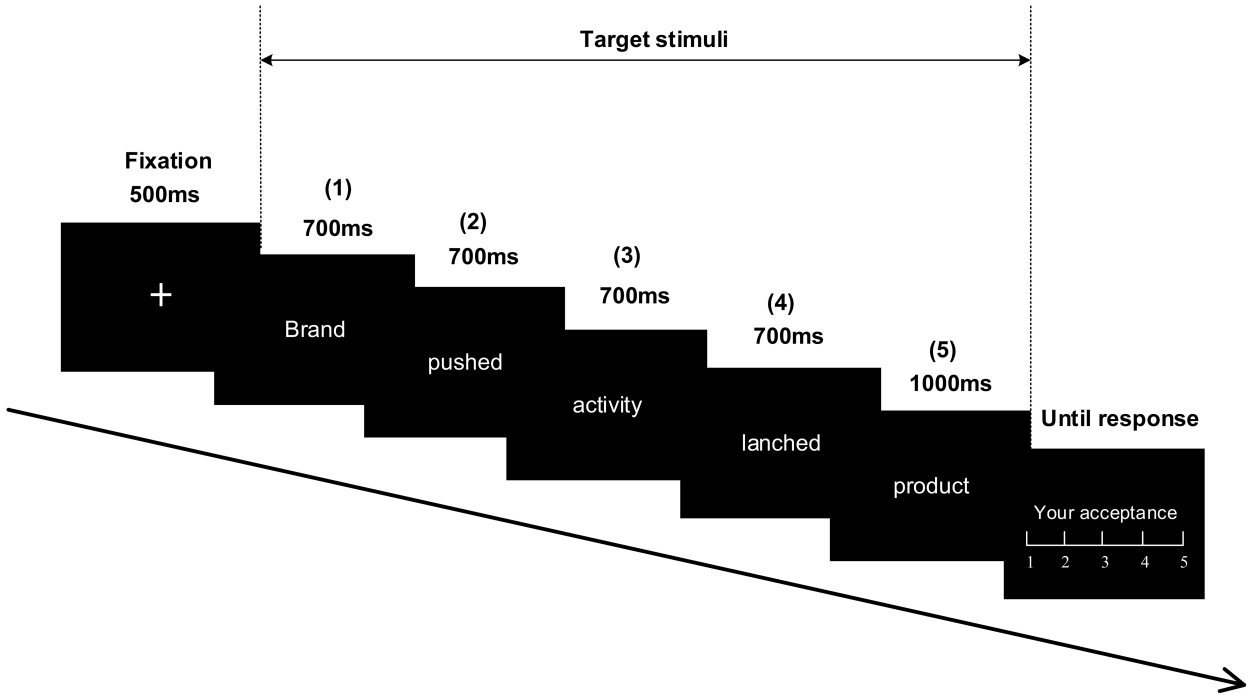

FIGURE 1 | Experimental procedure: participants were successively presented to a series of stimuli of which the five target stimuli formed as one sentence in Chinese. They were asked to press a button (1–5) based on their acceptance level toward the new product of a brand.

supraorbital and infraorbital location on the left and right eye and the two electrodes placed laterally at the outer canthi of both eyes. The scalp EEGs were online referenced to the Cz site and offline referenced the average of the TP9 (left mastoid) and TP10 (right mastoid) during recording.

The BrainVision Analyzer 2.1 software was used to analyze the offline EEG data. The data were filtered using a low-pass filter at 30 Hz (24 dB/Octave). According to Semlitsch et al. (1986), the independent component analysis (ICA) method was applied for correcting the artifacts (e.g., eye blink). The filtered EEG data were segmented into an 800 ms epoch surrounding the trigger with 200 ms before the stimuli onset of the product name presentation as a baseline. Any trials exceeding ± 100 V were rejected from the calculating. The EEG data are referenced to the average of all the electrodes. The EEG epochs were averaged separately for two groups of participants with the two association conditions (HE-CSR, HE-CC, LE-CSR, and LE-CC). On the basis of the visual observations of our data, N2 and P3 components were analyzed. For the N2, nine electrodes were selected (F1, Fz, F2, FC1, FCz, FC2, C1, Cz, and C2), following previous studies (Jing et al., 2019; Zhang et al., 2019), within the time window of 260–320 ms. For the P3, nine electrodes (C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2) were selected over the central-parietal area (Xie et al., 2016; Tang et al., 2021), within the time window of 350–450 ms. Repeated-measured ANOVAs were calculated for behavioral data and ERP data. If there was any interaction effect, a simple effect analysis was conducted. The Greenhouse–Geisser correction (Greenhouse and Geisser, 1959) was applied to correct the sphericity assumption violations. Spearman's correlation analyses were conducted between the empathy score of consumers and the acceptance level (AL) of brand extension, as well as between the P3 amplitude and the AL.

RESULTS

Behavioral Results

We performed a 2 (high empathy group vs. low empathy group) × 2 (corporate social responsibility association vs. corporate competence association) ANOVAs to analyze the reaction time (RT) and AL. For the RT, no significant main effect and interactive effect were observed ($p > 0.05$). For the AL, the main effect of the empathy group [$F(1, 19) = 65.109$, $p < 0.001$, $\eta 2$ $p = 0.774$] and brand association [$F(1, 19) = 54.194$, $p < 0.001$, $\eta 2$ $p = 0.740$], were significant. Besides, the AL for the HE group ($M = 3.198$, $SE = 0.073$) and CSR association ($M = 3.166$, $SE = 0.081$) was higher than LE group ($M = 2.472$, $SE = 0.077$) and brand CC association ($M = 2.504$, $SE = 0.068$), respectively. The interaction effect between the two empathy groups was notable [$F(1, 19) = 10.765$, $p < 0.05$, $\eta 2$ $p = 0.362$]. Thus, we conducted a simple effect analysis to evaluate the interactive effects (as shown in **Figure 2**). For the HE group, the difference between the CSR and CC association was significant [$F(1, 19) = 68.430$, $p < 0.001$, $\eta 2$ $p = 0.783$], indicating that consumers were more willing to accept the distant extension products when consumers perceived a brand with CSR association ($M = 3.740$, $SE = 0.086$) than CC association ($M = 2.656$, $SE = 0.109$). But for the LE group, no significant effect was found between the CSR and CC

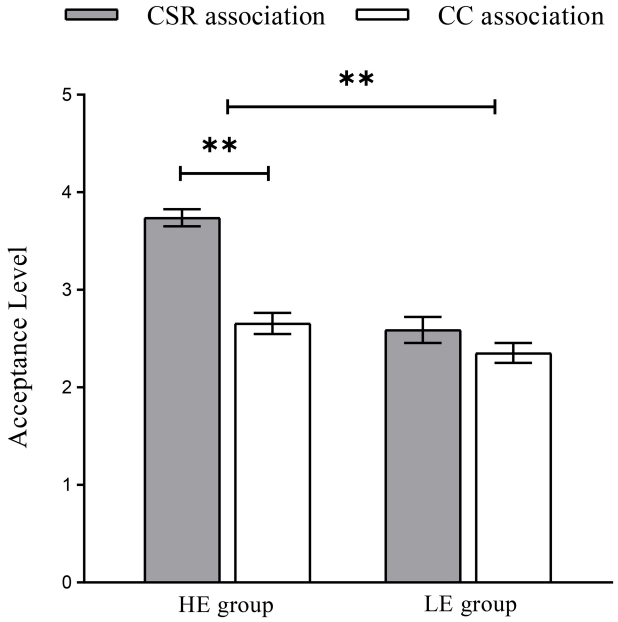

FIGURE 2 | The acceptance level of distant extension products under the corporate social responsibility (CSR) or corporate competence (CC) associations in HE and LE groups. $^{**}p < 0.01$.

association ($p > 0.05$). Spearman's correlation analyses showed that the empathy score of consumers was positively related to the AL ($r = 0.573$, $p < 0.001$).

Event-Related Potential Results

N2 (260–320 ms)

A 2 × 2 × 9 electrode ANOVA was conducted for N2. As shown in **Figure 3**, the results revealed a significant effect of the empathy group [$F(1, 19) = 18.922$, $p < 0.001$, $\eta 2\ p = 0.499$], the brand association [$F(1, 19) = 4.636$, $p < 0.05$, $\eta 2\ p = 0.196$], and the electrode [$F(1, 19) = 3.386$, $p < 0.05$, $\eta 2\ p = 0.693$]. The LE group ($M = -2.457\ \mu V$, $SE = 0.466$) elicited a slightly larger N2 than the HE group ($M = 0.803\ \mu V$, $SE = 0.646$). For the electrode distribution, the left sits distribute in F1, FC1, and C1 ($M = -0.935\ \mu V$, $SE = 0.240$) and the midline sites distribute in Fz, FCz, and Cz ($M = -0.936\ \mu V$, $SE = 0.281$) were larger than the right sites ($M = -0.583\ \mu V$, $SE = 0.297$). Meanwhile, there was a trend of brand association effect [$F(1, 19) = 3.351$, $p = 0.083$, $\eta 2\ p = 150$] in LE group. The CSR association ($M = -2.791\ \mu V$, $SE = 0.490$) elicited a larger N2 than the CC one ($M = -2.123\ \mu V$, $SE = 0.511$). But no brand association effect was found in HE group ($p > 0.1$).

P3 (350–450 ms)

The 2 × 2 × 9 ANOVA revealed a main effect of the empathy group [$F(1, 19) = 5.146$, $p < 0.05$, $\eta 2\ p = 0.213$]. The HE group ($M = 1.629\ \mu V$, $SE = 0.479$) elicited a significantly larger P3 than did the LE group ($M = 0.096\ \mu V$, $SE = 0.420$). The interaction effect between the empathy group and brand association [$F(1, 19) = 12.921$, $p < 0.05$, $\eta 2\ p = 0.405$] was notable. The simple effect analysis found that there was a significant effect of brand association [$F(1, 19) = 4.688$, $p < 0.05$, $\eta 2\ p = 0.198$] in HE group (as shown in **Figure 4**). Further, the CSR association ($M = 2.028\ \mu V$, $SE = 0.566$) elicited a larger P300 than the CC one ($M = 1.229\ \mu V$, $SE = 0.454$). But for LE group, no significant brand association effect was found ($p > 0.1$). Spearman's correlation analyses revealed that the P3 amplitudes on Cz ($r = 0.431$, $p < 0.001$), C2 ($r = 0.451$, $p < 0.001$), CP1 ($r = 0.312$, $p < 0.01$), and CP2 ($r = 0.329$, $p < 0.01$) were positively related to the AL.

DISCUSSION

The present study takes a new perspective by focusing on the factors of individual characteristics differences and brand associations influencing the brand extension evaluation. Since enterprises launching new category products can help extend their business scale, it is necessary to identify the potential factors that affect the evaluation of distant extension products and improve their success (Parker et al., 2017). Thus, this study aims to assess whether EEG analyses differ in the neural processing of the distant extension evaluations under CSR and CC associations. Further, considering the distinctions in individuals, we subdivided consumers into two levels of empathy, HE, and LE, to explore the issue.

With respect to the behavioral data, the AL toward distant extension products was higher in the HE group than in the LE group. The higher the empathy score of consumers was, the more they accepted the distant extensions. Previous studies have demonstrated that individuals who scored in high empathy are more inclined to make supporting behaviors toward brands (Kraus et al., 2012). In fact, new products of brands obtaining positive evaluation can help enterprises successfully broaden the product business scale and revenue streams. It may be that HE consumers were more apt to give a positive evaluation toward new products with good brand associations for supporting favorable brands. However, LE consumers, owing to their self-interest orientation, might not elicit good feelings when brands hold positive associations. Instead, they would consider the suitable level between the original brand and distant extension products from a personal perspective. Further, it is possible that LE consumers would not positively evaluate distant extensions for the reason of brands holding good associations. As for brand association, the AL was higher under CSR than CC association, exclusively in the HE group. Social responsibility associations mean a brand with prosocial traits, kindness, and helpfulness, while competence associations with capabilities, skillfulness, creativity, and high-quality signals (Brown and Dacin, 1997; Berens et al., 2007). Compared with CC associations, the orientation of CSR information is more congruent with HE consumers who focus positively on other- or social-related welfare (Johnson et al., 2017). Thereby, HE consumers might tend to positively evaluate the new products under CSR associations, even though they belong to a distinct category from their original brand products.

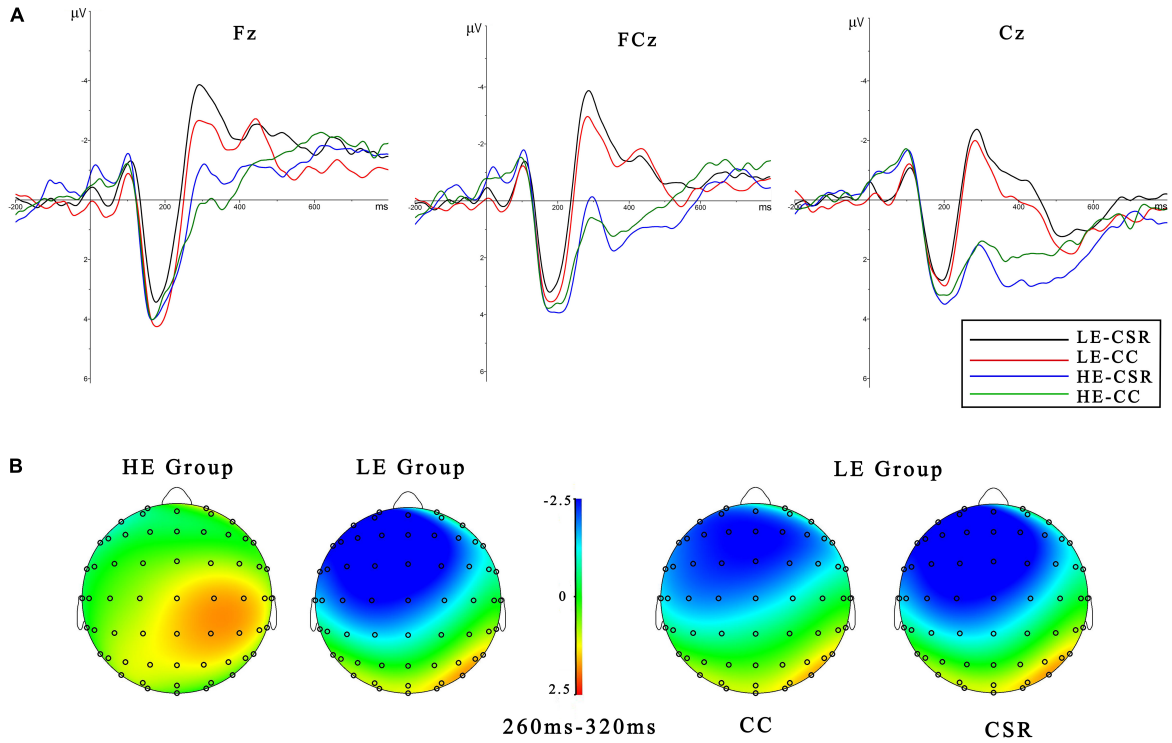

FIGURE 3 | Event-related potentials (ERPs) results. **(A)** Grand averaged waveforms of N2 for high empathy (HE) and low empathy (LE) groups under the two conditions of CSR and CC associations at midline electrodes (Fz, FCz, and Cz). **(B)** The topographic maps for different conditions with the window of 260–320 ms.

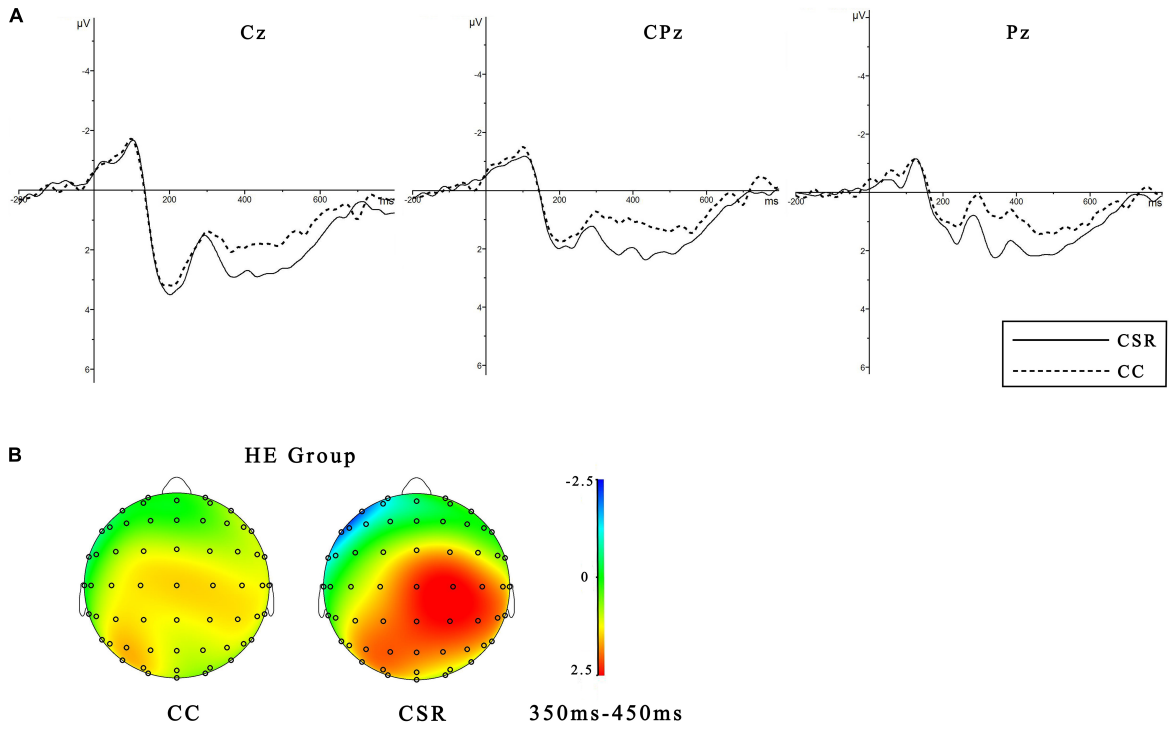

FIGURE 4 | Event-related potentials results. **(A)** Grand averaged waveforms of P3 for HE groups under the two conditions of CSR and CC associations at midline electrodes (Cz, CPz, and Pz). **(B)** The topographic maps for different conditions with the time window of 350–450 ms.

For the neural level, the N2 amplitude was greater in the LE group than in the HE group. Previous studies have demonstrated that N2 is an early component indicator of conflict detection or cognitive control (Folstein and Petten, 2008). The higher the conflict between the presented stimuli, the larger N2 amplitude was observed. In particular, in brand extension evaluation research, dissimilar extension products, due to their incongruence with their original brands, were elicited by an increased N2 than near extension products. Since the strategy of distant brand extensions was usually seen as illogical or impossible, it could recruit potential risk for original brands. The result of the current study is probably because the LE group might engage more cognitive resources in response to the distant brand extension at an early stage than the HE group. Specifically, participants low on empathy might objectively evaluate extended products from a rational perspective due to the much consideration of their own well-being. Thus, they may perceive greater risk and conflicts toward the extension products even though the given brands hold positive associations. Conversely, for individuals high on empathy, which are commonly characterized as emotional, a brand with good associations could elicit their positive affect. There is evidence that a positive emotion could decrease the conflict perception toward brand products, as reflected by a smaller N2 (Jin et al., 2018). In the current study, HE individuals might transfer the good affective toward brands to the extension products, which further lightens the conflict perception of distant extension products.

Moreover, a recent neuroimaging research verified that when consumers with characterizing as self-promotion or low social awareness processed CSR messages, brain areas associated with emotion regulation were strongly triggered (Medina et al., 2021). They explained that the type of self-orientation of consumers might lighten and regulate the potential positive emotions caused by CSR information. Similarly, in the present study, a stronger N2 amplitude was activated by CSR rather than CC information in the LE group. In fact, compared with underlying self-competence of enterprises, CSR activities primarily fulfill social-related obligations to benefit others. It may be that consumers with low empathy levels are usually focusing on the personal well-being, whose orientation does not fit the other-oriented goal of CSR context. Thus, they might need more cognitive resources to regulate the mismatch and conflict between their self-interest goal and the altruistic goal orientation of corporates.

Regarding the P3 component, previous brand extension research has revealed that enhanced P3 amplitudes were linked with category similarity (Ma et al., 2008; Fudali-Czyz et al., 2016; Shang et al., 2017) or impossibility target detection (Yang et al., 2018). Unlike those studies, the extension product stimuli were far from the original brands in the current study. Meanwhile, we observed that an enlarged P3 was elicited by the HE group than the LE group. Notably, prior studies have also shown that P3 was sensitive to motivational/affective salience stimuli and prosocial behavior, especially among humans with prosocial traits (Chiu Loke et al., 2011). In our experiment, the stimuli shown for participants were brands with good associations extending to new products. It has been reported that good associations could help consumers form a favorite brand impression (Keller, 1993). As mentioned above, the higher the empathy level of consumers is, the more acceptance they evaluate the distant extensions under positive brand associations. Compared with individuals with LE levels, empathic consumers are prosocial and generally apt to help persons or brands when they need assistance (Zerbini et al., 2019). Previous studies have found that the larger P3 amplitude is positively associated with more helping behaviors (Carlson et al., 2016). In line with previous studies, we observed a positive correlation between the P3 amplitude and behavioral responses of consumers. Specifically, the larger the P3 amplitudes were, the more the consumers were willing to accept the distant extensions. In fact, the aim of brands launching distant extension products is usually for expanding the business scale of company. In other words, the brands need support and assistance of consumers when launching distant extension products. In this study, HE consumers might hold stronger helping motivation, and thus, they would be more inclined to support favorable brands to launch new products than LE consumers.

In addition, a recent ERPs study has revealed that messages of corporate social responsibility and ability are processed differently in the human brain. To be specific, a CSR brand evoked greater LPP (P3 family) amplitude than ability descriptions when evaluating distant extensions, which suggested that consumers might hold stronger altruistic motivation and assistance intension for new products of a CSR brand. Similarly, in this study, we observed an enhanced P3 amplitude in response to CSR than CC associations, but only in the HE group. Compared with CC associations, the presentation of CSR messages represents helpful value to others (Peloza and Shang, 2010). Previous neural evidence has shown that high empathetic individuals are more willing to assist others whose personal values are similar to themselves (Masten et al., 2011). In the current study, one possible explanation is that HE consumers might be more apt to support the extension products from a brand with CSR associations due to their consistent value of other orientation. Furthermore, as the empathy-altruism hypothesis suggested, empathic individuals are more sensitive to social and emotional information and are commonly driven by altruistic motivation (Pelligra and Vásquez, 2020). Accordingly, the result of P3 could be explained by the augmented motivational salience and helping willingness when HE participants evaluate extension products from a brand with CSR associations.

To recap, the results from this study show that consumers who hold different levels of empathy respond to a brand with CSR and CC associations in different brain regions while evaluating distant extension products. Briefly, the HE group elicited decreased N2 and enhanced P3 amplitudes than the LE group. Moreover, larger N2 amplitudes in the LE group and P3 in the HE group were, respectively, observed under CSR than CC associations. The results might reflect that empathic participants allocate less cognitive conflict and stronger helpful motivation toward favorable brands when evaluating distant extensions. This context differs from prior brand extension research that assisted the value growth of brands *via* launching products of a near category to ensure success. From a new perspective, this study focuses on adopting appropriate brand association strategies to introduce extensions increasingly dissimilar to the core of brands

for extending business scale. Further, we subdivided different empathy characters of consumer groups to investigate these issues. Thus, the findings not only serve to understand the cognitive mechanisms of different consumers how to process brand association messages, but in an effort to give valuable guidance for market managers in distant extension strategies.

However, there are some limitations in this study. First, we only selected the empathy level as the individual difference examining factor in the experiment. Besides, demographic profiling factors, such as gender, should be seen as a proxy variable. A prior research has pointed out that women commonly score higher on the empathy level than men did, and the brand perception (e.g., perceived warmth or competence) was distinct between male and female subjects (Jaffee and Hyde, 2000; Xue et al., 2020). Future studies could consider the gender factor to examine the behavioral and neural differences when evaluating distant extensions under different brand association conditions. Second, considering the limited environmental and rigorous stimuli design requirements of ERP experiments, the current experiment used text presentation formation as stimuli similar to a previous brand extension research. Therefore, the brand association and extension evaluation scenario in the experiment was not perfectly close to reality. Indeed, future work can alter the presentation of stimulus materials and adopt other neuroscientific tools, such as FMRI, to overcome the issue.

CONCLUSION

The current study focused on individual empathy traits and brand associations, followed by the neural mechanism of CSR and CC associations affecting distant extension products in the high and low empathy groups. In the early stage of distant extension evaluation, the LE group elicited larger N2 amplitude than the HE group, which is a conflict detection processing. In addition, an augment N2 was found under CSR than CC associations in the LE group, reflecting that individuals with LE levels might allocate more cognitive resources to CSR than CC information. At the later stage, the HE group produced more positive P3 amplitude than the LE group. In addition, a larger P3 was observed under CSR than CC associations in the HE group. The results indicate that individuals with high empathy levels might engage the motivational salience and improve the helping willingness when evaluating the distant brand extension, especially under CSR associations. These findings suggest that brand association types (CSR and CC) influence distinct stages of mental processing of consumers with different empathy levels toward the distant extension evaluation.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the institutional review board of Yanshan University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ZS, CL, RS, and KJ contributed to the construction and design of the research. CL and RS performed the experiment. CL analyzed the data and wrote the manuscript. ZS, KJ, and RS reviewed the article. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.804797/full#supplementary-material

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Can Social Norms Promote Recycled Water Use on Campus? The Evidence From Event-Related Potentials

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The unwillingness of college students to use recycled water has become a key barrier to sewage recycling on campus, and it is critical to strengthen their inclination to do so. This paper used college students in Xi'an as a case study and adopted event-related potential technology to explore the effect of social norms on the willingness to use recycled water and the neural mechanism of cognitive processing. The results suggested the following: (1) The existence of social norms might influence college students' willingness to use recycled water. (2) When individuals' willingness to use recycled water is lower than the social norm, there is a bigger feedback-related negative amplitude. (3) College students pay more attention to social norms in groups with closer social distance. These findings can be used to provide a scientific basis for persuading the public to use recycled water from the perspective of the social norm to drive public acceptability.

Keywords: social norms, recycled water, public willingness, feedback-related negativity, social distance

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INTRODUCTION

By 2040, two billion people will be affected by the global groundwater crisis (Catley-Carlson, 2019; Tortajada and van Rensburg, 2020), as a result, forcing more and more cities to seek unconventional water sources. Sewage recycling is one of the most commonly used unconventional water sources. It alleviates water environmental pollution, the current challenge of water scarcity, and increases water resource use efficiency by re-developing and utilizing urban domestic sewage treatment after reaching the standard.

Many countries have been exploring recycled water treatment technology for a long time, and the utilization rate of recycled water has been included in the green building index and urban development planning index (Lee and Shepley, 2019; Lwin and Panuwatwanich, 2021). Currently, the recycled water treatment technology can almost produce recycled water that meets any water quality standards, and the technical issues are no longer an obstacle to its utilization (Fielding et al., 2019). The public's mistrust, prejudice, and rejection of recycled water have become the major roadblocks to the promotion of recycled water. Given the importance of public participation in the implementation of new technologies or policies (Guo et al., 2021), enhancing the public's willingness to use recycled water has become a pressing issue to be addressed.

Incentive theory proposes that the target population can be intervened externally through material and spiritual incentives to influence their behavior toward the intended outcome. In sewage regeneration and usage, using recycled water can reduce water costs by lowering the consumption of tap water, which is considered a material incentive (Deh-Haghi et al., 2020). When the price difference between recycled water and tap water is larger, the motivating power for potential recycled water users is stronger (Garcia-Cuerva et al., 2016).

However, in China, this material incentive has not been enough to persuade the public to use recycled water, mainly for two reasons: on one hand, China has had a long time implementation of the low-price policy for tap water, which often fails to reflect the scarcity of water (Mu et al., 2019). Even in some areas, meeting the development and operation expenditures of water conservancy facilities remains a challenge. On the other hand, the high costs of production and operation facilities for recycled water, as well as the cost input into the production process, limit the amount of room for the recycled water price reduction. Therefore, in China, it is difficult to implement a driving strategy to encourage the public to use recycled water through price differences.

Hence, more research has changed the focus to explore how spiritual motivation might be used to drive an individual to use recycled water (Liu et al., 2018; Xue et al., 2020). Social norms, which depend on individuals social characteristics and have an incentive influence on individual behavior through the external social environment of individuals, are considered to be one of the important variables affecting the public acceptability of recycled water use (Li et al., 2021). Existing studies mostly use social norms as auxiliary factors to explore the effect of social capital (Dean et al., 2016), conformity (Leong and Lebel, 2020), attitudes toward water sources (Mankad et al., 2019), and other influencing factors on the public's willingness to accept recycled water. However, from a cognitive level, there is no clear conclusion about whether social norms can promote public usage of recycled water. This study examines the neurological effects of social norms on campus recycled water use to further analyze the role of social norms in promoting recycled water projects.

THEORETICAL BACKGROUND AND RESEARCH QUESTIONS

The Guiding Effect of Social Norms on Individual Behavior

The concept of social norms originated in the sociological research field and has since been widely applied in neuroscience, management, psychology, and a variety of other fields, it conveys which opinions or behaviors can be accepted or agreed upon by a certain group. Social norms are different from moral norms, legal norms, personal norms, and habitual behaviors, which provide guidance or constraints for individual behaviors (Elster, 1989). Studies have shown that social norms have a significant impact on promoting pro-environmental behavior such as the use of recycled water (Hou et al., 2020). During the interaction between individuals and society, individuals will be strongly influenced by the attitudes and views of members around them on recycled water usage. Therefore, social norms have an important role in individuals' willingness to reuse recycled water.

Social Distance Leads to Heterogeneous Social Norms

The guiding effect of social norms on individual behavior or willingness has been demonstrated in many aspects, but the heterogeneity of the influence effect of social norms is often neglected. This heterogeneity is often caused by the social distance of the groups that establish social norms. The concept of social distance is beneficial for determining the level of intimacy between individuals and enhancing the impact of social emotions (Joo et al., 2018). Individual behaviors are often guided by social norms produced by different social distance groups (Lo et al., 2019). For pro-environmental behavior, the social distance attribute of the group that develops social norms will directly or indirectly affect the final acceptance effect of individuals to social norms (Huang et al., 2021). The difference in the impact of social distance on individuals is reflected in the transformation from self-identity to group identity. The social norms proposed by the social groups recognized by individuals could encourage everyone to strive toward a common goal (Kim et al., 2017). Hence, the heterogeneity of individuals under the influence of social norms created by different social distance groups must also be considered.

Event-Related Potentials Relate to Social Norms and Social Distance

Recently, scholars have gradually begun to pay attention to how individuals process acquired social norms cognitively at the neural level, and the guiding effect of social norms on individual behavior after cognitive processing (Du et al., 2019; Wang et al., 2019). Compared to other technologies, event-related potentials (ERPs) have been widely used in the study in cognitive neuroscience, due to its advantages of high time resolution, low cost, and ease of access (Hou et al., 2021), it makes a certain contribution for exploring individual's insight, emotion, and cognition of social norms. Therefore, ERPs experimental methodologies will also be applied in the study.

Feedback-Related Negativity Component

The research found that the anterior insula (AI) and anterior cingulate cortex (ACC), which sense motivational conflict and process negative emotions, were activated by norm violations (Rawls and Lamm, 2021). Feedback-related negativity (FRN), a component of ERPs derived from AI and ACC sites, was found to measure individual evaluation of outcomes (Holroyd and Coles, 2002). The FRN component is a steeply alternating positive-negative-positive waveform that typically peaks between 200 and 350 ms after stimulation (Sambrook and Goslin, 2015). It is often observed when there is a sense of result conflict. The FRN component is regarded as a reliable event-related potential component in social neuroscience, particularly in terms of monetary loss and moral perception, and it is sensitive to negative

feedback such as damage to interests and violation of social norms (Lu et al., 2020). Higher levels of FRN activation are often accompanied by a proclivity to pay close attention to existing social norms. Therefore, the FRN component would be selected as one of the representations in this study to portray college students' perceptual conflicts due to violation of social norms.

P300 Component

After the induction of FRN, several studies have also discovered that behaviors that cause a sense of violation of rules or expectations can induce the related subsequent P300 component (Niedeggen et al., 2019; Porcaro et al., 2019; Zhan et al., 2020). The P300 component that appears after the FRN amplitude peak usually reaches its maximum positive amplitude 200–600 ms after stimulation. The presence of this component is usually linked to the allocation of attentional resources among participants. Existing studies have suggested that the larger the amplitude of P300, the more attention is allocated to a particular task (Du et al., 2019). At the same time, in the "Judge-Advisor System" scenario commonly used to explore the influence of social norms, P300 has been confirmed to be related to the behavioral adjustments of individuals when they are aware of group opinions (Wang et al., 2019). Therefore, P300 will be used in this study as another representation of perceived conflict caused by violations of social norms among college students.

Research Questions

This study aims to help people better understand how social norms promote the use of recycled water on campus, using college students in Xi'an as a case study. We provided several suggestions to promote the use of recycled water on campus according to the research results. Specific research questions include:

(1) What kind of expression of social norms can better elicit the resonance of individuals?
(2) When individuals diverge from social norms, what attitudes will they have?
(3) What attitudes will individuals have when confronted with social norms proposed by different social distance groups?

MATERIALS AND METHODS

Experimental Tasks

The experimental tasks in this study included two stages: social norms scenario activation experiment and event-related potentials experiment.

The social norm scenario activation experiment was mainly carried out in the form of a questionnaire. The respondents were required to read social norm activation material. After confirming the social norm activation effect, the six-point Likert scale was used to collect the respondents' acceptance intention for 12 types of recycled water. According to the reading material, the respondents were divided into "no social norms group," "descriptive social norms activation group," and "injunctive social norms activation group." After reading the activation materials, respondents need to set corresponding questions to test the effect of social norm activation. Then the questionnaire data failing to activate social norms should be eliminated. According to the investigation results of this stage, a more effective presentation of social norms in ERP experiment was selected. Bringing experimental participants into the context of ERP experiment is an important purpose of taking social norm scenario activation experiment as pre-experiment. The false report method adopted in the research on college students' energy-saving behaviors by Hamon and Smith (2016) will be used to present social norms in the ERP experiment. In fact, these presented social norms are artificially manipulated by the experimental design. Therefore, in order to improve the credibility and effectiveness of stimulus materials presented in the ERPs experiment, it is necessary for participants to feel their willingness to participate in recycled water and those around them in advance.

The second stage was to conduct an ERP experiment on some of the "no social norms group" participants. The ERP experiment task of this study was adapted from the classic Judge-Advisor System (JAS) paradigm (Sniezek and Buckley, 1995). College students in this study would function as policymakers and choose the willingness to accept recycled water reuse as a decision task. The false report method was used to present the social norms created by different groups as suggestions for the subjects' reference. In addition, in this experiment, the difference between the decision maker's initial willingness value of recycled water usage and the presented social norm value was defined as the social norm deviation value. There is no social norm deviation when the value of social norm deviation is zero, in the opposite, there is social norm deviation. When social norm deviates, it is separated into two categories: positive social norm deviation and negative social norm deviation. Positive social norm deviation occurs when the social norm value presented exceeds the decision maker's initial willingness value of recycled water usage. Conversely, it is defined as negative social norm deviation. Different from the initial decision-making, others' suggestions, and final decision-making contained in the traditional JAS paradigm process, this study divided the advice-taking process into two tasks. Both tasks were repeated 240 times. In Task 1, the participants were informed about the social norms of the people around them after the participants made the initial choice of reclaiming water. In Task 2, the order of the trial will be reversed. Participants will first be informed about the social norms of people around them before being asked about their willingness to use recycled water. Prior to the experiment, the participants would be notified by experimental instructions that they would be taking part in a study on the willingness to use recycled water. Participants will then be instructed to press the space bar to proceed with the actual experiment after confirming the understanding of the experimental task. Before each trial of Task 1 starts, a " + " would be displayed in the center of the screen for 800 ms to focus the participants' mental energy. On the next page, the screen is randomly selected from six directions of recycled water reuse, participants would make their willingness choice on this interface. After presenting the results of participants' choice of willingness to reuse recycled water in 1,000 ms, the social norms of a certain social group in 1,500 ms

would be presented. The social norms presented in this interface are manipulated so that the difference between the values of the social norms presented and the values of the participants' willingness are as follows: 0 (80 trials), + 1 (26 trials), −1 (26 trials), + 2 (27 trials), −2 (27 trials), + 3 (27 trials), and −3 (27 trials) were evenly divided into three social distance groups. After a trial, the screen would be blank for 1,500 ms. The trial would be carried out 240 times. After Task 1 was completed, there would be a 5-min break before Task 2 began. The difference between the trial in Task 1 and Task 2 is the presentation of social norms placed before the participants' willingness choices. At the same time, the presented social norms were manipulated and randomly presented into 1 (40 trials), 2 (40 trials), 3 (40 trials), 4 (40 trials), 5 (40 trials), and 6 (40 trials), with each trial evenly divided into three social distance groups. This trial would also be carried out 240 times. The schematic information of the experimental structures of each trial in Task1 and Task 2 are shown in **Figure 1**. More detailed event-related potential experiment procedures for this study are presented in the **Supplementary Material**, and the original meaning of all abbreviations in the article can be found in **Appendix A**.

Participants

The participants in the social norm scenario activation experiment were college students from Xi'an University of Architecture and Technology. Questionnaires were distributed by random interviews. If the respondents were willing to participate in the ERPs Experiment, they would be given priority to fill in the questionnaire of the "no social norm group."

Then, thirty college students from Xi'an University of Architecture and Technology (15 males, 15 females; mean age: 23.14 ± 1.77 years) were recruited as participants in the formal event-related potential experiment. All participants were right-handed, had normal vision or corrected vision, had no history of neurological disease or genetic history, and had not previously participated in a similar experiment. All participants have filled in written informed consent before the experiment, and the study will strictly abide by the Declaration of Helsinki (General Assembly of the World Medical Association, 2014). The Internal Review Board of the Laboratory of Neuromanagement in Engineering approved this study.

Stimulative Materials

The independent sample T-test was used to determine the difference of the effects of descriptive social norms and injunctive social norms on college students' willingness to reuse recycled water. The results show that college students' willingness to reuse recycled water under the influence of descriptive social norms (4.631 ± 0.731) is higher than that under the influence of injunctive norms (4.234 ± 0.617), the independent sample T-test results showed that there was a statistical difference between the two ($T = 2.016$, $P = 0.003$). Descriptive social norms have a better activation effect on college students in the scenario of recycled water reuse. Therefore, descriptive social norms are selected as the presentation method of stimulus materials in ERPs experiment.

In the ERP experiment, the mismatch between the expected feedback and the actual feedback is one of the preconditions to induce FRN components (Li et al., 2018). In order to create a social norm deviation scenario, the first six reuse directions with large variance values were selected as stimulus materials for the ERP experimental task from the twelve types of recycled water reuse directions provided by the situational activation experiment (Variance goes from large to small:

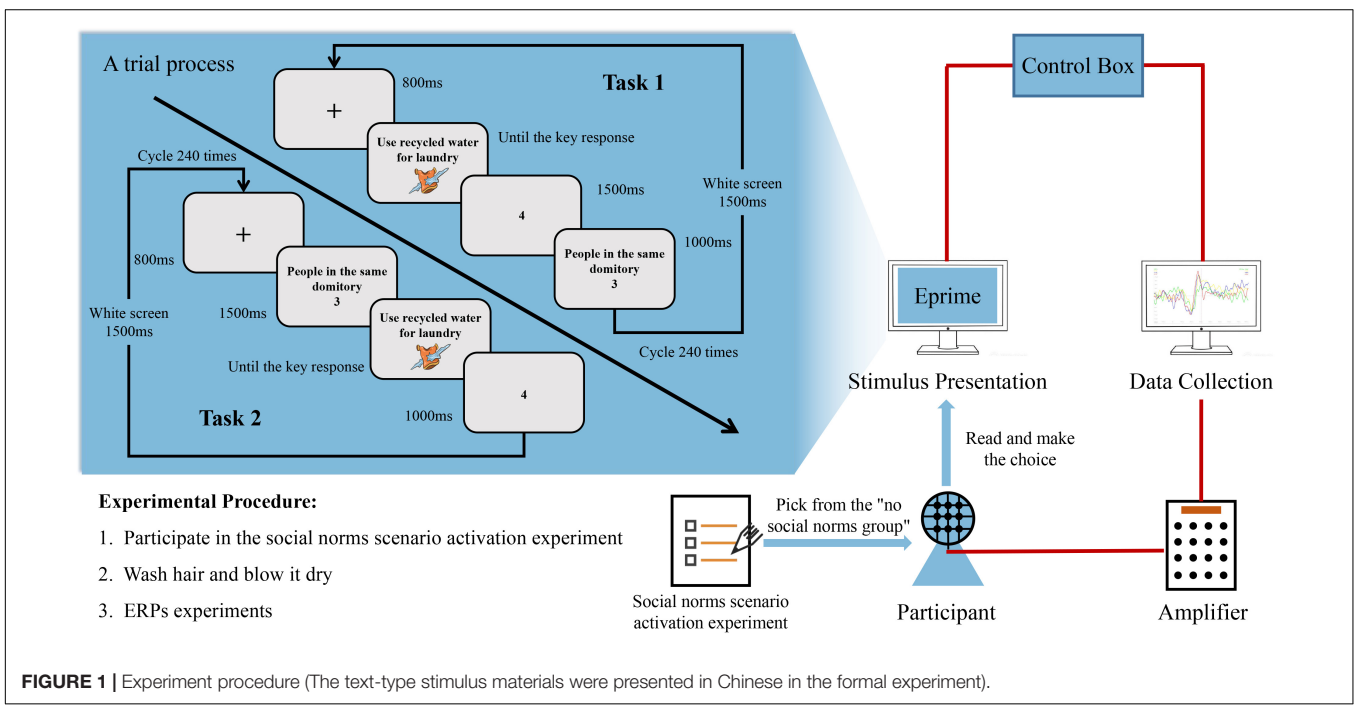

FIGURE 1 | Experiment procedure (The text-type stimulus materials were presented in Chinese in the formal experiment).

water the vegetables, take a shower, clean hands, wash clothes, brush teeth, drink).

This experiment assumes that the social distance of college students in the social group from far to near is the same school, the same major, and the same dormitory. At the same time, in order to ensure the credibility of social norm deviation scenarios, extreme value deviation should be avoided when presenting social norms. In this study, the range of the value deviation of descriptive social norms presented by participants after their initial willingness selection in Task 1 was controlled within ± 3. The stimulus materials involved in the event-related potential experiment of this study can be found in **Supplementary Material**.

Electroencephalography Data Collection and Analysis

This experiment was conducted in the Laboratory of Neuromanagement in Engineering, Xi'an University of Architecture and Technology. Experimental programming and presentation were implemented *via* E-Prime3.0. The experiments were divided into two phases: Task 1 (240 Trials) and Task 2 (240 Trials). Normally, the duration of each task is between 25 and 30 min. In order to ensure the participants' concentration during the experiment, a mandatory rest time of 5 min was set between two tasks. Before the ERP experiment, participants should come to the lab at least 45 min in advance to cooperate with the researchers to prepare for the experiment and inject electro-gel into each electrode on the electrode caps to reduce its resistance to less than 5 kΩ. In the formal experiment, participants were asked to watch the 22-in Dell Monitor, Dell Technologies, Texas, TX, United States, with a refresh rate of 60 Hz and a resolution of 1,920 × 1,080 pixels in soft indoor light at a visual distance of 100 cm. Experimental EEG signals were recorded using a Neuroscan Synamps2, Compumedics Neuroscan, North Carolina, NC, United States, amplifier connected to an elastic cap with 64 Sintered Ag/AgCl electrodes. The sampling rate was 1,000 Hz, GND and REF were the reference grounding electrodes, and the signals of bilateral mastoid electrodes were referenced. EEG signals are transmitted with a 0.01–70 Hz bandpass. The horizontal electrooculogram was recorded by placing the HEO electrode 1 cm behind the tail of both eyes while the vertical electrooculogram was recorded by placing the VEO electrode 1 cm above and below the left eye. In order to reduce the interference of blinking and other eye movements to electroencephalography signals, the aboveelectrooculogram data would be algorithmically corrected in Curry 8 processing. Artifact removal was performed based on baseline correction and EOG removal, electrical signals with amplitude greater than 100 μV would be regarded as bad blocks and will be ignored in the subsequent analysis. This experiment only focused on the EEG signal changes of participants after the introduction of social norms, therefore, the EEG fragments from 200 ms before the introduction of social norms to 700 ms after the introduction of social norms were intercepted. Combined with the final waveform of the experiment and previous studies, FRN and P300 components were chosen to indicate the influence of social norm deviation caused by different social distance groups. The amplitude of FRN was measured at FZ, FCZ, and CZ electrodes (Zioga et al., 2019), and the amplitude of P300 was measured at CZ, CPZ, and PZ electrodes (Yu et al., 2019).

In this study, in order to confirm college students' perceptions of social norm deviation scenarios, repeated-measures ANOVAs were used to verify the peak amplitude data of FRN and P300 in Task 1. In order to confirm the impact of social norm deviation scenarios produced by different social distance groups on the willingness of college students to reuse recycled water [2 (Social norm deviation: positive social norm deviation and negative social deviation) × 3 (Social distance: people in the same dormitory, people in the same major and people in the same school)], two-way ANOVA was used to verify the peak amplitude

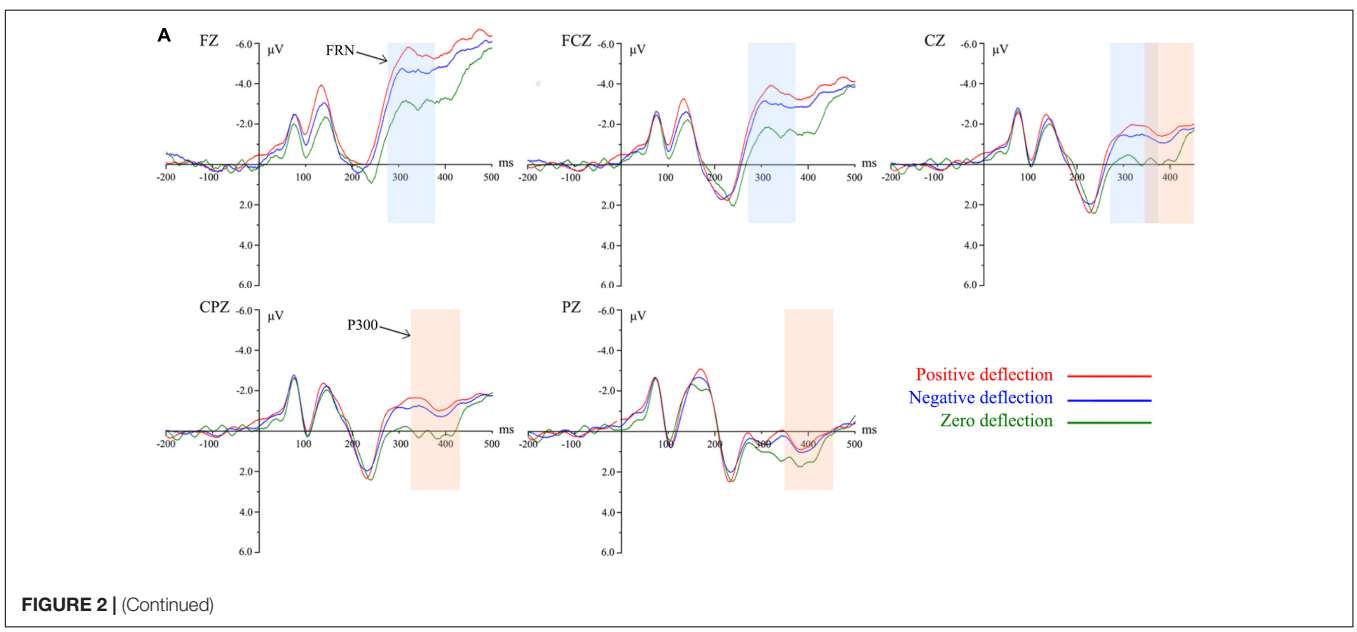

FIGURE 2 | (Continued)

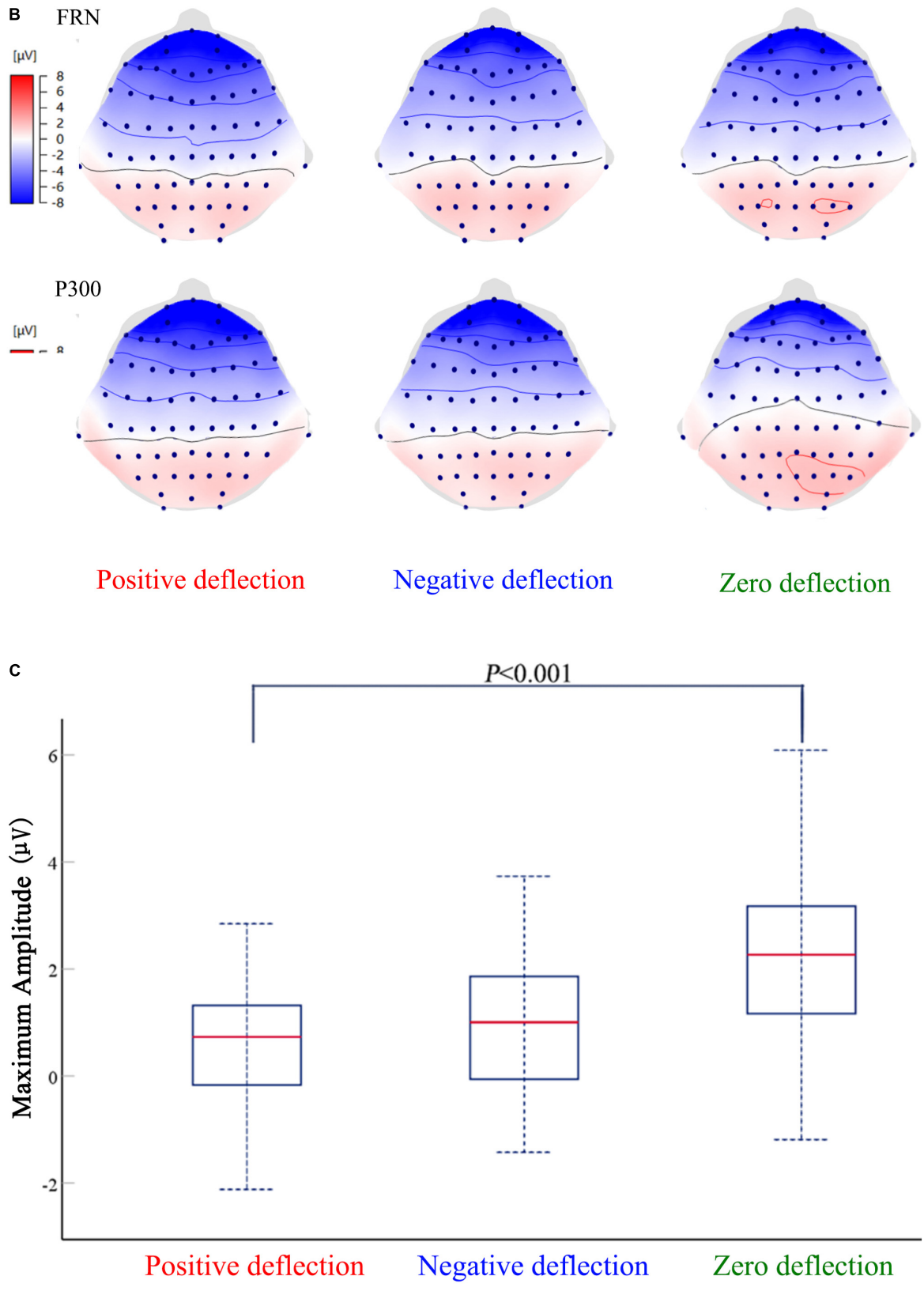

FIGURE 2 | (A) The grand averaged event-related potentials (ERPs) waveforms at FZ, FCZ, CZ, CPZ, and PZ of social norm deviation in Task 1. **(B)** The scalp distribution of feedback-related negativity (FRN) and P300 of social norm deviation in Task 1. **(C)** ANOVA results of social norm deviation in Task 1.

data of FRN and P300 in Task 1. Finally, the P300 amplitude peak data in Task 2 was verified by repeated-measures ANOVAs to supplement the cognitive attention of social distance among college students.

RESULTS

Perception of Social Norm Deviation

In order to explore college students' perception of social norm deviation in recycled water usage, the difference between participants' social norm situation and their willingness to use recycled water was divided into three categories: no social norm deviation, positive social norm deviation, and negative social deviation. **Figure 2A** shows the average ERPs waveform induced on FZ, FCZ, CZ, CPZ, and PZ electrodes in the above three scenarios. **Figures 2B,C** show the topographic maps and peak variance analysis of FRN and P300. **Table 1** shows the average peak value and standard error of FRN and P300 in the above three scenarios.

Feedback-Related Negativity

The stronger the participants' perceived motivation and emotion for the feedback results, the greater the amplitude of FRN induced. In this study, the EEG amplitude observed on FZ, FCZ, and CZ electrodes between 280 and 380 ms were observed as the FRN component. The amplitude reflected the views and attitudes of college students when their willingness was inconsistent with social norms. By comparing the FRN in the waveform, it can be observed that if there is a deviation between the willingness of self-recycled water reuse and the social norm, the FRN amplitude would most likely be more significant than without social deviation ($M = -1.985$, SE $= 2.798$). A repeated-measures ANOVAs result ($F = 5.588$, $P = 0.005$) reveals the above results. In other words, participants perceived their level of willingness to use recycled water as incorrect when the opinions around them differed from their own. In the deviation scenario, the positive deflection of the social norm ($M = -4.227$, SE $= 2.184$) induced a stronger FRN amplitude than the negative deflection of the social norm ($M = -3.392$, SE $= 2.842$). It was shown that positive social norm deviation in the use of recycled water could lead to a more erroneous perception among college students.

P300

The P300 component was related to the allocation of attention resources, and the larger the amplitude of the P300 component was, the more attention participants allocated. The P300 is also more sensitive to positive feedback. In this study, the P300 component was determined by measuring the EEG amplitude observed at CZ, CPZ, and PZ electrodes between 350 and 450 ms. The amplitude represented the degree of individual attention to different situations when college students' willingness and social norms were different. A repeated-measures of ANOVAs result of P300 amplitude revealed the primary effect of social norm deviation. When one's own choice was consistent with the choice of the surrounding people ($M = 2.330$, SE $= 1.650$), P300 would be more significant than the situation of social norm deviation. However, the independent sample T-test results revealed that there was no significant difference in P300 amplitude between positive social norm deviation and negative social norm deviation ($F = 0.940$, $P = 0.336$).

Perception of Social Norm Deviation Generated by Different Social Distance Groups

In order to further explore college students' attitudes toward social norms proposed by different social distance groups, we analyzed the FRN component (280–380 ms) and P300 component (350–450 ms), respectively, according to the FZ, FCZ, and CZ electrode waveforms in Task 1 and CZ, CPZ, and PZ electrode waveforms in Task 2. **Table 2** shows the average peak values and standard errors of FRN and P300 in the following three types of social distance: same dormitory, same major, and same school.

Feedback-Related Negativity

Figure 3A shows the average ERPs waveform of FRN induced by Task 1 at FZ, FCZ, and CZ electrodes for three social distance groups under positive social norm deviation and negative social norm deviation, respectively.

In **Figure 3B**, the FRN amplitude awakened by different social distances is always statistically significant in both positive and negative social norm deflection scenarios (positive deviation: $F = 10.507$, $P < 0.001$, negative deviation: $F = 4.315$, $P = 0.016$). In other words, when others' social norms are inconsistent with their own choices, college students pay different attention to the social norms proposed by different social distance groups. **Figure 3A** shows that compared with the people of the same major and the same school, the willingness of recycled water reuse of dormitories has the most obvious effect on the excitation of FRN amplitude (positive deviation: $M = -6.616$, SE $= 2.104$,

TABLE 1 | The average peak value and standard error of FRN and P300 in the social norm deviation scenario.

Social norm deflection scenario	EEG components			
	FRN		P300	
	Average peak value	Standard error	Average peak value	Standard error
Positive deflection	−4.227	2.184	0.613	1.150
Negative deflection	−3.392	2.842	0.990	1.310
Zero deflection	−1.985	2.798	2.330	1.650

TABLE 2 | The average peak value and standard error of FRN and P300 in different social distance scenarios.

Social norm scenario		EEG components			
Social norm deflection	Social distance	FRN		P300	
		Average peak value	Standard error	Average peak value	Standard error
Dormitory	Positive deflection	−6.616	2.104	1.920	1.343
	Negative deflection	−5.193	1.911		
Major	Positive deflection	−4.849	2.219	1.302	1.669
	Negative deflection	−4.380	2.251		
School	Positive deflection	−3.934	2.538	0.959	1.090
	Negative deflection	−3.523	2.415		

negative deflection: $M = -5.193$, SE = 1.911). However, the value of FRN amplitude of social norms produced for people in the same major (positive deviation: $M = -4.849$, SE = 2.219, negative deflection: $M = -4.380$, SE = 2.251) is slightly lower than that of people in the same school (positive deviation: $M = -3.934$, SE = 2.538, negative deflection: $M = -3.523$, SE = 2.415). The results support that social distance will affect the perceptual sensitivity of individual choice when it is inconsistent with group choice.

In **Figure 3B**, the social distance was used as a variable to compare the cognition of positive and negative social norm deviations of college students in the same group. After the ANOVA test, only the FRN amplitude of social norms in the same dormitory under different deviation scenarios was statistically significant ($F = 4.194$, $P = 0.045$). As shown in **Figure 3A**, positive social norm deflection causes larger FRN waves than negative social norm deflection. In other words, when dormitory mates have more positive intentions for using recycled water than their own, college students will have a more obvious false perception of their own choice. While when others have fewer intentions of using recycled water, their false perception will be significantly weakened. However, in the analysis of variance, the above results could not be confirmed in the same major group ($F = 0.423$, $P = 0.518$) and the same school group ($F = 0.136$, $P = 0.713$).

P300

The results of repeated-measures ANOVAs show that the P300 amplitude ($F = 0.511$, $P = 0.751$) of the students in Task 1 is not significant when they pay attention to the social norms produced by different social distance groups. Therefore, the EEG amplitude caused by the social norms of different social distance groups in Task 2 is considered as the analysis object of the P300 component.

We can see the average ERPs waveform induced by the three social distance groups in Task 2 at the CZ, CPZ, and PZ electrodes in **Figure 4A**. The ANOVA analysis results shown in **Figure 4B** confirmed that P300 at this stage was statistically significant ($F = 3.690$, $P = 0.029$). The EEG amplitude of CZ, CPZ, and PZ electrodes showed that the amplitude of the P300 component was larger in the group with closer social distance [dormitory ($M = 1.920$, SE = 1.343), major ($M = 1.302$, SE = 1.669), school ($M = 0.959$, SE = 1.090)]. In other words, people prefer to pay more attention to the attitudes and suggestions of the group closer to their society or spend more energy on the perceptual processing of the social norms of the group closer to their society.

Influence of Social Norms on Willingness to Reuse Recycled Water

In order to validate the impact of social norms, the following two behavioral data were used to analyze whether social norms would provide reference conditions for college students' willingness to recycle water.

First, matched samples *T*-test were used to determine whether participants' response time to keys could be shortened with social norms as reference. **Table 3** shows the mean and standard deviation of the selection results and response time of participants' intention to reuse recycled water in Task 1 and Task 2. The baseline key response time of participants was based on the key response time in Task 1, with an average level of 1974.737 ± 786.708 ms. The results are shown in **Figure 5A** demonstrate that the keystroke response time under the social norm reference condition was shorter than that without the social norm reference condition, and the difference between the two was statistically significant ($F = 10.181$, $P < 0.001$). The phenomenon of shorter decision response time suggested that social norms become the reference premise of decision execution in the process of the participants' decision of their willingness to use recycled water. In other words, the introduction of the social norm as a guide reduced the amount of time and energy spent on the participants' selection process.

Secondly, a one-way ANOVA was used to verify that the participants' willingness to reuse recycled water was indeed different under the influence of different social norms ($F = 12.067$, $P < 0.001$). The social norm scenarios in Task 2 were divided into Low and High Scenarios based on the mean intentions to reuse recycled water collected by Task 1 (Mean = 3.554, SD = 1.601). The participants' willingness to reuse recycled water under the influence of high social norms scenarios (Mean = 4.110, SD = 1.662) was higher than the previous baseline willingness, while the participants' willingness to use recycled water under the influence of low social norms scenarios (Mean = 3.160, SD = 1.595) was reduced (**Table 3**). Furthermore, **Figure 5B** shows the changes in the participants' recycled water reuse intention under the influence of different

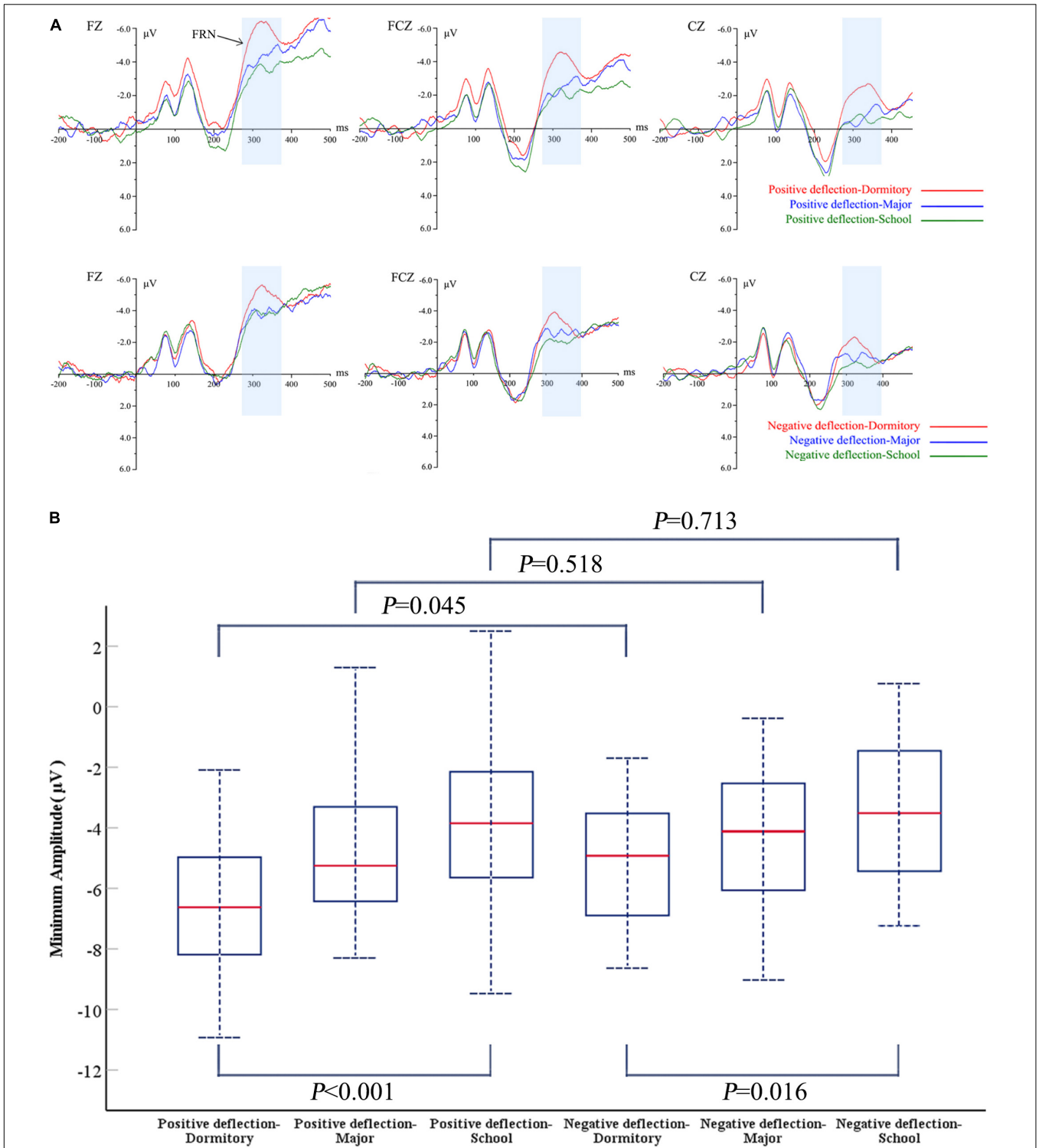

FIGURE 3 | (A) Grand averaged ERPs waveforms at FZ, FCZ, and CZ of social norm deviations from different social distances in Task 1. **(B)** ANOVA results of social norm deviations from different social distances in Task 1.

social norm values. The increase of the participants' willingness to reuse recycled water along with social norm value suggested an obvious correlation between both factors. One-way ANOVA was conducted with the willingness to reuse recycled water as the dependent variable and the social norm scenario type as the factor. The results also showed that the social norm scenario type

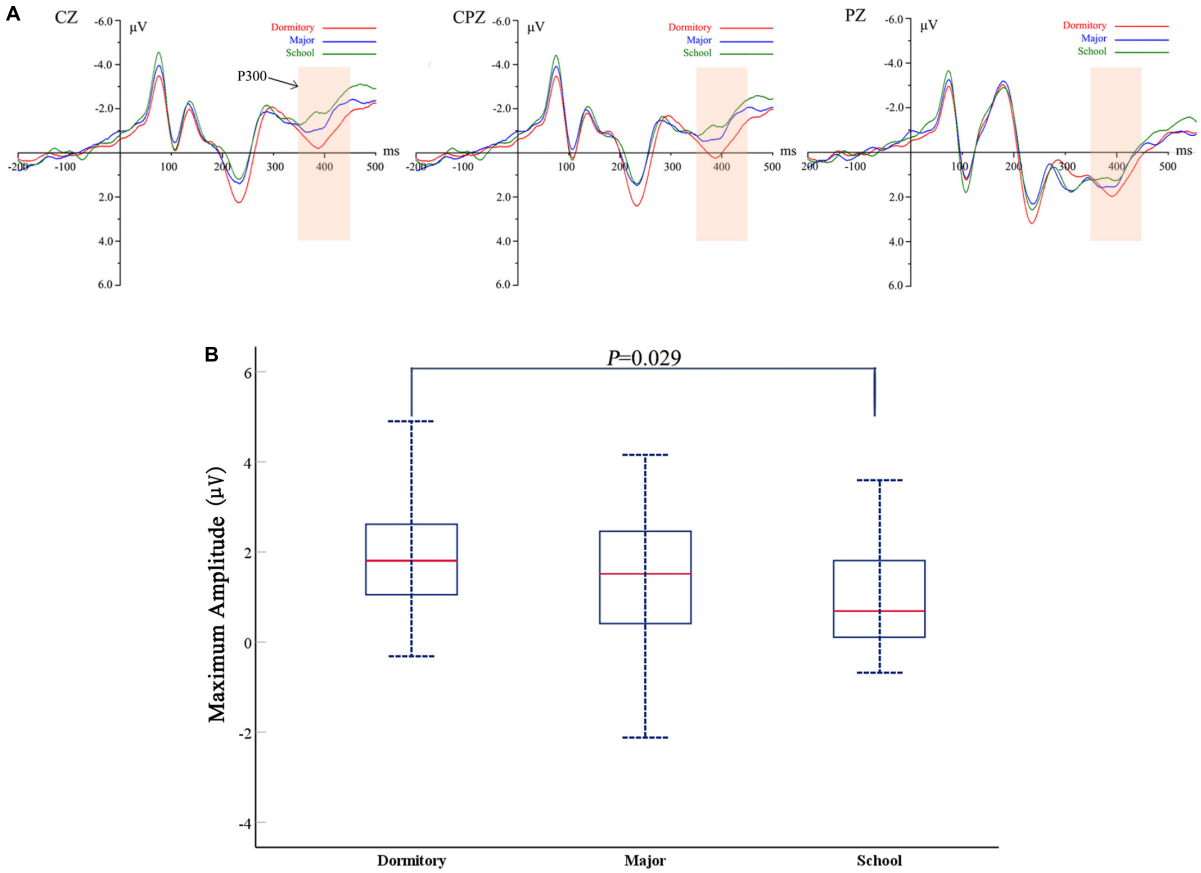

FIGURE 4 | (A) Grand averaged ERPs waveforms at CZ, CPZ, and PZ of social distances in Task 2. **(B)** ANOVA results of social distances in Task 2.

had a significant impact on the participants' willingness to use recycled water ($F = 688.433$, $P < 0.001$).

DISCUSSION

Discussion of Findings

For the purpose of the research, two phases of experiments were carried out. Firstly, in the social norm activation scenario experiment, the results have shown that the social norms after activation affected the college students' willingness to use recycled water. The results also suggested that descriptive social norms can lead to a greater degree of willingness to accept recycled water. The ERP experimental methods were adopted in the second stage of the experiment. In order to explore the social norm information processing process of college students for different social groups in the situation of recycled water reuse, a variant of the classic "Judge-Advisor System" paradigm was carried out. Through observation of FRN and P300 components in different experimental control groups, they reflected the motivational force of social norms developed by different social distances on college students' willingness to use recycled water. The results have shown that the activation level of the FRN component in the context of social norm deviation was higher than that in the context of no social norm deviation, and positive deviation could activate larger FRN amplitude in the experiment. The results of the P300 component analysis have shown that college students who participated in the experiment had a larger P300 amplitude to the social norms consistent with their willingness, meaning that students allocated more attention resources. In addition, this study also observed the influence of social distance on college students' acceptance of social norms. The results have shown that when college students deviated from the social norms proposed by the group with closer social distance, the greater the FRN amplitude was. Moreover, when facing the social norms proposed by the same dormitory group, the FRN amplitude caused by

TABLE 3 | Mean and standard deviation (M ± SD) of willingness to reuse recycled water and response time in various stages of ERPs experiment.

The experimental stage		Willingness to reuse recycled water	Response time (ms)
Task 1		3.554 ± 1.601	1974.737 ± 786.708
Task 2	High social norm scenarios	4.110 ± 1.662	1503.870 ± 1184.340
	Low social norm scenarios	3.160 ± 1.595	1556.190 ± 1238.536

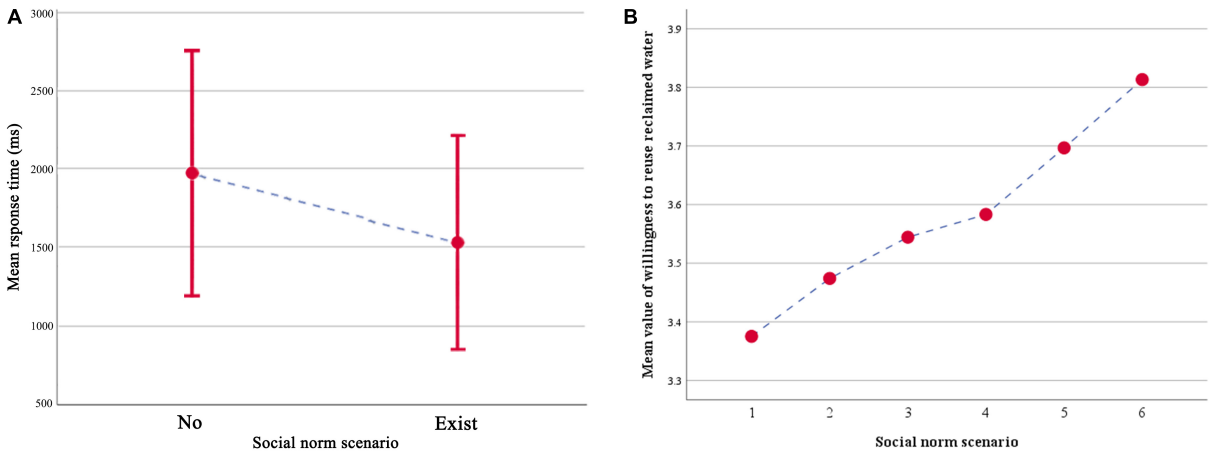

FIGURE 5 | (A) The mean response time of Task 1 with no social norm and Task 2 with the social norm. Error bars depict the standard error of the mean. **(B)** Take the social norm value in Task 2 as a function of *a priori* category.

the positive deviation was larger. However, this conclusion has not been confirmed in the same major group and the same school group. The P300 component analysis results showed that college students activated a larger P300 component when they saw the suggestions of social norms promoted by groups closer to their society.

For the condition that one's own opinions were consistent with social norms, the deviation between them induced a relatively large FRN amplitude, which was related to the cognitive processing after paying attention to the group judgment. That shows that when participants discovered that their willingness was inconsistent with the given social norms, they produced incorrect perceptual signals, resulting in strong negative emotions or motives. It may be one of the incentives for social norms to intervene in such behavioral decisions. At the same time, higher FRN amplitude was detected when the group social norm was higher than the participant's social norm and when individual willingness and social norm were deflected. This suggested that during behavioral intention selection of using recycled water, the group whose own intention is lower than the general environment will make participants have a more significant sense of error. On the contrary, when the individual's willingness to reuse recycled water was higher than the social norms proposed by other groups, the participants' sense of error was comparatively low. Combined with the observation of behavioral data, the low social norms had no significant impact on the participants' final decision of willingness to use recycled water. It is possible that the inducement for this phenomenon was that using recycle water protects the environment and provided participants a pleasant emotional valence. This emotion caused them to have an implicit attitude of "it is right for me to have a high willingness to use recycled water," and ultimately help reduce the guilt of breaking low social norms. Therefore, in the actual promotion process of recycled water, we should establish a high moral appraisal of recycled water usage behavior at the individual perception level through environmental motivation. In the scenario of recycled water usage, we attempted to induce individuals' positive psychology of upward social comparison to alleviate the negative influence of others' negative willingness of recycled water usage on college students' behavior choices. Although the inconsistency between individual and group attitudes might cause participants to feel as if they were making mistakes, the results of P300 showed that participants tended to devote attention resources to the suggestions of social norms that were consistent with their willingness. People usually recognize and praise people who have the same attitude as themselves. Therefore, our findings could suggest that the P300 component is related to the evaluation process of self-benefit, which is consistent with the view proposed by Chen et al. (2017). Self-efficacy here largely describes the quality of others' self-social evaluation. When combined with behavioral decision-making data, although college students are more likely to pay more attention when social norms are consistent with their willingness to use recycled water, violating social expectations may cause more intense conflict. Under this conflict, college students were more inclined to make willing behavioral judgments that fit the requirements of social norms in the next step.

In addition, this study also observed that when individual willingness differed from social norms, the social distance was found to be one of the important factors affecting college students' perception of social norms. The FRN indicated that when the individual willingness deviated from the social norm, the closer the social distance was and the larger the FRN amplitude was. This conclusion was especially obvious in the same dormitory group. This phenomenon was interpreted as that driven by self-expansion, the closer others will be more easily integrated into the self-structure to form self-friend overlapping (Liu et al., 2021). Therefore, when the behavior intention is inconsistent with the group with a similar self-structure, there would be a tendency to have more false conflict perception. The ability to utilize the conflict perception will be a breakthrough point to improve the willingness of college students to use recycled water. The result suggested that the positive deflection would cause larger FRN amplitude only in the same dormitory

group, but the main effect analysis was not significant in the same major group and the same school group. Presumably, because only dormitory mates were visualized in the "friends" group of participants, while there were no differences between the major group and school group and the "strangers" group.

The P300 observed in Task 2 indicates the participants' motivation and encoding of the emotional meaning of the social norms created by these three social distance groups. The social norms are given by people living in the same dormitory induced the highest P300 amplitude, followed by the same professional group, and the lowest among people living in the same school. It suggested that the use of recycled water promoted by close people drew higher attention from college students. Existing studies have shown that when suggestions deviate from their own were given by strangers, participants would get a lower P300 amplitude when they accept the group norms of the same strangers again (Schnuerch et al., 2014). In other words, the deviations from social norms tend to cause participants to pay less attention to the social norms of the same group. Surprisingly, this phenomenon was not observed in this study. It is probably because compared to strangers, groups with closer social distance have more social bonds which minimize the likelihood of ignoring social norms caused by conflict.

In sum, experimental results have shown that the impact of social norms on participating college students' willingness to use recycled water was not only related to the degree of deviation between individual will and social norms but also closely related to the group presenting social norms. When confronted with a situation involving social norms, participants tend to make a decision that is close to the norm. When they deviated from social norms, participants subconsciously believed that they had made a mistake. At the same time, people also pay more attention to the information of social norms presented by intimate groups. The advice and practice of "friends" greatly affected the willingness of the participating individual college students to use recycled water. Therefore, social norms would be an influential aspect that cannot be ignored in the promotion of recycled water on campus.

Limitations and Future Research Directions

It is important to note that this study still has some limitations. On one hand, this study demonstrates the possibility of the cognitive impact of short-term social norms on recycled water usage of college students from a neural level. However, in reality, social norms have a long-lasting and subtle influence on individual behavior. To pay attention to the long-term impact of social norms on college students' willingness to use recycled water is something we can further study in the future. On the other hand, this study focuses on the implementation of recycled water on campus from the perspective of the social norm. However, it is unclear whether social norms can have the same motivational effect on other groups with more complex demographics. In future studies, more groups with diverse characteristics will be found to explore the impact of social norms on their willingness to use recycled water.

CONCLUSION

The public's resistance to the reuse of recycled water has become a constraint to further promote the use of recycled water as an alternative water source. However, at present, the price of tap water is too low to encourage the public to reuse recycled water by widening the price difference between them. Therefore, this study is expected to find ways to improve college students' willingness to reuse recycled water from the perspective of social norms.

Conclusions of the study are as follows: (1) When the participants are guided by the suggestions of social norms, they will tend to make behavioral decisions consistent with the social norms, and at the same time shorten the keystroke response time. (2) When individual willingness is inconsistent with social norms, it will cause greater FRN amplitude and smaller P300 amplitude, while when they are consistent, it will cause smaller FRN amplitude and larger P300 amplitude. (3) The social norm deviation scenario caused by the group with closer social distance will cause greater FRN and P300 amplitude. When forming the social norms of recycled water usage among college students, we should begin with the group with close social relations, and then form the social norms of active use of recycled water from a point to an area. The upward social comparison psychology and group identity will support and superimpose each other, resulting in a favorable atmosphere of the use of recycled water in a virtuous circle and to achieve the expected goal of promoting college students' willingness to use recycled water through social norms.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Internal Review Board of the Laboratory of Neuromanagement in Engineering, Xi'an University of Architecture and Technology. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XL: responsible for the conceptualization, supervision, and funding acquisition. SC: responsible for the conceptualization, data curation, formal analysis, software, investigation, writing – original draft, and validation. XG: responsible for the methodology and revising the manuscript critically for important intellectual content. HF: responsible for the methodology, project administration, resources, funding acquisition, and validation. All authors contributed to the article and approved the submitted version.

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APPENDIX A

TABLE A1 | Symbol table.

Denotation	Abbreviation
event-related potentials	ERPs
anterior insula	AI
anterior cingulate cortex	ACC
feedback-related negativity	FRN
Judge-Advisor System	JAS

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"Sound" Decisions: The Combined Role of Ambient Noise and Cognitive Regulation on the Neurophysiology of Food Cravings

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Our ability to evaluate long-term goals over immediate rewards is manifested in the brain's decision circuit. Simplistically, it can be divided into a fast, impulsive, reward "system 1" and a slow, deliberate, control "system 2." In a noisy eating environment, our cognitive resources may get depleted, potentially leading to cognitive overload, emotional arousal, and consequently more rash decisions, such as unhealthy food choices. Here, we investigated the combined impact of cognitive regulation and ambient noise on food cravings through neurophysiological activity. Thirty-seven participants were recruited for an adapted version of the Regulation of Craving (ROC) task. All participants underwent two sessions of the ROC task; once with soft ambient restaurant noise (∼50 dB) and once with loud ambient restaurant noise (∼70 dB), while data from electroencephalography (EEG), electrodermal activity (EDA), and self-reported craving were collected for all palatable food images presented in the task. The results indicated that thinking about future ("later") consequences vs. immediate ("now") sensations associated with the food decreased cravings, which were mediated by frontal EEG alpha power. Likewise, "later" trials also increased frontal alpha asymmetry (FAA) —an index for emotional motivation. Furthermore, loud (vs. soft) noise increased alpha, beta, and theta activity, but for theta activity, this was solely occurring during "later" trials. Similarly, EDA signal peak probability was also higher during loud noise. Collectively, our findings suggest that the presence of loud ambient noise in conjunction with prospective thinking can lead to the highest emotional arousal and cognitive load as measured by EDA and EEG, respectively, both of which are important in regulating cravings and decisions. Thus, exploring the combined effects of interoceptive regulation and exteroceptive cues on food-related decision-making could be methodologically advantageous in consumer neuroscience and entail theoretical, commercial, and managerial implications.

Keywords: EEG, EDA, cognitive load, emotions, self-regulation, restaurant noise, decision-making, consumer behavior

INTRODUCTION

Value-Based Decision-Making

Our ability to evaluate long-term goals over immediate rewards is encoded in an array of complex computational processes in the brain (Rangel et al., 2008; Levin et al., 2012). These include resisting the impulse of consuming palatable foods, foreseeing the future potential health consequences associated, and at the same time being able to delay one's gratification by valuing the "rational" alternative despite temporal discounting (Volkow and Baler, 2015; Cai et al., 2019).

Indeed, our choices and decisions ought to fulfill both immediate needs and those that are better served for future gains (Motoki et al., 2019). To evolutionarily optimize such balanced utilitarian behaviors, the neural circuitry of human decision-making can simplistically be divided into two neuroanatomically and -functionally distinctive systems—an automatic, emotional, impulsive system (bottom-up) and a deliberate, reflective, control system (top-down)—popularly referred to as a fast "system 1" and a slow "system 2" (Evans, 2007; Chen et al., 2018). While the emotional and motivational behaviors of system 1 are manifested in deeper striatal brain structures, the prefrontal cortices govern the cognitive and prospective system 2 functions (Peng-Li et al., 2020c).

Without cognitive inhibition of system 2, the mere presence of appetitive and salient food cues reinforces anticipatory reward ("wanting") responses through sensitized neural firing of dopamine, potentially leading to excess food consumption, weight gain, and even addictive behaviors (Burger and Stice, 2012; Schulte et al., 2016; Coccurello and Maccarrone, 2018; Nguyen et al., 2021).

Top-Down Cognitive Regulation

In fact, several cognitive strategies have been proposed to facilitate top-down self-regulatory eating behaviors, such as mental imagery (Petit et al., 2017; Zorjan et al., 2020) or episodic future thinking (Dassen et al., 2016; Sun and Kober, 2020). These self-managerial strategies are important components in cognitive-behavioral treatments for treating obesity, eating disorders and addictions (Grilo et al., 2011; Gearhardt et al., 2012) and have been instrumentalized in experimental paradigms (Sun and Kober, 2020).

The Regulation of Craving (ROC) task, originally developed by Kober et al. (2010a) attempts to measure the specific causal effect of regulation strategies on craving for cigarette, alcohol, and/or foods (Kober et al., 2010b; Boswell et al., 2018; Suzuki et al., 2020). The ROC task enables quantification and casual inferences of the underlying neural mechanisms of cue-induced cravings from an immediate "now" perspective (anticipatory reward) and a future "later" decision perspective (delayed gratification). For instance, using functional Magnetic Resonance Imaging (fMRI), Kober et al. (2010b) demonstrated that cravings for both cigarettes and food decreased when thinking about long-term consequences vs. immediate sensations. These subjective ratings were reflected in the blood-oxygen-level-dependent (BOLD) signal which showed that later (vs. now) -trials increased activation in the dorsomedial prefrontal cortex (dmPFC), dorsolateral prefrontal cortex (dlPFC), and ventrolateral prefrontal cortex (vlPFC)—all a part of the reflective system 2—whereas they decreased activity in brain regions associated with emotion and reward valuation (system 1), i.e., ventral striatum and amygdala.

Similarly, an electroencephalogram (EEG) study focusing on event-related potentials (ERPs), showed that a later (vs. now) mindset reduced cravings for high-caloric foods as well as evoked larger late positive potential (LPP) compared to remaining conditions, suggesting that a cognitive focus on negative long-term consequences increases arousal (Meule et al., 2013).

Bottom-Up Auditory Manipulation

In commercial contexts, consumer researchers and behavioral economists have explored more bottom-up avenues for alleviating the "obesogenic" environment. Such sensory marketing strategies entail changing the so-called choice architecture by nudging consumers toward healthier behaviors through multisensory cues in the environment (Krishna, 2012; Bucher et al., 2016; Seo, 2020). Particularly, auditory contributions to this field have in the past decade emerged with numerous studies highlighting the often underestimated power of sound and noise on food choice (Huang and Labroo, 2019), liking (Alamir and Hansen, 2021), attention (Peng-Li et al., 2020b), and perception (Woods et al., 2011).

Louder (vs. softer) ambient noise has consistently shown adverse effects on psychophysiological mechanisms, including increased arousal states (Alvarsson et al., 2010) and cognitive load (Mehta et al., 2012), potentially resulting in poorer decisions and unhealthier food choices (Biswas et al., 2019; Volz et al., 2021; Peng-Li et al., 2022). These phenomena can be explained through the lenses of attentional processes and sensory overload (Doucé and Adams, 2020), whereby "*louder noise may diminish the ability to attend to specific elements of the experience*" (Bravo-Moncayo et al., 2020). In fact, attentional distractions have been associated with decreased functional brain connectivity between the inferior frontal gyrus (part of system 2) and the putamen (part of system 1) during goal-directed effort for food rewards (Duif et al., 2020). A complementary mechanism can be reasoned through evidence of sensation transference (Spence and Gallace, 2011), affective priming (Tay and Ng, 2019), or embodied cognition (Zhu and Meyers-Levy, 2005), all in which the ambient sounds physiologically change consumers' interoceptive, reward, and emotional responses (Salimpoor et al., 2011; Liu et al., 2018; Kantono et al., 2019).

Conceptual Framework

The evidence highlighted thus far conveys that our food cravings are driven by how we internally are able to regulate our valuation and decisions processes (system 1 or system 2), but at the same time, sensory distractions, such as ambient noise, are also influencing our cognitive resources and emotional states necessary for controlling and managing these behaviors. This implies that the underlying mechanisms of food-related decision-making are based on an integration of exteroceptive sensory inputs and interoceptive bodily states (Petit et al., 2016; Papies et al., 2020), that translate our somatic signals into feelings of

anticipation, desires, or cravings (Bechara et al., 2005; He et al., 2019).

To understand these different, yet possibly interacting factors, on a behavioral as well as neural level, the employment of implicit psychophysiological measures can be advantageous. One approach to assess this is through EEG. In addition to the measurement of electrophysiological activity response to a specific single time-locked stimulus or event as in ERP research (Shang et al., 2018), longer-lasting and continuous functional indices of neural activity are also possible via EEG (Fernandez Rojas et al., 2020; Firestone et al., 2020; Diao et al., 2021). Here, the EEG signal can be decomposed into various frequency spectra representing the oscillatory dynamics in the brain and correlated with certain mental processes (Barlaam et al., 2011; Diao et al., 2017; Aoh et al., 2019). In fact, the power spectral density (PSD) in specific frequency bands, e.g., theta (4–8), alpha (8–12 Hz), and beta (12–25 Hz), have been associated with various distinct cognitive and emotional states during food viewing (Tashiro et al., 2019; Biehl et al., 2020) and music/noise listening (Gleiss and Kayser, 2014; Chabin et al., 2020).

In the decision and cognitive science literature, both theta and alpha activity in frontal and parietal regions are commonly linked to measures of cognitive load, i.e., the used amount of working memory recourses (Stipacek et al., 2003; Antonenko et al., 2010; Brouwer et al., 2012), including focused attention and sensory processing (Cabañero et al., 2019). Particularly, spectral theta power has been found to increase with sustained concentration and task difficulty (Gevins and Smith, 2003), while alpha oscillatory activity has been associated with alertness (Kamzanova et al., 2014) and cognitive fatigue (Borghini et al., 2012). Likewise, a large body of evidence suggests that augmented PSD in the beta frequency band is related to active and analytical thinking (Zhang et al., 2008) as well as short-term memory (Palva et al., 2011) and mental workload (Coelli et al., 2015). Of course, delta and gamma band power have also been explored in the context of human behavior (Posada-Quintero et al., 2019), yet they are less related to cognitive and mental workload in decision research (Fernandez Rojas et al., 2020).

Instead, frontal lateralization, commonly referred to as frontal asymmetry (FA; Ramsøy et al., 2018), especially in the alpha frequency range, FA has been employed as an index of mental engagement, reward anticipation, and incentive salience and shown to converge with BOLD activity in frontal cortices (Gorka et al., 2015). In particular, greater right (vs. left) frontal hemispheric alpha power is indexed by a positive frontal alpha asymmetry (FAA) score, denoting emotional motivation and approach, whereas a negative FAA score is linked to avoidance and withdrawal behavior (van Bochove et al., 2016; Fischer et al., 2018). Preliminary evidence even suggests that FAA functions as a potential biomarker for affective neuromodulation (Sun et al., 2017). FAA might therefore be a useful measure for studying affective states and cognitive processes in response to multisensory stimuli.

In short, EEG frequency patterns can be an excellent tool and for measuring the underlying brain dynamics of food-related and managerial decision-making processes. Through spectral analyses, it offers an implicit, objective, and nuanced quantification of cognitive load and related emotional processes, which is not restrained by introspection, verbalization, or any other subjective and self-report limitations.

Similarly, measurements based on the sympathetic activity in the peripheral nervous system, including electrodermal activity (EDA), also referred to as galvanic skin response (GSR) can generate complementary biometric information of these affective processes. That is, EDA amplitude amplification, thereby higher EDA peak probability has been used to capture increased emotional arousal states. With increased sympathetic activity due to interoceptive or exteroceptive triggers, sweat production is elevated, leading to heightened/lowered skin conductance/resistance as an indication of elevated arousal (Kytö et al., 2019; Verastegui-Tena et al., 2019; Pedersen et al., 2021), as determined by the circumplex model of affect (Russell, 1980).

In light of the empirical framework, we here investigated the influences of self-regulatory decision strategy and ambient noise level on cue-induced food cravings by means of neurophysiological activity. We adapted an EEG-based ROC task (Kober et al., 2010b; Meule et al., 2013) in which participants should either focus on the long-term consequences or the immediate rewards of eating high-caloric palatable foods while listening to either soft or loud levels of restaurant noise. We hypothesized that both noise level and decision perspective would affect subjective food cravings as well as objective measures, including EDA and EEG, as measures of emotional arousal/motivation and cognitive load (**Figure 1**). Specifically, we expected, as a result of increased emotional arousal and motivation as well as cognitive load, that loud noise would potentially diminish the cognitive resources requisite for more top-down processing, important for especially thinking about future consequences associated with the food. To test this, we examined the PSD in the theta, alpha, and beta frequency bands in the fronto-cortical areas, FAA, as well as EDA during cognitive regulation in the presence of ambient noise and visual food presentation.

MATERIALS AND METHODS

Participants

Thirty-seven healthy Danish university students aged 18–35 years were recruited through the Sona recruitment system at the Cognition and Behavior (COBE) Lab, Aarhus University, Denmark.[1] The choice of sample size was based on previous EEG literature employing similar designs (n = 25; Meule et al., 2013; n = 28; Biehl et al., 2020; n = 19; Tashiro et al., 2019). As this is the first study implementing these conditions/manipulations, we computed a hypothetical power calculation in G*power (Faul et al., 2009). This yielded a required sample size of at least 28 participants at a power of 0.95, effect size of 0.1, and α of 0.05. All participants fulfilled the screening criteria and reported having a normal or corrected-to-normal hearing, normal or corrected-to-normal vision without color blindness, no food allergies, no dietary restraints, and no cardiovascular

[1] https://aucobe.sona-systems.com/default.aspx?logout=Y

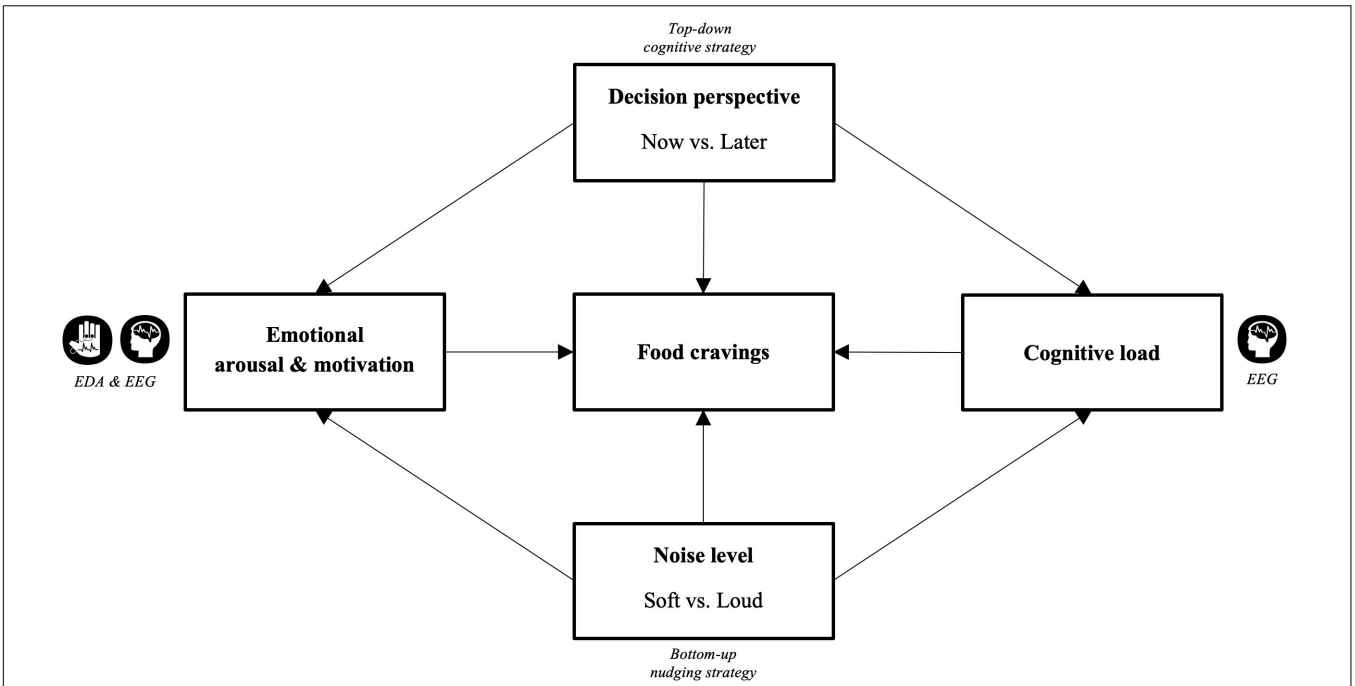

FIGURE 1 | Conceptual framework. Exploring the effects of top-down cognitive strategy (now vs. later decision perspective) and bottom-up nudging strategy (soft vs. loud ambient restaurant noise) on food cravings by means of cognitive load (EEG), emotional motivation (EEG), and emotional arousal (EDA).

or neurological diseases. One participant was omitted from the analysis due to unacceptable data quality, resulting in a valid sample size of 36 (mean age ± SD = 24.22 ± 3.59 years; mean BMI ± SD = 23.52 ± 3.90 kg/m^2; 50% females) all of whom provided written informed consent. The study was approved by the Aarhus University Ethics Committee (approval number: 2020-0184772) and conducted in accordance with the ethical standards laid out in the Declaration of Helsinki. All participants were compensated monetarily for their participation (250 DKK).

Regulation of Craving Task

The ROC task experimentally measures the specific causal effect of regulation strategies and self-management on craving, as well as allows to study its underlying neural mechanisms. The original ROC used images of cigarettes and unhealthy foods to induce cravings among cigarette smokers (Kober et al., 2010a). In our adapted version, we exclusively focused on high-calorie food items as craving cues. During each trial of the adapted ROC task (**Figure 2**), participants were exposed to one of these cues, preceded by the instruction to follow one of two decision perspectives: "now"—focus on the immediate sensations and feelings associated with consuming the food (e.g., it will taste good and satisfy my cravings), or "later"—focus on the long-term negative consequences associated with repeated consumption (e.g., it will increase my risk for weight gain and heart disease). Participants were then asked to rate their craving for the specific food they just saw ("how much do you crave this food?"), using a 1 (not at all) to 5 (very much) visual analog scale (VAS). The now or later instructions were presented for 3,000 ms and the subsequent food image for 5,000 ms. Between each trial, a jittered 2,000–2,400 ms fixation cross was inserted. We implemented 60 different trials (30 now-trials and 30 later-trials) per experimental block, which was repeated for each of the two sound conditions (soft noise vs. loud noise), resulting in a total of 120 trials in the experiment. Trials were presented in a randomized order and blocks were counterbalanced across participants. The adapted ROC task was programmed in the iMotions software (Copenhagen, Denmark)[2].

Self-Regulation of Eating Behavior Questionnaire

The 5-item Self-Regulation of Eating Behavior Questionnaire (SREBQ) is a measure of eating self-regulatory capacity (Kliemann et al., 2016). The SREBQ assesses people's capacity to control and manage their eating behavior in order to achieve and/or maintain their eating intentions. We adapted the original SREBQ into a Danish version using back-translation. The total score cut-off points include < 2.8 = low self-regulation, 2.8–3.6 = medium self-regulation > 3.6 = high self-regulation.

Visual Stimuli

Thirty high-resolution standardized high-caloric food images from the *Full4Health Image Collection* (Charbonnier et al., 2016) were selected for the current study ($\text{mean}_{\text{calorie}}$ = 384 kcal/100 g; mean_{fat} = 21 g/100 g). The images were balanced in terms of taste, such that 15 images were categorized as sweet food items and 15 as savory food items (**Table 1**). The images were taken in a closed 60 × 60 × 60 cm cubic photo tent. Two

[2]https://imotions.com

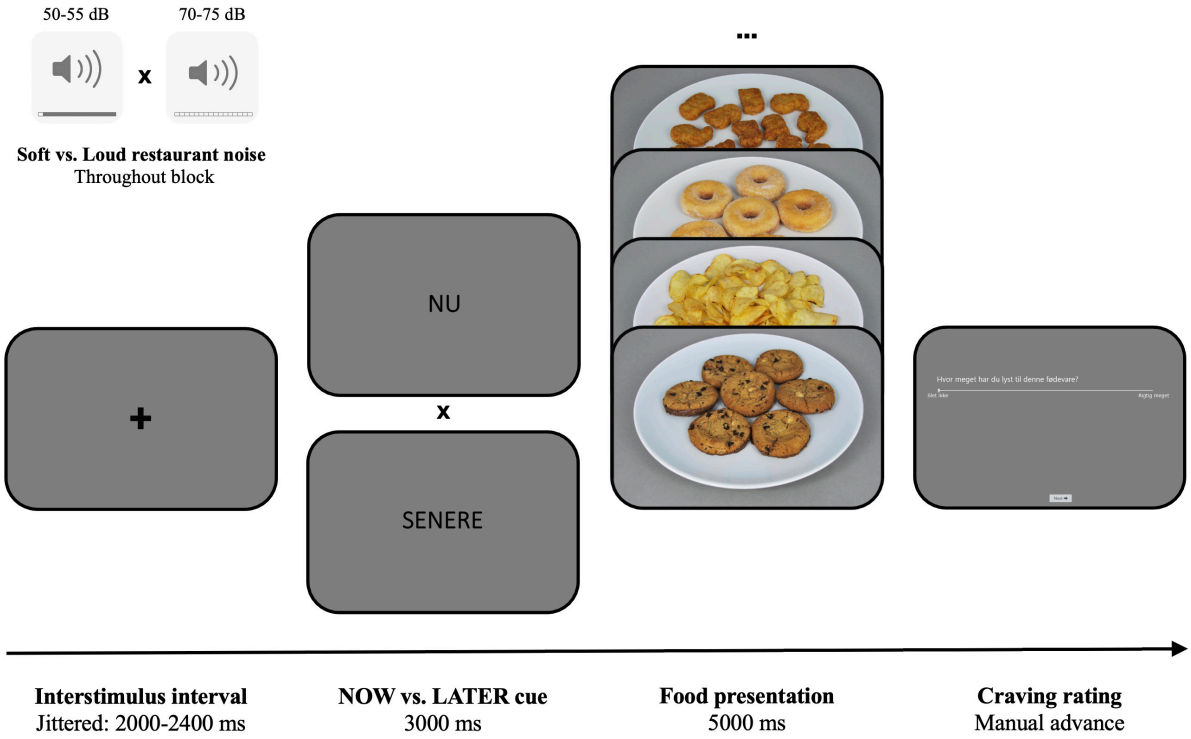

FIGURE 2 | The adapted ROC task. Before each trial, a jittered inter-trial interval (fixation cross) is presented for 2–2.4 s. Then either a now or later cue (nu or senere in Danish) is shown for 3 s, followed by 5 s exposure of a high-calorie food item. Finally, participants rate how much they want the presented food on a VAS from "not at all" to "very much." Either soft or loud noise is played in the background throughout the entire block.

daylight lamps (E27/55W) were used to create optimal lighting conditions. The lens angle was approximately 45°, the distance from center plate to center tripod was 39.5 cm, and the height of the center of the camera on the tripod was 38 cm to resemble the viewing of a plate of food on a table during mealtime. Each food was presented on a white plate with a diameter of 17.0 cm. A light gray background was chosen to ensure sufficient contrast between plate and background. To standardize the background, MeVisLab (MeVis Medical Solutions AG, Bremen, Germany) and the open-source registration software Elastix[3] were used (Klein et al., 2010). Each plate was segmented, registered on a standardized background from one image, and smoothened on the plate edges. The complete photographing protocol is described in Charbonnier et al. (2016).

Auditory Stimuli

Two versions of a restaurant noisescape (chattering and tableware noises) retrieved from Freesound[4] were used for the study. The volume level of the noisescape was manipulated based on the Loudness Unit Full Scale (LUFS) by the European Broadcast Union (EBU) standards (European Broadcast Union, 2016). To attain a soft volume version, the noisescape was decreased to approximately –30 LUFS, while the loud version was increased to approximately –4 LUFS via Logic Pro Version 10.6.1 (Apple Inc.). This was done to ensure the sound intensity (dB) matched 50–55 dB (soft) and 70–75 dB (loud) after audio calibration. The volume levels were chosen based on prior research, which has indicated sound at 80 dB leads to negative affect and even loss of hearing, and sound below 50 dB is often not detected (Witt, 2008). Furthermore, previous food-sound studies have used sound/noise levels in similar ranges (Woods et al., 2011; Biswas et al., 2019). The two noisescapes were first validated in a separate online test (N = 91) in which participants listened to each version and rated them in terms of relaxation/arousal on a VAS from 1 to 9. Soft restaurant noise (mean rating ± SD = 4.27 ± 2.25) was expectably perceived as being more relaxing (vs. arousing) compared to loud restaurant noise (mean rating ± SD = 7.49 ± 1.04). The final noisescapes used for the study can be heard at: https://soundcloud.com/danni-peng-li/sets/eeg-roc-t-sound-study.

Design and Procedure

To control for possible hunger effects, participants were asked to fast for 2 h (i.e., no food intake but water intake was allowed) and refrain from consuming alcoholic drinks for 24 h prior to the study (Frank et al., 2010; Hume et al., 2015; Zhang and Seo, 2015). On testing days (between 9 am to 5 pm), participants arrived at the laboratory for a 1.5 h session where they were informed about the study procedure and provided written informed consent. Participants were seated 70 cm from the HP EliteDisplay E243i, 24," 16:10 monitor (screen resolution of 1,920 × 1,080 pixels),

[3]http://elastix.isi.uu.nl/
[4]https://freesound.org

TABLE 1 | Calorie and fat content per 100 g of the 30 food images included in the study.

Food item	Taste category	Calorie (kcal/100 g)	Fat (g/100 g)	Image no.
Potato crisps (natural)	Savory	541	33.5	1
Spring rolls	Savory	181	8.2	10
Chicken nuggets	Savory	272	17.1	12
French fries	Savory	306	14.3	16
Nacho-cheese tortilla chips	Savory	487	22.3	24
Pepper potato crisps	Savory	544	33.0	122
Croissants	Savory	424	23.0	130
Wotsits cheesey (chips)	Savory	547	33.0	185
Pizza Bolognese	Savory	234	9.5	245
Paprika chips	Savory	544	33.0	316
Cheese burgers	Savory	246	12.0	317
Pita with doner	Savory	218	14.0	318
Turkish pizza with doner	Savory	233	10.0	319
Pizza margarita	Savory	251	12.3	321
French fries with ketchup	Savory	268	11.9	322
Donuts with icing	Sweet	416	27.8	25
Chocolate chip cookies	Sweet	500	25.0	26
Milk chocolate	Sweet	546	32.5	32
Chocolate nuts	Sweet	584	42.1	36
Brownies	Sweet	401	20.0	43
Whipped cream pie	Sweet	350	25.0	44
Mini donuts	Sweet	358	21.1	100
Pancakes	Sweet	196	4.9	101
Syrup waffles	Sweet	473	19.3	109
Cake with chocolate	Sweet	450	25.0	112
Strawberry pie	Sweet	205	11.0	117
Cake	Sweet	424	23.9	118
Round pastry/danish	Sweet	315	9.0	289
Knoppers	Sweet	548	33.4	302
Prince biscuits	Sweet	469	17.0	304
Average		*384*	*21*	

Image no. refers to the Full4Health Image Collection numbering (Charbonnier et al., 2016).

while EEG and EDA electrodes were applied while checking signal quality in the iMotions software. No natural light entered the room (i.e., only artificial LED light). To reduce movement artifacts participants rested their heads on a chinrest attached to the table. During the paradigm introduction, participants were instructed to minimize head movements throughout the recordings. They also rated how hungry they were on a 9-point VAS. They then completed 4 practice trials to familiarize themselves with the task. After ensuring that participants understood the procedure, they initiated the two counterbalanced experimental blocks (conditions) of the adapted ROC-task—one block with soft ambient restaurant noise and one block with loud ambient restaurant noise—with a 5 min break between blocks and an optional break within each block. The adapted ROC task was followed by a manipulation check, i.e., arousal, valence, and distraction ratings of the noisescapes on a 9-point VAS, as well as completion of the SREBQ. Finally, demographic information was collected.

Signal Processing

EEG data were collected from 32 Ag/AgCl electrodes (Fp_1, Fz, F_3, F_4, FT_9, FC_5, FC_7, C_3, T_7, TP_9, CP_5, CP_1, Pz, P_3, P_7, O_1, Oz, O_2, P_4, P_9, TP_{10}, CP_6, CP_2, Cz, C_4, T_8, FT_{10}, FC_6, FC_2, F_4, F_8, Fp_2) placed according to the 10–20 system using actiCap (Brain Products GmbH, Gilching, Germany) with a sampling rate of 500 Hz. Raw EEG data were filtered (Butterworth) with a zero phase-lag band-pass filter [0.5–100 Hz] and a zero phase-lag notch filter (50 Hz), re-referenced to the mastoid reference electrode placed at TP9. Artifacts were then rejected using an artifact threshold [120 μV] based on the absolute signal value. Power spectra analysis was computed using Fast Fourier Transform (FFT; Welch method; Welch, 1967), by splitting pre-processed data into 1-s time windows with an overlap of 50% and submitted to the FFT, resulting in one power spectrum per 0.5 s. Finally, theta, alpha, and beta activities were calculated by averaging the power spectral density within the standard power bands: theta [4–8 Hz], alpha [8–12 Hz], and beta [12–25 Hz] (**Figure 3B**). We focused on a hypothesis-based region of interest (ROI) by clustering the frontal electrodes (Fp_1, Fz, F_3, F_4, FT_9, FC_5, FC_7, FT_{10}, FC_6, FC_2, F_4, F_8, Fp_2; **Figure 3A**). This electrode clustering was chosen based on previous literature showing various cognitive processes related to the multiple frontal regions as described in the "Introduction" section as well as to avoid loss in statistical power (Moazami-Goudarzi et al., 2008). Furthermore, FAA scores were computed using two frontal electrodes (F_3 and F_4) on each hemisphere using the formula according to Allen et al. (2004):

$$Frontal\ Alpha\ Asymmetry\ (FAA) = \ln(\frac{\alpha_{F_4}}{\alpha_{F_3}})$$

EDA data was collected from two analog electrode channels placed on the tip of the fingers using a Shimmer3 GSR+ (Shimmer Sensing, Dublin, Ireland). The phasic signal was extracted using a median filter over a time window of 8,000 ms, and a low-pass Butterworth filter with a cutoff frequency of 5 Hz was applied to the phasic signal. Peak onset thresholds [0.01 μS] and offset thresholds [0 μS] were then detected on the phasic signal. EDA peak amplitude threshold was set at 0.005 μS with a minimum peak duration of 500 ms. All physiological measures were enclosed to a time window of 5 s, i.e., during food presentation in order to capture audiovisual stimulations of food and noise. Signal processing steps for EEG and EDA were carried out in iMotions through an integrated R algorithm.

Data Analysis

All physiological and behavioral data were imported and analyzed in R version 4.0.2 for Mac OS. A manipulation check was performed using a pairwise *t*-test based on VAS ratings to ensure that the two soundscapes were in fact perceived differently in terms of arousal (1 = very relaxing; 9 = very arousing), valence (1 = very pleasant; 9 = very unpleasant), and distraction (1 = not distracting at all; 9 = very distracting).

To investigate the effects of ambient noise and cognitive regulation strategy on EEG, EDA, and self-reported cravings,

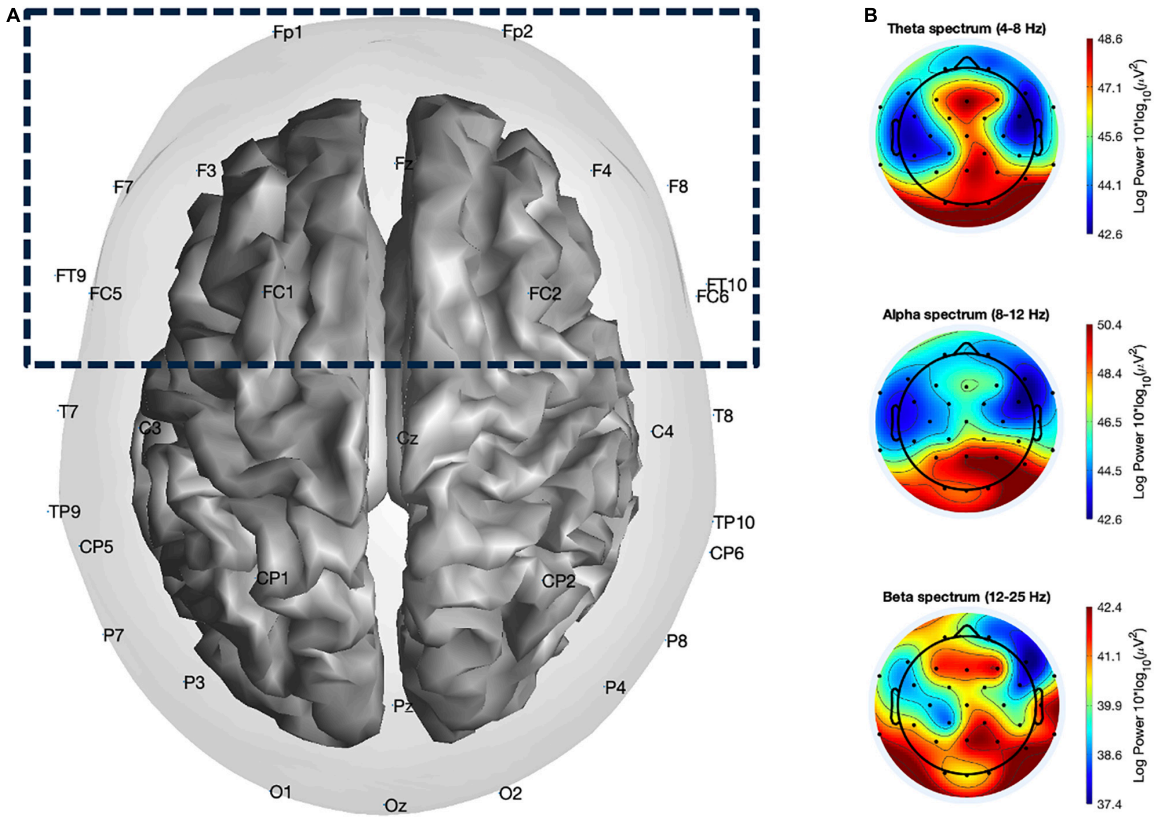

FIGURE 3 | Illustration of **(A)** channel locations of the 32 electrodes with the frontal ROI highlighted, including Fp_1, Fz, F_3, F_4, FT_9, FC_5, FC_7, FT_{10}, FC_6, FC_2, F_4, F_8, Fp_2, and **(B)** example topographical maps of theta (4–8 Hz), alpha (8–12 Hz), and beta (12–25 Hz) power band activity across conditions.

we carried out generalized linear mixed models (GLMMs) via the *glmer()*-function of the *lme4* package. The GLMMs account for the hierarchical structure, non-independence of observations from individual participants in the repeated measure design, and to satisfy the normality assumptions without transformation. EEG and craving data were fitted using a *Gaussian* distribution with the *restricted maximum likelihood* (*REML*) method (Heller et al., 2016), while EDA peak detection was fitted using *Poisson* distribution (Bolker et al., 2009). In all models, the independent variables were noise level (soft vs. loud) and decision perspective (now vs. later), which were coded as fixed effects. Participant ID entered the model as a random effect. Furthermore, we controlled for possible confounds by adding BMI, hunger status, and SREBQ scores as covariates to the models. However, none of the covariates contributed significantly to any of the models, and as we did not have any *a priori* hypotheses regarding these factors, they were therefore removed from the analyses [BMI_{theta}: $F_{(1, 34)} = 0.39$; $p = 0.538$; BMI_{alpha}: $F_{(1, 34)} = 0.26$; $p = 0.614$; BMI_{beta}: $F_{(1, 34)} = 0.21$; $p = 0.653$; $Hunger_{theta}$: $F_{(1, 34)} = 1.45$; $p = 0.237$; $Hunger_{alpha}$: $F_{(1, 34)} = 0.33$; $p = 0.567$; $Hunger_{beta}$: $F_{(1, 34)} = 3.35$; $p = 0.076$; $SREBQ_{theta}$: $F_{(1, 34)} = 0.11$; $p = 0.738$; $SREBQ_{alpha}$: $F_{(1, 34)} = 0.53$; $p = 0.470$; $SREBQ_{beta}$: $F_{(1, 34)} = 0.46$; $p = 0.502$]. The dependent variables of interest included frontal theta power, frontal alpha power, frontal beta power, FAA, EDA peaks, and food craving. Omnibus tests were carried out to test the main effects and interactions between the fixed independent variables. If a significant interaction was indicated by the GLMM, Tukey's HSD *post hoc* tests were performed to explore the corrected pairwise comparisons.

Finally, to theorize our conceptual model, we computed four conjoint multiple mediation analyses using the *lavaan* structural equation modeling package (Rosseel, 2012). Noise level and decision perspective, respectively, entered the models as the binary independent/exogenous variables, craving as the dependent/endogenous variable, and measures of cognitive load (frontal theta power, frontal alpha power, and frontal beta power) as well as emotional arousal (EDA) and emotional motivation (FAA) as the mediators. The multiple mediation analyses were carried out using bootstrapping procedure with the *DWLS* estimator for 1,000 bootstrapped samples.

RESULTS

Manipulation Check

In terms of arousal, the loud noise (mean rating ± SD = 7.22 ± 1.37) compared to the soft noise (mean rating ± SD = 3.99 ± 1.71) was perceived as being significantly more arousing [vs. relaxing; $t_{(35)} = 10.98$; $p < 0.001$]. For valence, the soft noise (mean rating ± SD = 4.03 ± 1.60) compared to

the loud noise (mean rating ± SD = 6.88 ± 1.64) was likewise perceived as being significantly more pleasant [vs. unpleasant; $t_{(35)} = 8.53$; $p < 0.001$]. Finally, with regard to distraction, the loud noise (mean rating ± SD = 7.57 ± 1.34) compared to the soft noise (mean rating ± SD = 3.73 ± 1.81) was perceived as being significantly more distracting [$t_{(35)} = 12.86$; $p < 0.001$].

Behavioral Analysis

The GLMM did not detect any significant interaction, but a main effect of decision perspective was observed with food cravings being reportedly significantly stronger in now (vs. later) -trials [$F_{(1,\ 4222)} = 1{,}032.92$; $p < 0.001$; **Table 2** and **Figure 4**].

Electroencephalography Power Spectral Analysis

For frontal theta power, the GLMM indicated a significant interaction effect between noise level and decision perspective [$F_{(1,\ 4222)} = 5.49$; $p = 0.019$; **Table 3** and **Figure 5A**]. *Post hoc* analyses showed that only in the loud noise condition, the theta band power was stronger for later (vs. now) decisions [$z_{(1609)} = 2.72$; $p = 0.033$]. The GLMM for frontal alpha power did not detect any significant interaction but, a main effect of both noise level and decision perspective was observed with alpha band power being stronger during the loud noise [$F_{(1,\ 4222)} = 10.59$; $p = 0.001$] and later decision perspective [$F_{(1,\ 4222)} = 16.49$; $p < 0.001$] conditions (**Table 3** and **Figure 5B**). Similarly, the GLMM for frontal beta power did not detect any significant interaction, but a main effect of noise level was observed with beta band power being stronger in the loud noise condition [$F_{(1,\ 4222)} = 12.86$; $p < 0.001$; **Table 3** and **Figure 5C**]. Finally, for FAA, the GLMM did not detect any significant interaction, but a main effect of decision perspective was observed with FAA being higher in the later decision perspective condition [$F_{(1,\ 4222)} = 6.08$; $p = 0.014$; **Table 3** and **Figure 5D**].

Biometric Analysis

The EDA-based GLMM did not detect any significant interaction, but a main effect of noise level was observed with a higher probability of EDA peak threshold during loud (vs. soft) noise [$z_{(4122)} = 3.27$; $p = 0.001$; **Table 4** and **Figure 6**].

Multiple Mediation Analysis

Figure 7 illustrates all of the regression coefficients between independent variables and the mediators as well as the pathways from the mediators onto the dependent variable. With noise level ($_{NL}$) as the independent variable, the mediation analysis indicated that the standardized indirect effects of neither cognitive load measures (frontal theta power, frontal alpha power, and frontal beta power) nor emotional measures (EDA and FAA) were significant, although frontal alpha power denoted a trend ($a_{NL2}{}^{*}b_2$; β = 0.01; $z = 1.76$; $p = 0.079$). Similarly, the direct effect of noise level on cravings was insignificant (c_{NL}'; β = 0.02; $z = -1.34$; $p = 0.179$). With decision perspective ($_{DP}$) as the independent variable, the mediation analysis signified that the standardized indirect effects of frontal alpha power were significant ($a_{DP2}{}^{*}b_2$; β = 0.01; $z = 1.95$; $p = 0.050$), while the remaining mediators were not. Once this mediator was accounted for, there was still a significant direct effect of decision perspective on cravings (c_{DP}'; β = –0.41; $z = 30.69$; $p < 0.001$), suggesting

TABLE 2 | Overview of the GLMM omnibus tests for self-reported cravings.

Craving			
Fixed effects	*F*	*df*	*p*
Noise level	2.16	1, 4230	0.141
Decision perspective	1,032.92	1, 4222	< 0.001***
Noise level × Decision perspective	0.24	1, 4222	0.623

****p < 0.001.*

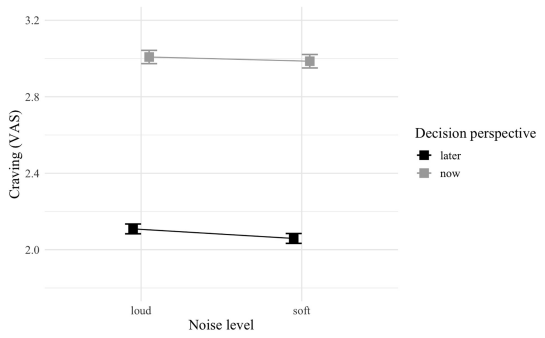

FIGURE 4 | Interaction plot of self-reported cravings between noise level (soft vs. loud) and decision perspective (now vs. later). Error bars represent standard error.

TABLE 3 | Overview of the GLMM omnibus tests for frontal theta power, frontal alpha power, frontal beta power, and frontal alpha asymmetry.

EEG frontal theta power			
Fixed effects	*F*	*df*	*p*
Noise level	0.31	1, 4222	0.576
Decision perspective	2.18	1, 4222	0.140
Noise level × Decision perspective	5.49	1, 4222	0.019*
EEG frontal alpha power			
Fixed effects	*F*	*df*	*p*
Noise level	10.59	1, 4222	0.001**
Decision perspective	16.49	1, 4222	<0.001***
Noise level × Decision perspective	2.05	1, 4222	0.152
EEG frontal beta power			
Fixed effects	*F*	*df*	*p*
Noise level	12.86	1, 4222	<0.001***
Decision perspective	1.35	1, 4222	0.245
Noise level × Decision perspective	1.29	1, 4222	0.257
EEG frontal alpha asymmetry			
Fixed effects	*F*	*df*	*p*
Noise level	1.92	1, 4222	0.166
Decision perspective	6.08	1, 4222	0.014*
Noise level × Decision perspective	0.55	1, 4222	0.457

**p < 0.05; **p < 0.01; ***p < 0.001.*

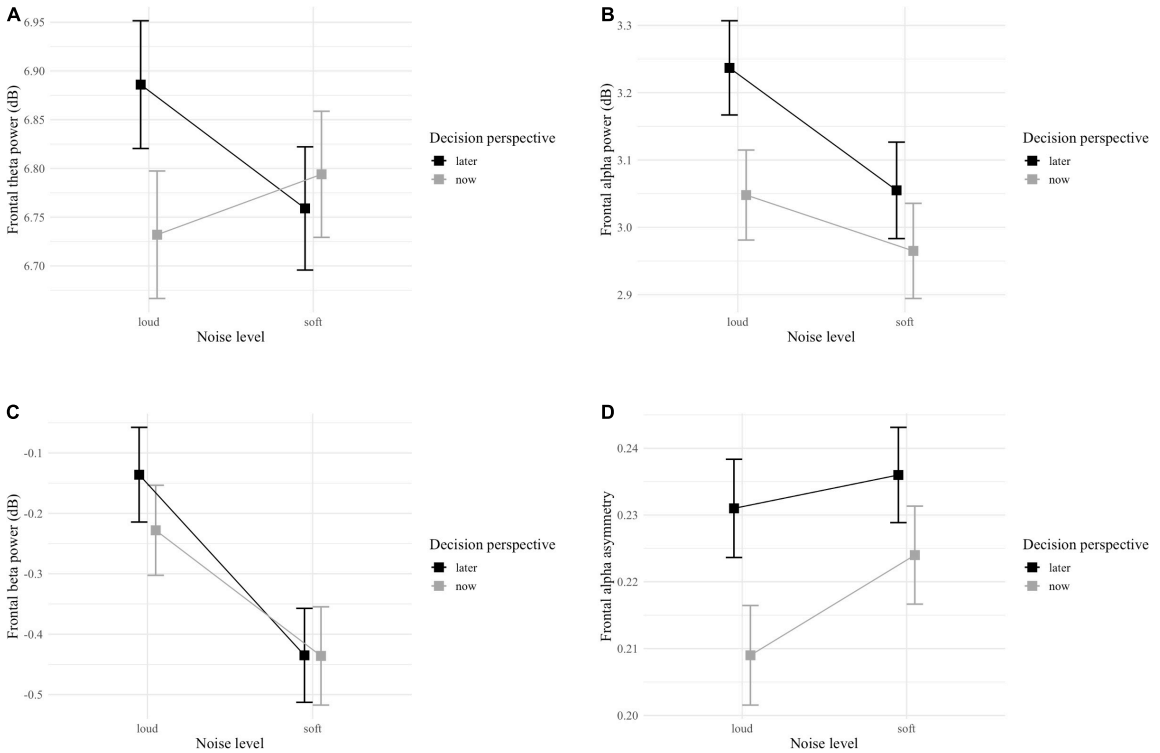

FIGURE 5 | Interaction plots of **(A)** frontal theta power, **(B)** frontal alpha power, **(C)** frontal beta power frontal, and **(D)** alpha asymmetry between noise level (soft vs. loud) and decision perspective (now vs. later). Error bars represent standard error.

TABLE 4 | Overview of the GLMM omnibus tests for EDA peaks.

EDA peaks			
Fixed effects	*z*	*df*	*p*
Noise level	3.27	4122	0.001**
Decision perspective	0.15	4122	0.874
Noise level × Decision perspective	0.87	4122	0.384

*$^{**}p < 0.01$.

a partial mediation effect of the frontal EEG alpha power on self-reported food cravings.

DISCUSSION

While a body of psychiatric and neuroscientific research has investigated the impact of top-down cognitive strategies, self-regulation, and managerial decision-making on the neurophysiological underpinnings of food cravings, empirical findings in sensory and consumer science have shown that bottom-up auditory nudging strategies can also influence eating motivation and food valuation. In the current study, we explored both avenues in a single experimental paradigm employing an adapted version of the ROC task.

Our findings do not only provide direct support for our hypothesis that prospectively thinking about long-term consequences can effectively reduce food cravings as demonstrated in Kober et al. (2010a), but simultaneously our results suggest that the underlying causal mechanisms of these self-regulated cravings may at least partially be explained through frontal brain oscillations. That is, the multiple mediation analysis signified a partial mediation effect of decision perspective on self-reported cravings through frontal alpha power. This denotes that in particular augmented activity in the alpha frequency range is associated with increased cravings of high-calorie foods and potentially unhealthy eating behavior. Additionally, irrespectively of behavioral ratings, we found that during delayed (vs. immediate) gratification of food rewards, i.e., in later-trials, the PSD in both the theta and alpha frequency spectra as well as FAA were increased.

This is in line with previous neuroimaging research using the ROC, which has shown increased BOLD activation in frontal regions associated with cognitive control, including the dmPFC, dlPFC, and vlPFC (Kober et al., 2010b). A hyperactivation of these regions might therefore denote cognitive overload (Matsuo et al., 2007). In fact, structural MRI studies have consistently reported reduced gray matter volume in these frontal regions (Horstmann et al., 2011; He et al., 2013) as well as lower structural connectivity between frontal and limbic structures associated with decision-making, reward, and interoceptive awareness (Gupta et al., 2015; Peng-Li et al., 2020c) in individuals with elevated impulsivity and poorer self-regulation abilities. An EEG study by Meule et al. (2013) also found larger LPP amplitude (350–550 ms after onset)—an ERP component commonly linked

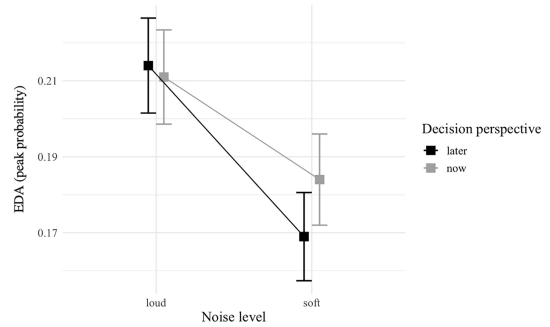

FIGURE 6 | Interaction plot of EDA peaks between noise level (soft vs. loud) and decision perspective (now vs. later). Error bars represent standard error.

to attention capture (Zorjan et al., 2020) and emotion regulation (Hajcak et al., 2010).

Likewise, empirical findings in consumer neuroscience, popularly referred to as neuromarketing, have utilized FA and FAA to objectively quantify consumer behaviors (Bazzani et al., 2020), such as willingness to pay (Ramsøy et al., 2018), hedonic food valuation (van Bochove et al., 2016), and attention biases (McGeown and Davis, 2018). This suggests that FAA cannot only be used as a measure of cognitive engagement but also as an emotional valence marker denoting affective and reward processes, including anticipatory pleasure and incentive salience ("wanting"). Although, one might expect that the FAA ought to be greater during now-trials due to closer reward proximity and delayed discounting, the manifestation of the opposite pattern can be reasoned through higher incentive salience and valuation of health benefits. That is, participants may have considered the future rewards of controlling their consumption of unhealthy foods in the presence. Nevertheless, this evidence, across different neuroimaging modalities and metrics, suggests increased cognitive demand and emotional engagement, especially when actively deliberating on long-term consequences (system 2) rather than simply evaluating immediate rewards in the present (system 1).

Importantly, these psychophysiological processes may be even more intensified during exteroceptive sensory inputs and distractions including ambient noise, as the increased theta activity in the later-trials was only occurring in the presence of loud (vs. soft) ambient noise. Correspondingly, alpha activity was also augmented during the loud noise condition, yet serving as a main (and not interaction) effect. As theta and alpha waves are arguably the power spectra mostly associated with cognitive/work load and attention (Klimesch, 1996; O'Keefe and Burgess, 1999; Stipacek et al., 2003; Antonenko et al., 2010; Brouwer et al., 2012; Wang et al., 2019), a combination of reflective system 2 thinking during prospective thinking and environmental auditory disturbances requires the most cognitive resources.

However, the power of the cerebral oscillations in the higher beta frequency spectra was not affected by decision perspective but solely augmented in the loud noise condition. Salisbury et al. (2002) similarly observed that background noise increased the latency of the P300 component, even while performance was unaffected. In an EEG review, Blume et al. (2019) have highlighted the elevated resting-state beta activity in fronto-central regions in individuals with obesity and binge-eating disorder. The authors argued that this increased beta activity may be the manifestation of the hyper-awareness of food cues and

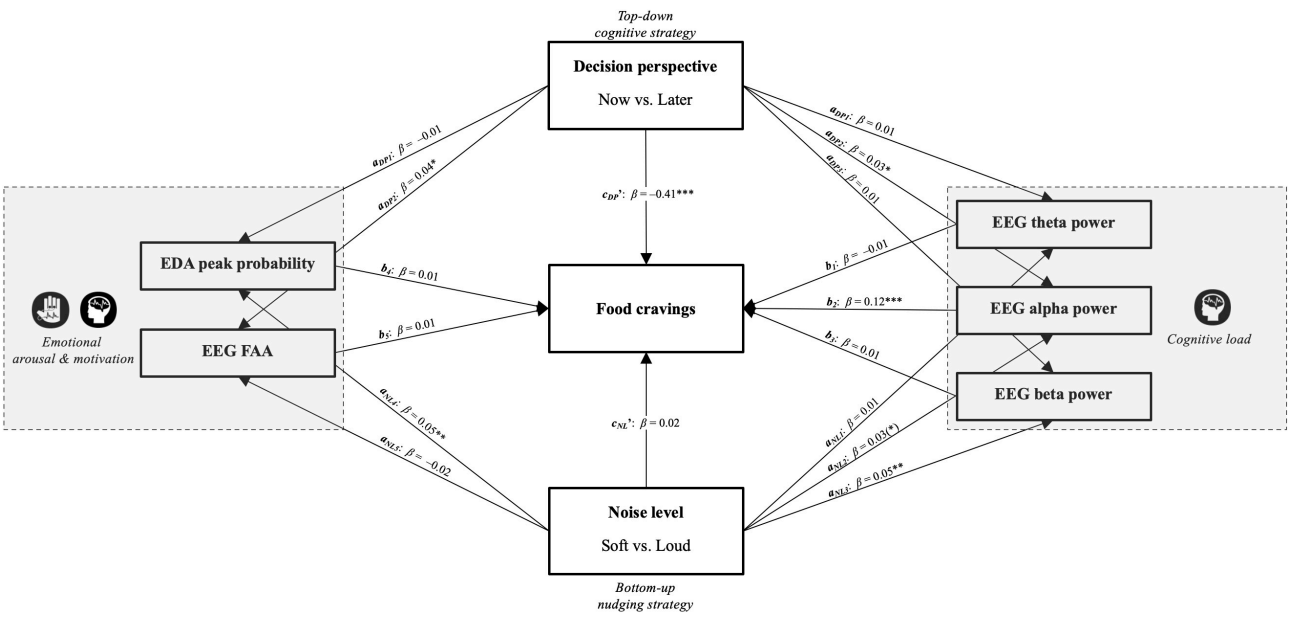

FIGURE 7 | Diagram of the multiple mediation analyses based on our conceptual framework in **Figure 1** with noise level ($_{NL}$) and decision perspective ($_{DP}$) as the independent variables, cravings as the dependent variable, and frontal theta power, frontal alpha power, frontal beta power and EDA as the mediators. Paths are shown with standardized regression coefficients and *p*-values (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

maladaptive eating behavior. Through deductive reasoning and in light of these collateral findings in combination with the results from the present study, it can be inferred that excessively loud noise indeed has neurophysiological impacts. This is measured by means of augmented beta activity, which in turn may provoke adverse effects on food-seeking behavior, even though we did not establish that link between beta activity (only alpha) and behavior (cravings) in the mediation analysis.

In addition, we found that the probability for EDA peak detection was also higher during the exposure to loud noise, indicating elevated arousal state (Salimpoor et al., 2011; Kantono et al., 2019). Louder noise may lead to a more stressful mindset that in turn diminishes the cognitive resources requisite for processing and making more rational and healthy decisions (Caviola et al., 2021). In contrast, when consumers are not interrupted by loud restaurant noises, they are in a more relaxed psychological state, which places them in a better position of restraining and managing their irrational and unhealthy food choices (Peng-Li et al., 2021). In fact, fast tempo and high volume of sound, both of which elevate physiological arousal (Liu et al., 2018; Biswas et al., 2019), have been reported to reduce one's cognitive abilities, such as decision accuracy (Day et al., 2009), task performance (Nagar and Pandey, 1987), and creative thinking (Mehta et al., 2012).

Altogether, the findings are partly in line with our hypothesis that both noise level and decision perspective would influence subjective food cravings and objective measures, including EDA and EEG. However, we did not observe that the manipulations of both noise level and decision perspective had an impact on all measures. Indeed, alpha activity was affected by both loud noise and prospective thinking and could even predict food cravings based on the mediation analysis. Theta activity was influenced by the interaction of these, i.e., only loud noise and later decision perspective. Yet, beta activity and EDA peak probability were solely determined by noise level, while FAA and food cravings were influenced by decision perspective only. Hence, it can be inferred that louder noise and prospective thinking strategy can at least to some degree elevate neurophysiological constructs of emotional arousal and motivation as well as cognitive load, but will not necessarily help consumers regulate and manage their ultimate subjective food cravings.

Managerial Implications

Due to the interdisciplinary nature and methodological novelty of our study, the results have several translational implications both clinically and commercially. First, we have demonstrated that food cravings could be restrained effectively merely via a single cognitive strategy involving deliberately devaluing the immediate rewards and delaying one's gratification for future and long-term health benefits. Thus, we build on the previous literature that has incorporated cognitive strategies to highlight the use of interoceptive regulation and managerial decision-making in food (Kober et al., 2010b; Meule et al., 2013; Boswell et al., 2018) and other substance (Kober et al., 2010a; Naqvi et al., 2015; Suzuki et al., 2020) cravings, which collectively reinforces the theoretical foundation for practically implementing these measures in clinical contexts to help individuals who exhibit maladaptive eating behaviors.

Secondly, the identified underlying neurophysiological mechanisms by which top-down self-regulation alleviates cravings, are essential for understanding people's subconscious and at times suboptimal eating behaviors. In addition, by applying exteroceptive auditory manipulations that analogously affect these fronto-cortical brain oscillations, we emphasize the importance of the power of a well-engineered acoustic environment. Hence, managers and other practitioners, who are at least partly responsible for the consumer, could try to establish eating atmospheres that reinforce healthier eating behavior by reducing stress, arousal and mental load (Doucé and Adams, 2020). Especially, in the times of COVID-19, in which several patients have suffered from anosmia (i.e., loss of smell) and/or ageusia (i.e., loss of taste), focusing on other attributes of the food, such as the texture, could help regaining the hedonic eating experience (Høier et al., 2021). Broaden out, one could also imagine that auditory cues, both intrinsic (i.e., the inherent sound of the food) and extrinsic/contextual (e.g., background music), might sensorily compensate for the loss of olfactory and gustatory perception.

Finally, with the current study being a cross-over between sensory and consumer science and cognitive neuroscience, the framework of the experiment in itself advocates the relevance of robust multidisciplinary research in decision sciences. Particularly, there has been increasing employment of neuroimaging procedures and biometric measurements in (food) market research (Knutson et al., 2007; Plassmann et al., 2008; Clement et al., 2013; Motoki and Suzuki, 2020), and neuromarketing and neuroeconomics have received considerable attention in both the scientific community and the media (Platt and Huettel, 2008; Ariely and Berns, 2010; Plassmann et al., 2012; Zhang et al., 2019). Thus, with the implementation of both EEG and EDA measurements, the study is of commercial and managerial interest. These tools can offer objective quantitative insights beyond traditional subjective and explicit methods that may be constrained by introspection and verbalization. From an industrial management perspective, consistent utilization of such multimodal methods might enable valid forecasting about consumers' intentions, behaviors, and ultimately purchases. At the same time, it would at least to some degree increase reproducibility and circumvent the consequences of the replication crisis (Chives, 2019). Yet, to optimally exploit this attention and potential, while preventing it from becoming a mere marketing gimmick, academics in the respective fields should exploit their experience and ask relevant questions that can in fact provide useful inputs to marketers and managers in addition to conventional marketing research.

Limitations

Despite these abovementioned implications, our study involves several limitations. First, it should be noted that the physiological signal analyses were based on rather conservative pre-processing procedures due to the employment of the integrated R algorithm of iMotions. This implicates inflexible parameter adjustments during data pre-processing of EEG and EDA. The EEG signal

was referenced to a single mastoid instead of e.g., two mastoids or an average reference, but lateralized metrics, such as FAA can be prone to confounds (Lei and Liao, 2017). Analogously, we could not carry out scrutinized eye-blink detection, manual removal of single trials or events, nor independent component analysis (ICA), but only rely on the simple automated algorithm. Notably, according to a methodological review by Allen et al. (2004), for some spectral computations (e.g., FAA), artifact thresholding alone might be as adequate as using other manual accessorial procedures, such as electrooculography (EOG) and electromyography (EMG).

Secondly, due to the nature of our controlled experimental setup, our findings cannot necessarily be directly generalized to naturalistic food choice settings (Andrade, 2018) in which multiple other external factors (including price, labeling, and social factors) may affect the consumers' emotional states, cognitive processing, and behaviors (Sørensen et al., 2013; Spence et al., 2014; Petit et al., 2015). Besides, albeit food cravings are strong predictors of eating behavior and food choice (Boswell et al., 2018; Chen et al., 2018; Sun and Kober, 2020), we cannot assure that these independent results encompass ecological validity and are applicable in a real-life managerial decision context.

Thirdly, we did not incorporate any neutral/silent condition, which could have strengthened the comparability within the study, as done in some previous food, sound, and decision research (Alamir et al., 2020; Peng-Li et al., 2020a). However, the longer design could have been time-consuming and fatiguing for the participants. Besides, one could argue that the soft noise condition would serve as a control condition since complete silence is highly unlikely in a normal eating situation.

Finally, we simply confined our EEG analyses to the frontal part of the brain through theta, alpha, and beta activity based on our conceptual framework. While, several studies have investigated the oscillatory power in other or smaller ROIs (Tashiro et al., 2019; Biehl et al., 2020) as well as other frequency bands (i.e., delta and gamma; Colrain et al., 2009; Dimigen et al., 2009) during mental operations, we chose not to, as the analyses would be unreasonably extensive and outside the scope of our framework.

CONCLUSION

To conclude, the present study has underlined the combined effects of cognitive regulation and ambient restaurant noise on food cravings through EDA peak probability as well as fronto-cortical brain oscillations as quantitative measures of emotional arousal, motivation, and cognitive load. More broadly, we have highlighted the prospect of and need for considering both interoceptive states and exteroceptive cues, while employing different physiological measurements to more holistically, objectively, and optimally study food-related decision-making that can provoke an actual societal and managerial impact. This is not solely confined to the field of sensory and consumer neuroscience, but for any decision sciences, this seems applicable and highly pertinent.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Aarhus University Ethics Committee (approval number: 2020-0184772). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DP-L: conceptualization, methodology, formal analysis, investigation, resources, data curation, project administration, writing—original draft, writing—review and editing, and visualization. PA: conceptualization and writing—review and editing. CC: investigation and writing—review and editing. RC: writing—review and editing and supervision. DB and QW: conceptualization, writing—review and editing, and supervision. All authors contributed to the article and approved the submitted version.

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The Effectiveness of Price Promotions in Purchasing Affordable Luxury Products: An Event-Related Potential Study

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Similar to traditional luxuries, affordable luxuries enjoy a high level of perceived product quality and perceived social status, but the effectiveness of price promotions of purchasing affordable luxury products is different from that of traditional luxuries. In order to further investigate the purchases of affordable luxuries, we used event-related potential (ERP) technology to reveal the formation of the purchase intention toward affordable luxuries at original prices (high or low) and current prices (discounted or non-discounted). Compared with the high-priced affordable luxury without a price promotion and the low-priced affordable luxury with a price promotion, consumers showed a stronger intention toward the high-priced affordable luxury with a price promotion, by weighing up three factors, perceived product quality, perceived social status, and perceived monetary saving at the behavioral level. A shorter reaction time emerged in the price promotion condition than in the absent price promotion condition when the original price was low. At the neural level, a decrease in N2 amplitude was found in the high original price and discounted current price condition than the high original price and non-discounted current price condition and the low original price and discounted current price condition, respectively, suggesting that the price information of the latter two conditions might not be the expectation information of subjects, and thus, the enhanced conflict is produced. The high-priced affordable luxury product without a price discount evoked a more positive LPP amplitude than the high-priced affordable luxury product with price promotions or than the low-priced affordable luxury item without price promotions, demonstrating that participants could regard the former as an evaluative inconsistent condition and the latter as evaluative consistent conditions. These results are helpful to better understand the effects of price promotions on purchasing affordable luxury products at different original prices.

Keywords: affordable luxuries, price promotions, event-related potentials, N2, LPP, consumer neuroscience

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INTRODUCTION

Traditional luxuries are products of high quality and high price, and it makes consumers feel socially superior (Mazzocco et al., 2012) and proud (Bellezza and Keinan, 2014). Traditional luxuries tend to combine high perceived prestige with extremely high price premiums. In contrast, affordable luxury products are sold at reasonable price premiums for mass and still enjoy a neutral

and reasonable level of perceived prestige (Silverstein and Fiske, 2005). Thus, affordable luxuries are more accessible for middle-class or lower-class consumers (Truong et al., 2009).

There are some similar findings for traditional and affordable luxury consumption. Compared with necessities, consumers think that affordable luxuries representing a signal of economic power have the same goods characteristics (such as high quality, high priced, and exclusive) as the traditional luxuries (Mundel et al., 2017). Not only for traditional luxuries but also for affordable luxuries, the self-monitoring and need for uniqueness can predict a consumer's attitude toward a brand (Ajitha and Sivakumar, 2019): self-monitoring in association with social identity can positively affect social-adjustive attitude toward a brand (Shavitt et al., 1992) and need for uniqueness involving self-image and social representation can also positively affect value-expressive attitude (Vigneron and Johnson, 2004). High-order social and psychological desires, as one of the most influential factors, can drive both traditional (Wiedmann et al., 2009) and affordable luxury purchases (Shahid et al., 2021).

On the other hand, there is a potential difference between traditional and affordable luxuries in terms of the influence of price promotions. Price promotion as one of marketing promotions is often employed by companies and can increase perceived monetary savings (e.g., Chandon et al., 2000). However, a price promotion sometimes cannot spur the demand for goods. People who are high in need for status exhibit a negative attitude toward a luxury hotel and have less intention of returning to a hotel when a price promotion is presented, but it is not the case in consumers who are low in need for status (Yang et al., 2015). The reason for the results is that the former group's people regard price exclusivity for luxury hotel as a means of signaling his or her wealthy identity (Han et al., 2010) but the price promotion can make a luxury hotel more accessible to the masses. In contrast, offering a price discount for, respectively, a low-priced room in a luxury hotel can increase booking behavior (Jang and Moutinho, 2019). The price of this type of room is more reasonable for the masses. Consumers enjoy a reasonable level of perceived social status, and they place a greater weight on the benefit of luxury accommodation and amenities. As mentioned above, the main difference between traditional and affordable luxuries is price. Therefore, affordable luxury products are similar to a low-priced room in a luxury hotel, and price promotions have a positive influence in promoting the purchases of affordable luxury. Additionally, Jang and Moutinho (2019) showed that the effectiveness of price promotions in booking behavior depends on the extent to which consumers perceive social status for luxuries. Only when perceived social status is high is price promotion effective. Considering that perceived social status is positively related to the price of affordable luxuries (Truong et al., 2009), when the original price of affordable luxuries is high, the need for social status could be met first, and price promotions could increase perceived monetary savings to promote purchases; when the original price is low, perceived social status is also low, and thus, even if price promotions mean monetary savings, the savings could not influence purchase intention. In sum, the higher the original price of affordable luxuries, the more effective the price promotion is, and the moderation effect could be mediated by perceived social status.

To further investigate these effects, we have had insight into neural mechanisms underlying behaviors on affordable luxury items. Specifically, two aspects are considered: how price promotion information is processed for high-priced and low-priced items, respectively, and what ultimately determines consumers' final purchase decision.

Event-related potentials (ERPs) as a noninvasive scalpoimaging technique was applied to provide information about the timing of brain activities in the present study. The ERP technique can measure a participant's response effectively and objectively, and it is much more inexpensive than the other neuroscience techniques, such as functional magnetic resonance imaging (fMRI), position emission topography (PET), and event-related magnetic fields (ERMFs), thus, more accessible to many researchers. ERPs can provide a window into consumer behaviors and is helpful for marketing researchers and professionals.

Two ERP components, N2 and late positive potential (LPP) were considered in the study. N2 is a negative-going ERP component, peaking between 200 and 400 ms post-stimuli. The component is related to cognitive conflict (Folstein and Van Petten, 2008). For example, in the go/no-go paradigm, participants have to respond to one stimulus (go response) and do not to the other stimulus (no-go response). When the no-go stimulus is presented, this produces conflict between go response and no-go response and leads to an increase in N2 amplitude (Bruin and Wijers, 2002). More recent work about consumer neuroscience showed that although consumers show a preference for hedonic products with mixed promotion (a combination of price discount and donation to charity), they anticipate more negative pure price promotion to reject purchases (Mei et al., 2021). Thus, when the positive promotion information is presented, conflict and a higher N2 amplitude emerge. Actually, discrepancy for N2 amplitude between conditions depends on decision pattern. Subjects tended to purchase high-quality products, leading to conflict for the product information with risk of low quality (Wang et al., 2016; Jin et al., 2017). Participants wanted to reject purchases, producing anticipation conflict in the more positive mixed promotion (Mei et al., 2021). In the go/no-go paradigm, subjects wanted to make a manual response, and thus, a higher N2 amplitude was elicited in the no-go condition (Bruin and Wijers, 2002). As mentioned above, consumers could anticipate that price promotions emerge in high-priced affordable luxuries rather than in low-priced ones. Therefore, when the original price is high, a non-discounted current price could produce conflict and leads to an increase in N2 amplitude compared with a discounted price; when the original price is low, there could be no difference between the price promotion condition and the absent price promotion condition in N2 amplitude.

Late positive potential (LPP), a member of the P300 family, is a positive component that peaks approximately 600 ms post-stimuli. A body of research demonstrates that this ERP component is related to the evaluative properties of stimuli. For example, both positively and negatively affective stimuli can elicit an enhanced LPP amplitude compared with neural stimuli

(Hajcak and Olvet, 2008). During online purchase decision, participants categorized online reviews into consistent positive reviews, consistent negative reviews, and inconsistent reviews (Chen et al., 2010). Two types of consistent reviews as higher evaluation categorizations evoke a larger LPP amplitude than inconsistent reviews. Besides, this cognitive process of evaluative categorization is sensitive to a preceding context as well (e.g., Cacioppo et al., 1993; Ito et al., 1998). Using the oddball paradigm, Dhont et al. (2012) created the sequence counting one target within a context of some context stimuli. When participants were instructed to indicate the valence of stimuli (positive or negative), the valence category of target, which is inconsistent with one of context stimuli (e.g., positive target and negative context stimuli), led to an enhancement of LPP amplitude than the consistent target regardless of political target words and non-political ones (Dhont et al., 2012). In a sequential priming paradigm, subjects have to pay attention to the first stimuli (the prime) and indicate the pleasantness of the second stimuli (the target). A larger LPP can be observed for evaluatively incongruent stimuli (i.e., pleasant–unpleasant, unpleasant–pleasant) than evaluatively congruent stimuli (i.e., pleasant–pleasant, unpleasant–unpleasant) (Zhang et al., 2010; Herring et al., 2011). During the current experiment, the original price was presented first and then the current price was presented. High original price meaning high social status (Truong et al., 2009) serves as positive stimulus; meantime price promotions could be effective, suggesting that a non-discounted current price serves as a negative stimulus, and a discounted price serves as a positive stimulus. Therefore, when the original price is high, a non-discounted current price could produce inconsistent evaluation compared with a discounted current price and a non-discounted current price could lead to a larger LPP; low original price meaning low social status serves as positive stimulus; meantime price promotions could be ineffective, suggesting that both a non-discounted price and a discounted price serve as negative stimuli. Therefore, there could be no difference between the price promotion condition and the absent price promotion in LPP amplitude.

In summary, we predict that the original price of affordable luxuries could moderate the effectiveness of price promotions, and the effect could be mediated by perceived social status. We expect that the moderation effect of original price could be manifested in N2 and LPP amplitudes.

MATERIALS AND METHODS

Participants

Twenty right-handed female graduate students (mean age: 24.10, S.D. = 1.12) who were familiar with the preselected luxury brand and had purchased the luxury brand products were recruited. The brand is targeted at women, and thus, we only recruited female participants. These subjects were all native Chinese speakers and had normal or corrected-to-normal vision with no history of neurological disorders or mental diseases. The study was approved by the institutional review board, and written informed consent was provided before the experiment. The data of one participant was discarded due to excessive artifacts.

Experimental Stimuli

To avoid the effect of consumer preference for different items, only one Coach handbag with high sales was used from the official flagship store of Coach in Taobao, which is one of the largest online retailers in China. Coach is a popular affordable luxury brand around the world (Wang, 2013; Wang and Qiao, 2020). Two pictures including the front and the back of this handbag were created and processed to the size of 300 × 270 pixels. In total, there are 12 stores in this experiment and their names are represented by English letters from A to L (totaling 12). In Taobao, the prices of products in other stores are often lower than that in the official flagship store. Therefore, based on the original price (4,900 yuan, approximately 760 dollars) in the official flagship store, eight kinds of different prices, 4,820, 4,830, 4,840, 4,850, 4,860, 4,870, 4,880, and 4,890 yuan, in other stores were regarded as high price, and the other eight kinds of different prices, 2,820, 2,830, 2,840, 2,850, 2,860, 2,870, 2,880, and 2,890 yuan, were regarded as low price. To check the manipulation of this factor, a questionnaire was conducted before the experiment, and it consisted of two questions: to what extent do you agree that a Coach handbag with the price range of 4,820 to 4,890 is a high-priced item, and to what extent do you agree that a Coach handbag with the price range of 2,820 to 2,890 is a low-priced item (where 1 = "not at all agreeable" and 7 = "extremely agreeable")? Confirming the manipulation, the ratings of two questions were larger than the midpoint of the questionnaire of four ($ps < 0.05$). In order to make a decision easily and quickly, the difference between the discounted price and the corresponding original price was 1,000 yuan according to offers from past shopping festivals. The stimuli contained 64 pairs of product pictures with the original and the present price information, i.e., 2 pictures × 16 categories of original price information (including eight kinds of high-priced information and eight kinds of low-priced information) × 2 price promotion conditions (present or absent). Each pair of stimuli was repeated three times, and thus, there were 192 trials in the entire experiment.

Procedure

Participants sat in a comfortable chair in a sound-attenuated room 80 cm away from the 23-inch monitor (1,360 × 768 pixels, 60 Hz). A keyboard was provided for participants to input appropriate choices. The Psychophysics Toolbox (Brainard, 1997) was used to control the stimuli and to acquire the behavioral data.

Prior to the formal experiment, participants were informed to image that they had a stable job with a high income and tended to purchase one Coach handbag during the Double 11 shopping festival. They needed to indicate their purchase intention according to price information from different stores. Double 11 is one of the biggest shopping festivals in China. As such, participants were willing to trust that the discounted price in this festival is true.

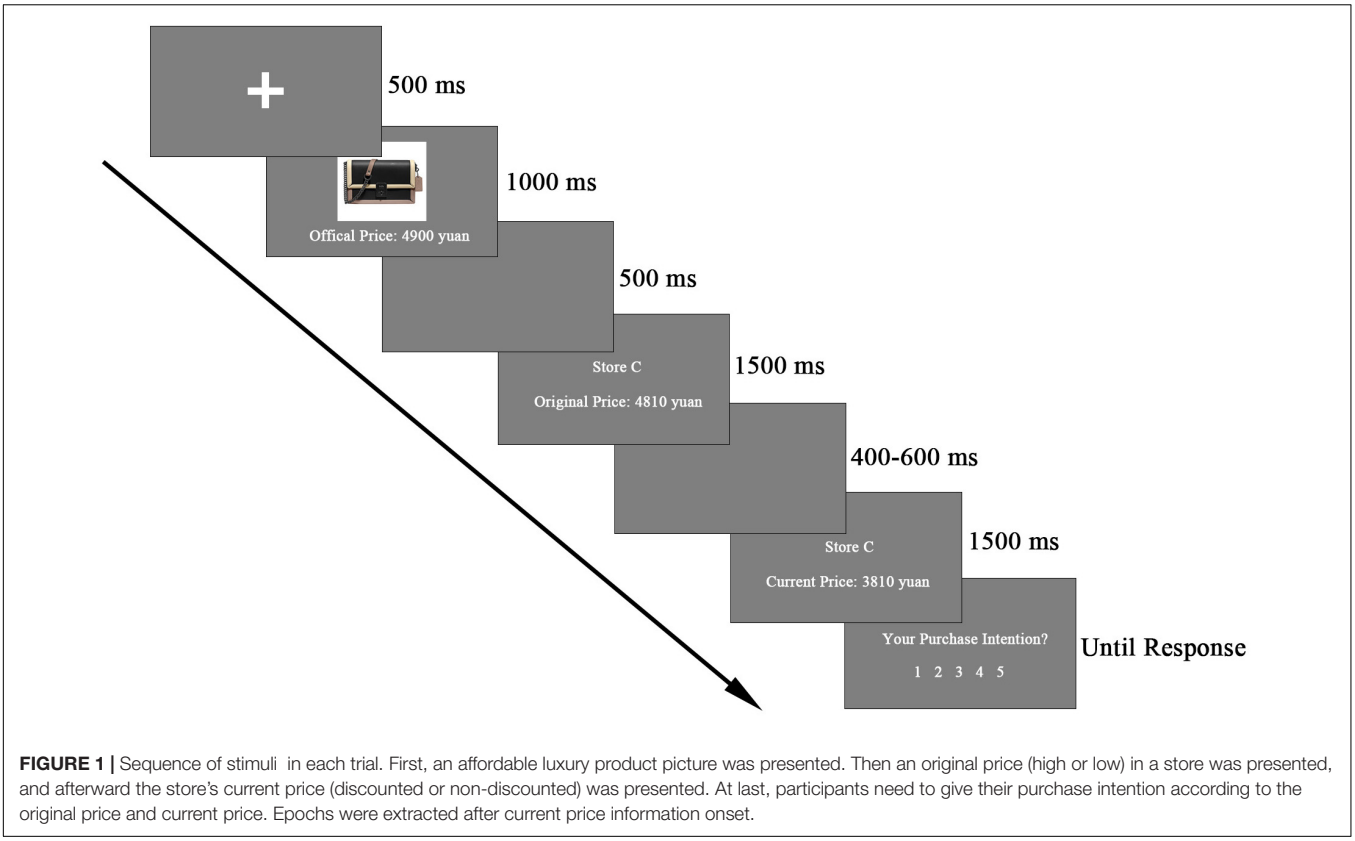

FIGURE 1 | Sequence of stimuli in each trial. First, an affordable luxury product picture was presented. Then an original price (high or low) in a store was presented, and afterward the store's current price (discounted or non-discounted) was presented. At last, participants need to give their purchase intention according to the original price and current price. Epochs were extracted after current price information onset.

Figure 1 illustrates the trial structure. Each trial began with a fixation cross presented for 500 ms. Following the fixation, an affordable luxury product picture along with the official price information was displayed against a gray background for 1,000 ms and was then replaced by an empty screen for 500 ms. The first presentation of official price aims to decrease individual difference. Specifically, if the official price subjects estimated were higher (lower) than the actual official price, they would probably serve all the original prices as low (high) price. Thus, to decrease this effect, the official price presented first in this experiment can provide the subjects with a reference to judge whether the original price was high or low in a clearer way. Afterward, the original price information was presented for 1,500 ms, with the phrase "Original Price" and the price placed right below the store name, followed by a blank screen ranging from 400 to 600 ms. Then the discounted price information was displayed for 1,500 ms. In this stimulus, the presentation was similar to the original price information stimulus. Finally, subjects have to rate the purchase intention for this offer in the store on a five-point scale (1 = I do not want to purchase the item with this offer at all, 5 = I really want to purchase the item with this offer). Each store name was randomly presented 16 times, and all trials were randomly classified into four blocks.

After the experiment, participants were instructed to complete a rating task. For different-priced affordable luxury products (high-priced vs. low-priced) with a price promotion or without, they have to, respectively, rate perceived monetary savings, perceived quality, and perceived social status. Perceived monetary savings was accessed with three items (α = 0.97): "I really save money by buying this coach handbag," "I feel that I am getting a good idea by buying this coach handbag," and "I really spend less by buying this coach handbag" from Chandon et al. (2000). Perceived quality was addressed with five items (α = 0.98): "The likelihood that this coach handbag would be reliable is very high," "The workmanship of this coach handbag would be very high," "This coach handbag should be of very good quality," "The likelihood that this coach handbag is dependable is very high," and "This coach handbag would seem to be durable" from Dodds et al. (1991). Perceived social status was accessed with three items (α = 0.97): "Buying this coach handbag means wealth," "Buying this coach handbag is a social status symbol for me," "Buying this coach handbag is a symbol of success and prestige," and "Buying this coach handbag is to show off or to be noticed" from Correia et al. (2018).

Electroencephalogram Recording and Analysis

Electroencephalogram (EEG) was recorded with a Brain actiCHamp amplifier (Brain Products GmbH, Munich, Germany) at 64 scalp sites using Ag/AgCl electrodes attached to an elastic cap. All scalp electrodes were referenced on-line to the Cz site. The electrodes placed supra- and intra-orbital to both eyes and lateral to the outer canthi of both eyes

were used to measure the electrooculogram (EOG). Electrode impedances were kept below 10 kΩ. EEG signals were sampled at a rate of 500 Hz.

BrainVision Analyzer 2.1 (Brain Products) was used to preprocess the EEG signals. Off-line low-pass filter was 30 Hz (24 dB/Octave) and the average of left and right mastoid recording as an offline reference. EOG artifacts were corrected by the independent component analysis (ICA) method in the Analyzer program. The epoch was extracted from 200 ms before the onset of current price information to 800 ms after its onset. Epochs with a maximum difference between two adjacent voltage points > 75 μV were rejected. The EEG recordings for each subject were averaged for the four conditions (2 categories of original price × 2 categories of current price).

Based on the visual inspection of the grand average waveforms and the neuroscience research mentioned in the introduction, the 270- to 330-ms time window and 10 electrodes (F3, F1, Fz, F2, F4, FC3, FC1, FCz, FC2, and FC4) in the frontal-central area were specified for the N2 component, the 550- to 700-ms time window and 10 electrodes (CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, and P4) in the central-parietal area were specified for the LPP component. Repeated-measure analyses of variance (ANOVAs) were performed for behavioral data and ERP data. The Greenhouse–Geisser correction was used when necessary (uncorrected d*f* was reported with the ε and corrected *p*-value). All values of purchase intention, reaction time, mean scores of questionnaire, and ERP amplitudes are expressed as mean ± SEM.

RESULTS

Behavioral Results

Behavioral results are shown in **Figure 2** and **Tables 1**–**3**. The purchase intention and reaction time were analyzed, respectively, by two-way 2 (original price: high vs. low) × 2 (price promotion: present vs. absent) repeated-measure ANOVAs. Regarding the purchase intention, two significant main effects of the original price [$F_{(1,19)}$ = 31.804, p < 0.001, η_p^2 = 0.626] and the price promotion [$F_{(1,19)}$ = 18.959, p < 0.001, η_p^2 = 0.499] and a significant interaction effect between these two factors [$F_{(1,19)}$ = 44.894, p < 0.001, η_p^2 = 0.703] were found. As a confirmatory follow-up, the simple effect analyses revealed that when the original price was high, participants showed stronger purchase intention to the affordable luxury product with a price promotion (4.353 ± 0.097) than that without (2.661 ± 0.203, p < 0.001) and that when the original price was low, there was no significant difference between the absent (2.273 ± 0.123) and present (2.144 ± 0.257, p = 0.599) price promotion conditions. As for the reaction time, there was a significant main effect of the price promotion [$F_{(1,19)}$ = 12.067, p = 0.003, η_p^2 = 0.388] and insignificant main effect of original price [$F_{(1,19)}$ = 0.368, p = 0.551]. The interaction effect was marginally significant [$F_{(1,19)}$ = 3.120, p = 0.093, η_p^2 = 0.141]. The simple effect analyses showed that when the original price was high, significant difference between absent (737.069 ± 53.924 ms) and present (680.799 ± 52.622 ms, p = 0.140) price promotion conditions was not found and that when the original price was low, subjects responded to the discounted price (648.322 ± 40.522 ms) more quickly than the non-discounted price (801.621 ± 73.399ms, p = 0.003).

As shown in **Table 1**, the mean score for each factor in the rating task was, respectively, collected in a 2 (original price) × 2 (price promotion) ANOVA. All the main effects were significant, whereas all interaction effects were insignificant. Perceived monetary savings in the low-priced product condition was higher than that in the high-priced product condition and there was an increase in the price promotion condition compared with the absent price promotion condition. Moreover, subjects perceived higher product quality and higher social status for both the high-priced affordable luxury product and the absent price promotion.

Furthermore, we used the linear mixed models (LMM) procedure in SPSS to show how the original price affects the effectiveness of price promotions. The LMM procedure extends the generalized linear model to allow for moderation and mediation analyses of repeated measurements (Kenny et al., 2003; Huang and Yuan, 2017). As mentioned in the *Introduction* section, we hypothesized that the influence of original price was mediated by perceived social status. To confirm this hypothesis, we took causal steps approach (Baron and Kenny, 1986; Huang and Yuan, 2017). Step 1: examining whether perceived social status can moderate the influence of perceived monetary savings on affordable luxury purchases. If the effect is significant, go to the next step. Step 2: examining whether the original price can influence perceived social status. If the effect is significant, go to the next step. Step 3: when considering the moderation effect of original price, examining whether perceived social status can moderate the influence of perceived monetary savings on affordable luxury purchases. If the effect is significant, the mediation effect of perceived social status would be significant. The results[1] (**Table 2**) supported the interaction effect hypothesis. The main relationships among these variables are shown in **Figure 3**. Additionally, a median split (median = 3.25) was used to divide perceived social status into two groups for further analyses. As shown in **Table 3**, when consumers perceived high social status, the effect of perceived quality was significant (b = 0.279, t = 2.778, p = 0.013), and the effect of perceived monetary savings was marginally significant (b = 0.193, t = 1.792, p = 0.087); both perceived quality and perceived monetary savings positively influenced purchase intention. When perceived social status was low, the effect of perceived monetary savings was marginally significant (b = −0.344, t = −1.882, p = 0.070), and the effect of perceived quality was insignificant (b = 0.245, t = 1.416, p = 0.169); perceived monetary savings negatively influenced purchase intention.

Event-Related Potential Results

The grand mean ERPs and the brain topographies are shown in **Figures 4**, **5**. The three-way 2 (original price: high vs. low) × 2 (price promotion: present vs. absent) × 10 (electrode)

[1]Since the original price influenced perceived quality, we also considered perceived quality as a mediator for analysis.

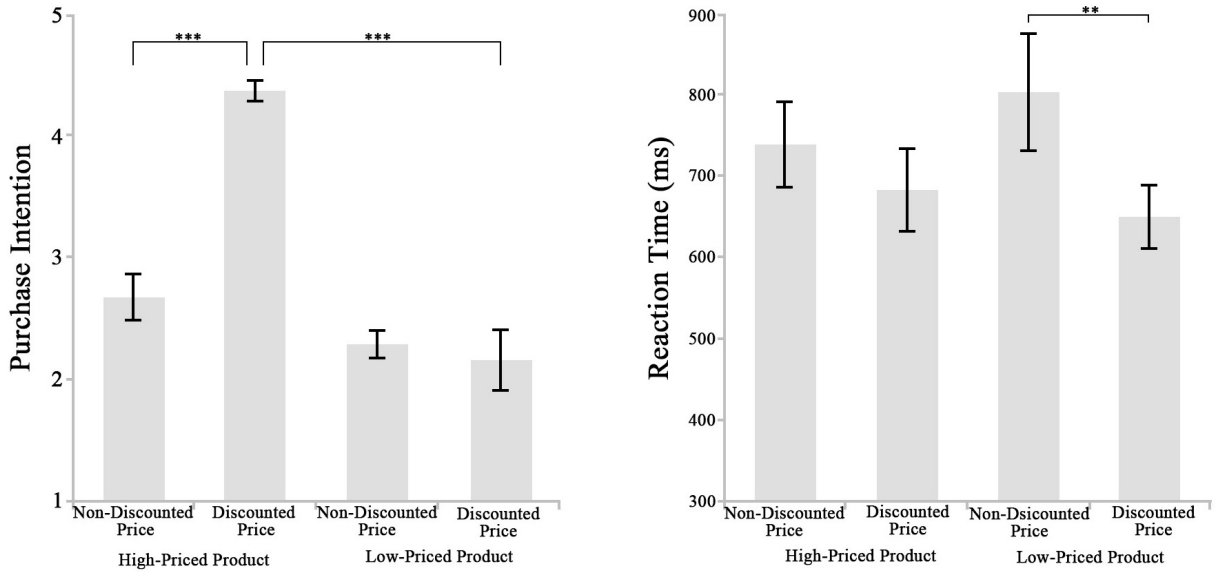

FIGURE 2 | Mean purchase intentions **(left)** and mean reaction times **(right)** for four conditions (high-priced product with discounted price or with non-discounted price, low-priced product with discounted price or with non-discounted price). The error bars suggest standard error of the mean. $^{**}p < 0.01$, $^{***}p < 0.001$.

TABLE 1 | The ANOVA results of the rating task.

	High-priced product		Low-priced product		Main effect of original price *F*(*p*)	Main effect of price promotion *F*(*p*)	Interaction effect *F*(*p*)
Price promotion	**Present**	**Absent**	**Present**	**Absent**			
Perceived monetary savings	3.42 ± 0.63	2.52 ± 0.81	6.30 ± 0.56	5.72 ± 0.60	342.295 (<0.001)	41.131 (<0.001)	2.660 (0.119)
Perceived quality	5.45 ± 0.82	5.95 ± 0.60	2.27 ± 0.74	2.89 ± 0.79	148.248 (<0.001)	45.003 (<0.001)	0.383 (0.543)
Perceived social status	3.86 ± 0.97	4.14 ± 0.80	2.13 ± 0.92	2.46 ± 0.75	44.126 (<0.001)	15.111 (0.001)	0.291 (0.596)

repeated-measure ANOVAs for N2 and LPP were conducted. The ANOVA of N2 revealed a marginally significant main effect on the original price [$F_{(1,18)} = 3.492$, $p = 0.078$, $\eta_p^2 = 0.162$] and a significant effect on the price promotion [$F_{(1,18)} = 6.017$, $p = 0.025$, $\eta_p^2 = 0.251$]. The interaction effect between the two conditions was marginally significant [$F_{(1,18)} = 3.116$, $p = 0.094$, $\eta_p^2 = 0.148$]. The simple effect analyses were conducted, which showed that when the original price was high, the N2 amplitude was more negative for the non-discounted price (-0.426 ± 0.527 μV) than the discounted price (0.414 ± 0.692 μV, $p = 0.021$) and that when the original price was low, the significant difference between the non-discounted (-0.805 ± 0.447 μV) and discounted prices (-0.684 ± 0.450 μV, $p = 0.595$) was not found.

The LPP result showed two significant main effects of the original price [$F_{(1,18)} = 5.422$, $p = 0.032$, $\eta_p^2 = 0.231$] and the price promotion [$F_{(1,18)} = 5.681$, $p = 0.028$, $\eta_p^2 = 0.240$] as well as the marginally significant interaction effect between the two factors [$F_{(1,18)} = 3.281$, $p = 0.087$, $\eta_p^2 = 0.154$]. As a confirmatory follow-up, the simple effect analyses revealed that in the high original price condition, the non-discounted price information evoked a higher LPP amplitude (2.522 ± 0.653 μV) than did the price promotion information (1.146 ± 0.608 μV, $p = 0.010$); in the low original price condition, the significant difference between the non-discounted (1.503 ± 0.642 μV) and discounted prices (1.337 ± 0.426 μV, $p = 0.718$) was not observed.

Because P2 and N400 amplitudes seemed different among four conditions in the frontal electrodes, we also conducted ANOVAs for these two components. The 160- to 220-ms time window was selected for P2, and the 380–440 ms was selected for N400. Ten electrodes (F3, F1, Fz, F2, F4, FC3, FC1, FCz, FC2, and FC4) were specified for P2 and N400. The results on P2 and N400 amplitudes showed that all the main and interaction effects were insignificant ($Fs < 2.55$, $ps > 0.12$).

DISCUSSION

The main purpose of the current study was to investigate price promotions' effects on purchasing affordable luxury products at different original prices and the neural mechanism underlying these behaviors. Although affordable luxuries are similar to traditional luxuries in many aspects, such as high quality and high social status, price promotions, as a common marketing strategy, do not cause consistent influences on these two types of luxury. Since price exclusivity can be regarded as a method of meeting

TABLE 2 | The linear mixed models (LMM) analysis results for mediation effect of perceived social status.

Dependent variable	Independent variable	*b*	*t*	*p*-Value
Purchase intention	Price promotions	1.013	4.79	< 0.001
	Original price	0.518	1.195	0.237
	Perceived monetary savings	−1.09	−3.194	0.004
	Original price × Perceived monetary savings	1.379	3.467	0.001
Perceived monetary savings	Price promotions	0.707	4.945	< 0.001
	Original price	−3.015	−20.879	< 0.001
Perceived social status	Price promotions	−5.253	−1.604	0.113
	Original price	1.397	9.015	< 0.001
Perceived quality	Price promotions	−0.317	−3.381	0.001
	Original price	1.776	19.001	< 0.001
Purchase intention	Price promotions	1.234	5.843	< 0.001
	Original price	−0.294	−0.637	0.527
	Perceived monetary savings	−1.041	−2.16	0.042
	Perceived social status	−0.266	−1.862	0.071
	Perceived quality	0.685	3.256	0.003
	Original price × Perceived monetary savings	1.399	2.112	0.043
	Perceived social status × Perceived monetary savings	−0.312	−1.828	0.073
	Perceived quality × Perceived monetary savings	0.217	0.958	0.343

TABLE 3 | The LMM analysis results for the groups of high perceived social status and low perceived social status.

	Independent variable	*b*	*t*	*p*-Value
High perceived social status	Price promotions	1.515	7.482	<0.001
	Perceived monetary savings	0.193	1.792	0.087
	Perceived quality	0.279	2.778	0.013
Low perceived social status	Price promotions	0.526	2.269	0.029
	Perceived monetary savings	−0.34	−1.882	0.07
	Perceived quality	0.245	1.416	0.169

the need for social status, the influences of price promotions on the high-priced and the low-priced affordable luxuries could be differential. In addition, to better understand the effectiveness of price promotions, we applied the ERP technique to give us a measure of the moment-by-moment brain activity to reveal the cognitive processing of different price information.

Behaviorally, higher purchase intention was found in the high-priced affordable luxury product with price promotions than in the high-priced affordable luxury product with non-discounted price, whereas the difference in purchase intension was not significant in the low-priced condition. The following rating task showed that consumers perceived higher quality, higher social status, and less perceived monetary savings in the high-priced product compared with the low-priced, as well as in the non-discounted price than the discounted price. Furthermore, the original price moderated the influence of perceived monetary savings on purchase intention to affect the effectiveness of price promotions. The moderation effect of original price was mediated by perceived social status: When perceived social status was high, both perceived quality and perceived monetary savings had positive influence on purchase intention; when perceived social status was low, perceived monetary savings had negative influence on purchase intention. Combining these results from the formal experiment and the post questionnaire, we contend that consumers need to weigh up three factors product quality, social status, and monetary savings when making a purchase decision. When affordable luxuries are high priced, consumers perceived high social status. In this condition, price promotions positively influence affordable luxury purchases and perceived monetary savings, and price promotions negatively affect perceived quality; meantime, perceived monetary savings and perceived quality positively promote purchases; by weighing up these relationships, consumers have a stronger purchase intention toward price promotions. When affordable luxuries are low priced, consumers perceived low social status. In this condition, price promotions positively influence affordable luxury purchases and perceived monetary savings, and price promotions negatively affect perceived quality; meantime, perceived monetary savings negatively promote purchases; by weighing up these relationships, consumers would not show preference to price promotions. In addition, we observed a significant effect of the price promotion in the reaction time for the low-priced affordable luxury product. Previous studies have suggested that the reaction time is positively associated with task difficulty and cognitive load (Sweller, 1988; Wang et al., 2016). A shorter reaction time was found in the price promotion condition than in the absent price promotion condition. It takes less cognitive effort for consumers to decide whether to buy a low-priced product with a price promotion. Although consumers display low purchase intention to a low-priced product no matter whether it is with a price discount or not, they could make it more likely to form a negative attitude toward a discounted price.

Regarding the ERP component, the amplitude of N2 may be indicative of cognitive conflict (Folstein and Van Petten, 2008). The conflict will emerge when expectation stimuli are not presented to participants in a body of consumer neuroscience research (e.g., Mei et al., 2021). In the current study, we obtained a marginally significant interaction effect between the original price and the price promotion, and the N2 amplitude was less negative in the high-priced affordable luxury item with a price promotion than in the high-priced affordable luxury item without a price promotion, but it is

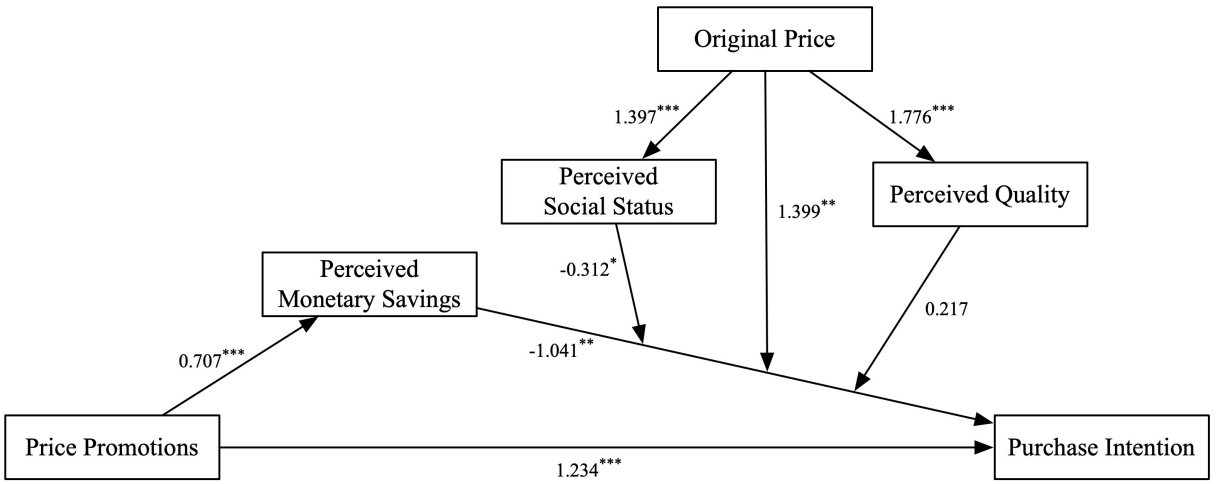

FIGURE 3 | The casual relationship model among variables and the results of moderation and mediation analyses. The figures near arrows suggest coefficients of independent variables. $*p < 0.1$, $**p < 0.05$, $***p < 0.001$.

not the case in the low original price condition. Consumers expect high quality and status granting from affordable luxuries at relatively low price (Mundel et al., 2017). As the post questionnaire shows, consumers can perceive a high-priced affordable luxury product as high quality and high social status and price promotions can create savings of paying for affordable luxuries. By weighing up these factors, consumers exhibit a more positive attitude and stronger purchase intention to purchase a high-priced product with a price discount, which belongs to a kind of expectation stimuli. Meantime, though a high original price lives up to the expectation of consumers, a non-discounted current price cannot help to acquire the benefits of affordable luxuries at a relatively low price. Similarly, a low-priced affordable luxury product with a price discount saves much more money, but this product's quality and social status produced by this product to signal are too low to reach the expectation of consumers. Since consumers anticipate a high-priced affordable luxury item with a price discount, the presentation of a non-discounted current price produces the conflict between the presented information and the expected information and evokes an enhanced N2 amplitude. Meantime, there will be no significant discrepancy between non-discounted and discounted current prices in perceived conflict and N2 amplitude.

Late positive potential is a late positive-going component that is sensitive to the evaluative properties of stimuli and incongruence with a preceding context (e.g., Dhont et al., 2012). When people are asked to evaluate stimuli (positive or negative), the LPP amplitude is influenced by preceding stimuli, and it is larger to evaluative inconsistent stimuli (positive prime and negative target, or negative prime and positive target) than evaluative consistent stimuli (positive prime and positive target, or negative prime and negative target). In the current study, we found a more positive LPP amplitude in non-discounted price condition than in discounted price condition when the original price was high, and there was no significant difference when the original price was low. Consumers regard high-priced affordable luxuries as the products of high quality and signaling social status, and thus, high original prices are positive information as context stimuli or prime stimuli. As consumers are less willing to purchase an affordable luxury product without a price promotion than with one, they would form a negative attitude when a non-discounted price is presented, which is evaluatively incongruent with the preceding stimuli (i.e., positive–negative), leading to an increase in LPP amplitude than the discounted price stimuli preceded by high original price stimuli (i.e., positive–positive). Besides, a low-priced affordable luxury item is perceived to a decline in quality and to have difficulty in social granting; thus, low original price is a kind of negative information, whereas consumers show low purchase intention to a low-priced product regardless of with a price discount or without. When a current price preceded by low original price is non-discounted or discounted, consumers would evaluate both prices as negative information, which is evaluatively consistent conditions (i.e., negative-negative) and leads to insignificant difference in LPP amplitude.

On the other hand, practical implications for sellers should be discussed. First, we found that price promotions are effective in promoting the purchases of high-priced affordable luxuries, and that for this type of luxuries, consumers expect price promotion and give a positive evaluation. Sellers should take part in some shopping festivals, such as Double 11 in China, Black Friday in America, which can attract many consumers, to promote high-priced affordable luxuries to increase sales. Second, the current results showed that price promotions are inappropriate for promoting the purchases of low-priced affordable luxuries. Consumers perceive low product quality and low social status for low-priced affordable luxuries regardless of whether price promotions are present or absent. Thus, sellers are capable of designing promotional advertisement that show consumers what social status low-priced affordable luxuries can

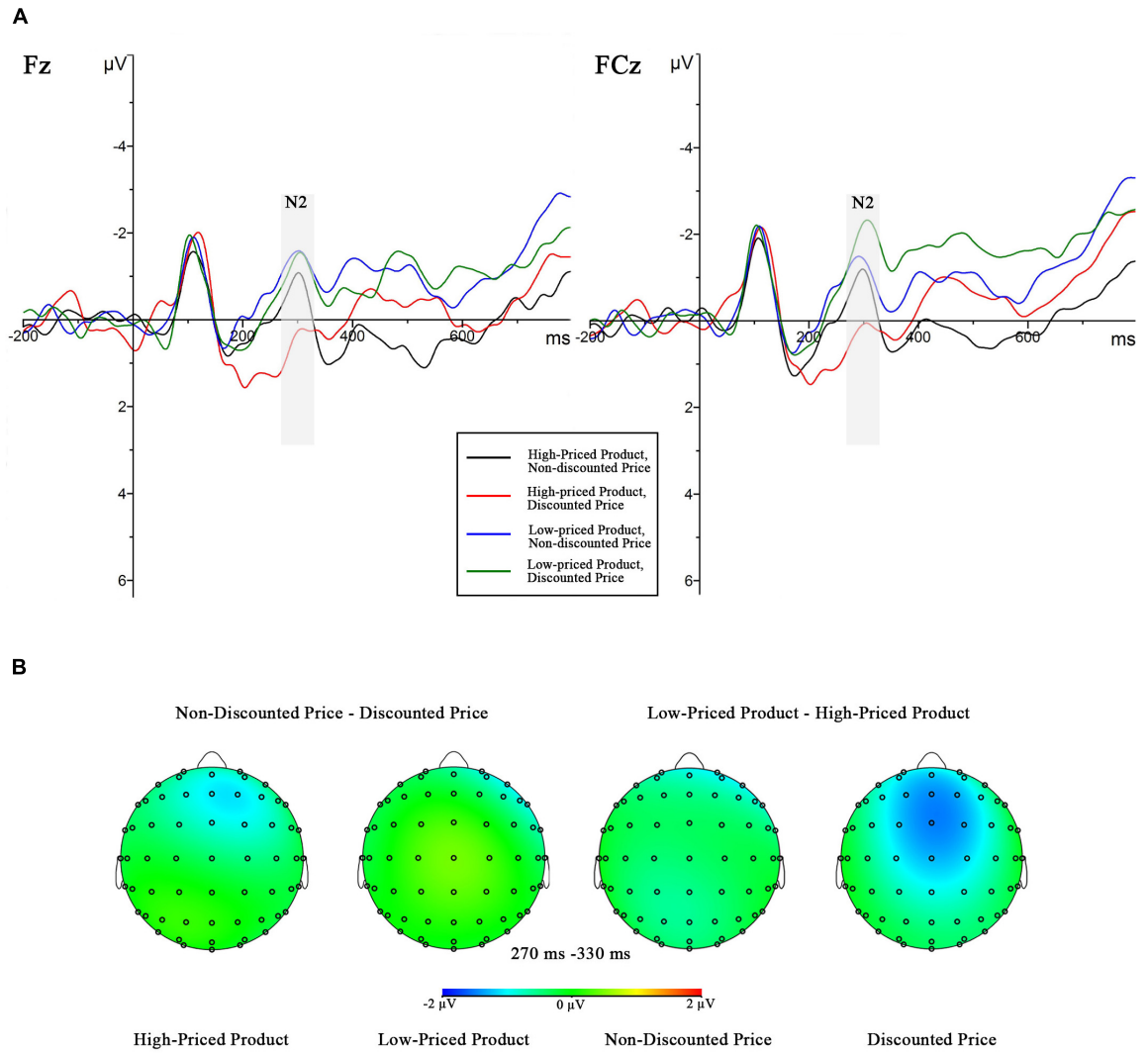

FIGURE 4 | (A) Grand-averaged event-related potential (ERP) waveforms within the N2 time window (270–330 ms) across four conditions (high-priced product with discounted price or with non-discounted price, low-priced product with discounted price or with non-discounted price) with two electrodes (Fz and FCz). **(B)** Difference maps corresponding to the N2 amplitudes.

represent and how low-priced affordable luxuries are of good quality.

LIMITATIONS AND EXTENTIONS

First, during the current experiment, the evaluatively consistent condition evoked a higher LPP amplitude than the evaluatively inconsistent condition. In the research of Jing et al. (2019), a hedonic product picture was first presented. Subsequently, subjects were exposed to promotion information and made purchase decision. Though hedonic products, which can meet emotional needs and improve living standards, are regarded as the positive context stimuli, positive information (i.e., positive–positive, an evaluative consistent condition) elicits a larger LPP amplitude than negative information (i.e., positive–negative, an evaluative inconsistent condition) (Jing et al., 2019). In this regard, one could speculate that consumers could have focused on promotion information but paid less attention to hedonic pictures, whereas subjects need to know original prices (context stimuli) before forming attitudes in the current study. Future research should explore whether conscious and unconscious signals can modulate the amplitude deflection of the LPP component in the consumer neuroscience area.

Second, some factors could influence the effectiveness of price promotions. In the experiment, only female consumers were recruited for the preselected affordable brand, but the gender plays a significant role in moderating brand perception and purchase intention (e.g., Gilal et al., 2018, 2020); Yang et al. (2015) showed that consumers who are high in need for status exhibit a negative attitude toward a luxury hotel with a price

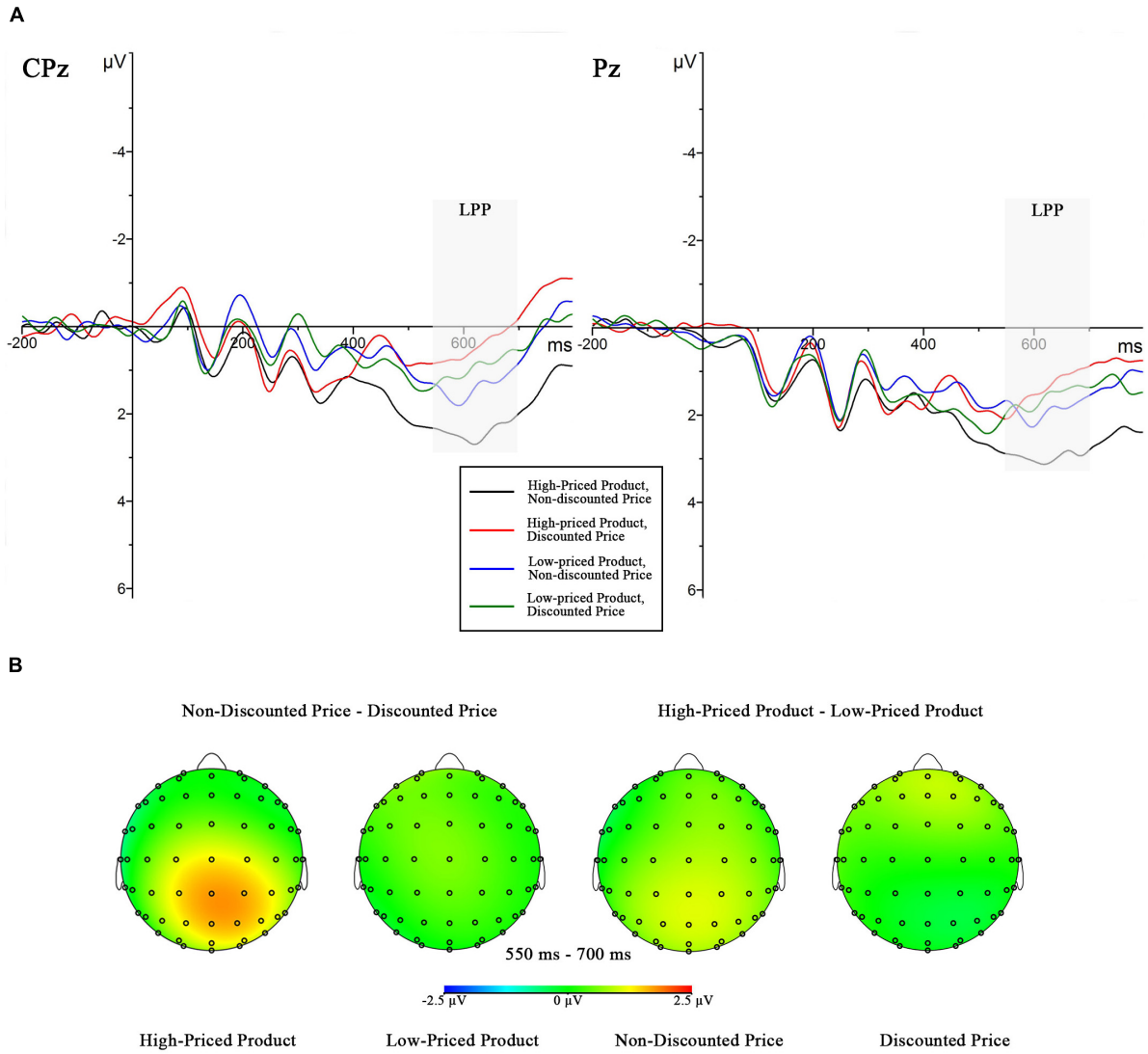

FIGURE 5 | (A) Grand-averaged ERP waveforms within the late positive potential (LPP) time window (550–700 ms) across four conditions (high-priced product with discounted price or with non-discounted price, low-priced product with discounted price or with non-discounted price) with two electrodes (CPz and Pz). **(B)** Difference maps corresponding to the LPP amplitudes.

promotion. It seems that need for status plays a key role in doing promotions; the effectiveness of price promotions has been found in utilitarian and hedonic items as well (Kivetz and Zheng, 2017), but the discount level increases promotional effectiveness for utilitarian more than for hedonic products (Eisenbeiss et al., 2015); participants could have speculated that the affordable luxuries with a high price were genuine and that the ones with a low price were counterfeit, since counterfeit products are generally cheaper than genuine products (e.g., Wu and Chiu, 2014). If the official price did not emerge, participants might have served low-priced products as normal ones. In sum, gender, need for status, discount levels, and whether the official price is concealed or revealed are all valuable extensions in the future.

Third, price promotion is a common type of marketing strategy in regular merchandise. However, since affordable luxury products have many similar aspects to traditional luxuries as mentioned in the *Introduction* section, many marketing strategies as effective method in promoting traditional luxury purchases like behavioral targeting (Yu et al., 2017), cross-market selling channel strategies (Huang et al., 2020), and social media marketing activities (Athwal et al., 2019) should be investigated further in affordable luxuries. Also, future research can focus on the affordable luxuries and traditional luxury purchases together to explore the effects of price promotions or other factors mentioned above. At last, it is noted that there were some marginally significant effects in behavioral and ERP results. One of the reasons might be that the sample size is too low in the study. Future research could use a greater sample size to further verify these findings.

CONCLUSION

Behaviorally, price promotions for a high-priced affordable luxury product are effective, but it is not the case for a low-priced affordable luxury product, which is the result of weighing up product quality, social status, and monetary savings. Consumers respond more quickly to make decisions to discounted prices than non-discounted prices when original prices are low because of lower processing difficulty. At the neural level, people expect a high original price and a discounted price, and thus, other price information produces conflict and elicits a more negative N2 amplitude. The LPP amplitude is larger to a high-priced affordable luxury without a price discount than a high-priced affordable luxury with a price discount. The LPP amplitude differences are the result of the evaluative inconsistency effect, and the former is an evaluative inconsistent condition, and the latter is an evaluative consistent condition.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Internal Review Board of the Laboratory of Cognitive Neuroscience, Yanshan University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KJ, LC, and YM conceived and designed the experiment. KJ and LC performed the experiment, wrote, and edited the manuscript. KJ and YM analyzed the data. All authors contributed to the article and approved the submitted version.

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How Does the Implicit Awareness of Consumers Influence the Effectiveness of Public Service Announcements? A Functional Near-Infrared Spectroscopy Study

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A large number of scholars have conducted detailed studies on the effectiveness of commercial advertising by using neuroimaging methods, but only a few scholars have used this method to study the effectiveness of public service announcements (PSAs). To research the relationship between the effectiveness of PSAs and the audience's implicit awareness, functional near-infrared spectroscopy (fNIRS) was employed to record the neural activity data of participants in this study. The results showed that there was a correlation between activation of dorsolateral prefrontal cortex (dlPFC) and the effectiveness of PSAs; The activation of the dlPFC could also be used as an indicator to represent the appeal of advertising content. The results means that neuroimaging tool can also be used to investigate the effectiveness of PSAs, not just commercial advertisements and a few PSAs study, and that neural activity can predict and improve the effectiveness of PSAs before they are released.

Keywords: neuromarketing, functional near-infrared spectroscopy (fNIRS), PSAs, dorsolateral prefrontal cortex (dlPFC), implicit awareness, purchase decision

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INTRODUCTION

Advertising effectiveness is one of the most important indicators for advertisers. For all advertising campaigns, consumers are the recipients of advertising, and the effectiveness of advertising is ultimately reflected by the behavior of consumers (Ramsoy, 2019). To obtain better advertising outcomes, enterprises design different advertisements to promote new products and hire celebrities to endorse their products at great cost (Clark et al., 2018). Some companies have established a good brand image and gained good revenue through these methods, but there are also some companies that have not met their expectations (Huang et al., 2018). In addition to commercial advertisements, public service announcements (PSAs) focus on advertising effectiveness.

The existing studies of the effectiveness of PSAs are mostly focused on acquired immunodeficiency syndrome (AIDS) prevention (David and Cindy, 1996; Wang and Arpan, 2008), smoking cessation (Shen, 2010; Wang et al., 2013), drug rehabilitation (Fishbein et al., 2002), traffic safety (Santa and Cochran, 2008), etc. All of these studies evaluate the effectiveness of PSAs by understanding people's views on PSAs through interviews, questionnaires, and other forms

of self-report. However, self-repots sometimes do not reflect what people really think (Dmochowski et al., 2014). Evaluating the effectiveness of PSAs solely on self-reports may lead to wrong conclusion, which will greatly reduce the effectiveness of them.

The emergence of neuromarketing offers a new approach to the study of advertising effectiveness. Telpaz et al. (2015) believe that people are often reluctant to express themselves or unable to express themselves correctly, but their neural activity, heart rate, and other implicit awareness indicate what they are truly thinking. Neuromarketing, unlike traditional marketing approaches, employs neuroimaging tools to record consumers' neural responses to products, brands, and advertisements and can be used to analyze neural data to explain and predict consumers' decisions (Lim, 2018; Hakim and Levy, 2019). Several scholars have proved that neural activity can provide higher prediction accuracy than self-report (Dmochowski et al., 2014; Boksem and Smidts, 2015; Telpaz et al., 2015; Barnett and Cerf, 2017; Chan et al., 2019).

Some researchers have introduced neuroimaging tools into the study of PSAs. They have studied the predictability of advertising effect in PSAs (Falk et al., 2012), the relationship among advertising effect, content, and neural activity (Wang et al., 2013), and the indicators that distinguish effective PSAs from ineffective PSAs by neural activity (Cartocci et al., 2018). However, despite the abundance of previous studies, three problems remain. First, most of the previous studies were posterior and did not reveal indicators that could improve effectiveness of PSAs; Second, almost all of previous studies using neuroimaging tools were on anti-smoking PSAs, and the applicability of the findings to other types of PSAs remains to be tested; Third, functional MRI (fMRI), the neuroimaging machine used in the previous studies, is extremely expensive and large, making it difficult to scale up widely.

Therefore, in this study, functional near-infrared spectroscopy (fNIRS), a new, cheaper and more portable neuroimaging tool, was used to measure participants' neural activity while viewing PSAs, with the goal of finding indicators that could improve the effectiveness of PSAs. An experiment on agricultural PSAs was conducted to find indicators of neural activity that would improve the effectiveness of PSAs. In this paper, the progress of related studies is summarized and hypotheses are presented in the Literature Review. Then the experimental design and data processing are described in the Method. The results of data analysis are shown in the Results. Then after that, the findings are discussed and compared with literature in the Discussion. Finally, in the Conclusion, conclusions are stated and possible topic selections for future research are suggested.

LITERATURE REVIEW

Advertising effect has received much attention in neuromarketing, and numerous studies have investigated the relationship between neural activity and advertising effect. Previous studies have shown that neural activity is a better predictor of advertising effect than self-report. By analyzing neural activity of the ventral striatum, Berns and Moore (2012) found that the activation within the ventral striatum was correlated with the sales of music albums, while self-report was not. Not limited to music albums, the advertising effect of printer poster can also be accurately predicted. In analyzing the neural activity of participants' viewing advertising poster for chocolate bars at different times, Kühn et al. (2016) assigned different weight to different brain region and successfully predicted the sale ranking of chocolate bars at different times, which was not possible for self-report.

Within the field of PSAs, several studies have focused on investigating the relationship between anti-smoking PSAs effectiveness and neural activity. One study found that neural activity was also a much better predictor of PSAs than self-report. Falk et al. (2012) found that medial prefrontal cortical neural activity, while participants viewed anti-smoking PSAs was associated with the number of calls to an anti-smoking hotline. Previous studies have found that the content and format influence the effectiveness of PSAs (Dillard and Peck, 2000; Santa and Cochran, 2008). Several scholars have studied how content and format affect the effectiveness of PSAs through neuroimaging tools. By comparing participants' neural activity and behavior after viewing anti-smoking PSAs, Wang et al. (2013) found that neural activity evoked by PSAs with different content differed significantly in the inferior frontal gyrus, the precuneus and the dorsomedial prefrontal cortex (dmPFC), and that neural activity in dmPFC could predict the urine cotinine levels 1 month later, which reflected participants' smoking intensity. Through measurement and analysis of multiple instruments, Cartocci et al. (2018) found that effective ads focused on visual elements while ineffective ads focused on text.

Interestingly, the prefrontal cortex (PFC) has been frequently mentioned in studies of PSAs effect. Functionally, the PFC can be divided into three parts, the orbitofrontal cortex (OFC), ventral prefrontal cortex (vPFC), and the dorsal prefrontal cortex (dPFC; Parnamets et al., 2020). The OFC is the brain region associated with value assessment, the vPFC is the brain region associated with emotions, and the dPFC is the brain region associated with working memory and rational thinking (Plassmann et al., 2015; Karmarkar and Plassmann, 2019). Notably, the PFC is also the main area of interest for scholars who have used fNIRS for advertising effect. Most of the existing studies of advertising effects *via* fNIRS chose the dorsolateral prefrontal cortex (dlPFC) as the observed brain region. Some scholars have verified the reliability of fNIRS in advertising effect research by repeating previous fMRI experiments (Krampe et al., 2018; Gier et al., 2020; Meyerding and Mehlhose, 2020). Gier et al. (2020) repeated Kühn et al. (2016) study on the advertising effect of chocolate bars by measuring the neural activity of dlPFC, and obtained a high accuracy. Some scholars have also used fNIRS to measure neural activity in the dlPFC to reveal a variety of factors that influence the effectiveness of advertising, such as gender differences (Duan et al., 2021), preference differences (Qing et al., 2021), etc. However, fNIRS also has disadvantages. Limited by the penetrating ability of NIR light, fNIRS cannot measure neural activity in deep brain regions, such as the ventral medial prefrontal cortex.

TABLE 1 | Task materials.

Number	Agricultural products	Origin
v1	Carambola	Fujian
v2	Red date	Xinjiang
v3	Red kiwi	Jiangxi
v4	Apple	Sichuan
v5	Navel orange	Chongqing
v6	Pomelo	Fujian
v7	Passion fruit	Fujian
v8	Milk	Gansu
v9	Pitaya	Guangxi
v10	Roxburgh rose	Guizhou

Therefore, in this study, the dlPFC was selected as the target observation region to collect neural activity of participants while viewing PSAs. The following hypothesis has been proposed that the dlPFC activity can predict the effectiveness of PSAs and help improve the advertising effect.

MATERIALS AND METHODS

Participants

Fourteen males and 16 females participated in this experiment (age $M = 24.47$, years, $SD = 1.69$). All participants attended Zhengzhou Light Industry University, were right-handed, had normal or corrected-to-normal vision, no brain injury, no history of psychiatric disorders, no recent use of tranquilizers, and no previous participation in neuroscience experiments. The experiment was approved by the ethics committee of the university.

Materials

The year 2021 is the first year that China has declared that everyone is free from poverty, and almost all Chinese people have focused on the cause of poverty eradication. China Central Television (CCTV) has released many PSAs to help poor regions promote their special products and industries during the fight against poverty. Since all Chinese people are aware of the project of fighting poverty, we chose PSAs related to this project as experimental materials. The PSAs released by CCTV contain three themes: tourism, represented by landscapes, agricultural products, represented by fruits, vegetables and meat, and traditional handicrafts. Considering that the participants were university students, fruit and milk ads were chosen as the stimulus material for this experiment in order to be more relevant to reality. Ten different ads were selected from the agricultural PSAs released by CCTV from January 2020 to December 2020[1], as shown in **Table 1**.

Task Design

In this experiment, participants were told that purchasing the products in PSAs was considered as a willingness to support the anti-poverty project, and participants' willingness to purchase the products in the PSAs was considered as an indicator of advertising effect. To determine what factors can enhance advertising effect, a control group containing price was added into the experiment, which was designed whether people would actually behave as expected in PSAs when they are in their lives. After the experiment, participants in the experiment group and control group were randomly invited to participate in a telephone interview, with the aim of finding the reason for the difference in the result between two groups.

The group that did not include price was named group A and the group that included price was named group B. Before the experiment began, participants were randomly assigned to group A and group B. Participants in group A were told that they did not need to take price into account, and they could make decisions based on their own preferences. In contrast, participants in group B were told that the product price would be displayed during the decision phase and that they should make a decision choice based on their real needs.

The experiment consists of two parts, the first part collected neural data when participants were resting and the second part collected neural data when participants were watching the advertisement. In the first part, a landscape picture that lasted 60 s would appear on the screen, and participants simply watched the picture without any reaction. After the picture disappeared, the participants rested for 30 s and then entered the second part. The second part consisted of 10 trials, each of which containing an advertising video and a decision-making session. The ads lasted 60 s, and the decision-making session had no time limit until the participants made a choice. In decision-making session, only product pictures in the ads appeared in group A while product pictures and prices appeared in group B. There was a 30-s break at the end of the decision-making session, and the experimental flow is shown in **Figure 1**.

Data Acquisition and Processing

The portable fNIRS used in the experiments was Artinis Brite 24 (10 transmitters and eight receivers), which emits NIR light at 762 and 841 nm and has a sampling rate of 10 Hz. Transmitter and receiver were separated from each other by a distance of 3 cm in order to guarantee signal quality. They were placed with reference to the 10–20 standard EEG positions, centered on F3 and F4 and symmetrically distributed along the central sulcus, as shown in **Figure 2**. E-Prime 3.0 was used to present the experimental stimuli, and Oxysoft (v3.2.72) was used as data collection software.

NIRS_KIT (Hou et al., 2021) was used to process the raw data and analysis. The pre-processing of the raw data went through the following steps: first detrending of the raw data, then Motion correction of the data by TDDR method, and finally band-pass filtering of the data by IIR method at 0.01–0.1 Hz. The preprocessed data were entered into the data analysis phase, and as oxyhemoglobin (HbO) correlates more with cerebral blood flow than deoxyhemoglobin (Hb; Strangman et al., 2002), only HbO was focused on in the next analysis.

For every participant, a general linear model (GLM) was set up to model neural activity during the experimental task. The model contained 11 parameters, respectively, "rest" and

[1]Experimental material source website: https://ggjzfp.cctv.com

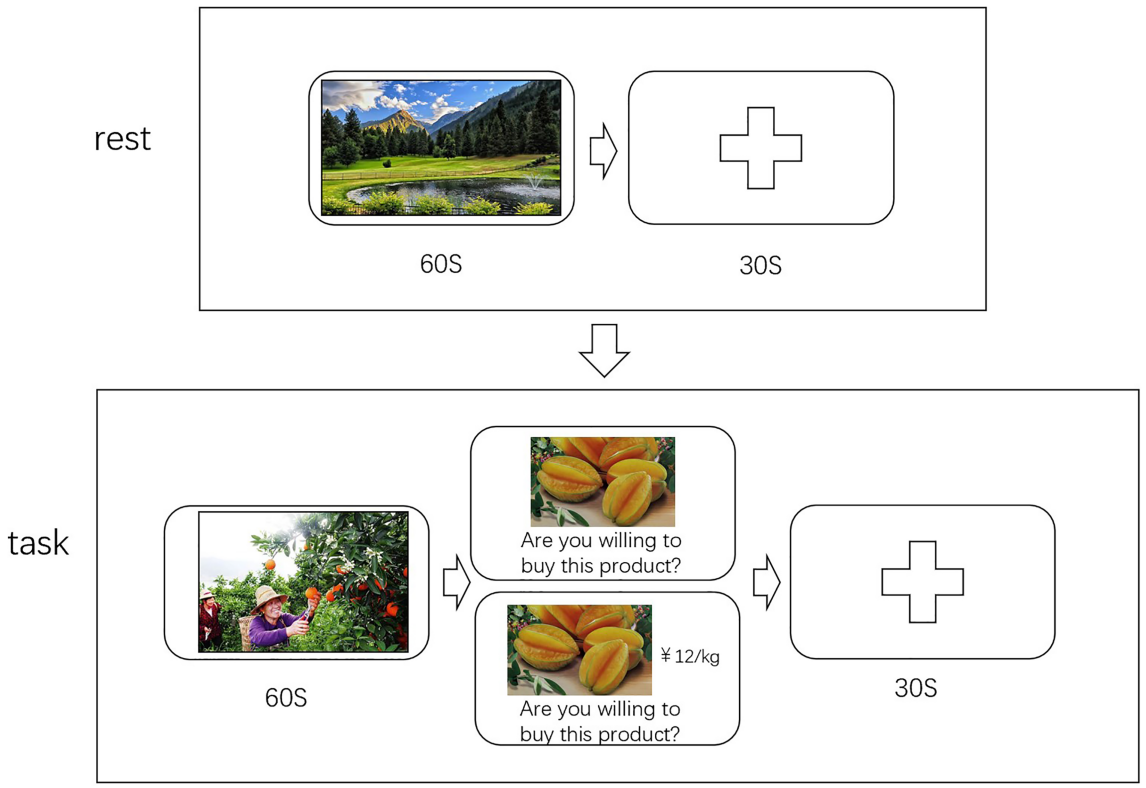

FIGURE 1 | The top half of the picture "rest" is the first part of the experiment, where participants view the picture for 60 s and then rest for 30 s before moving on to the second part. The bottom half of the picture, "task," shows the process of each trial in the second part, including an ad and a decision-making session.

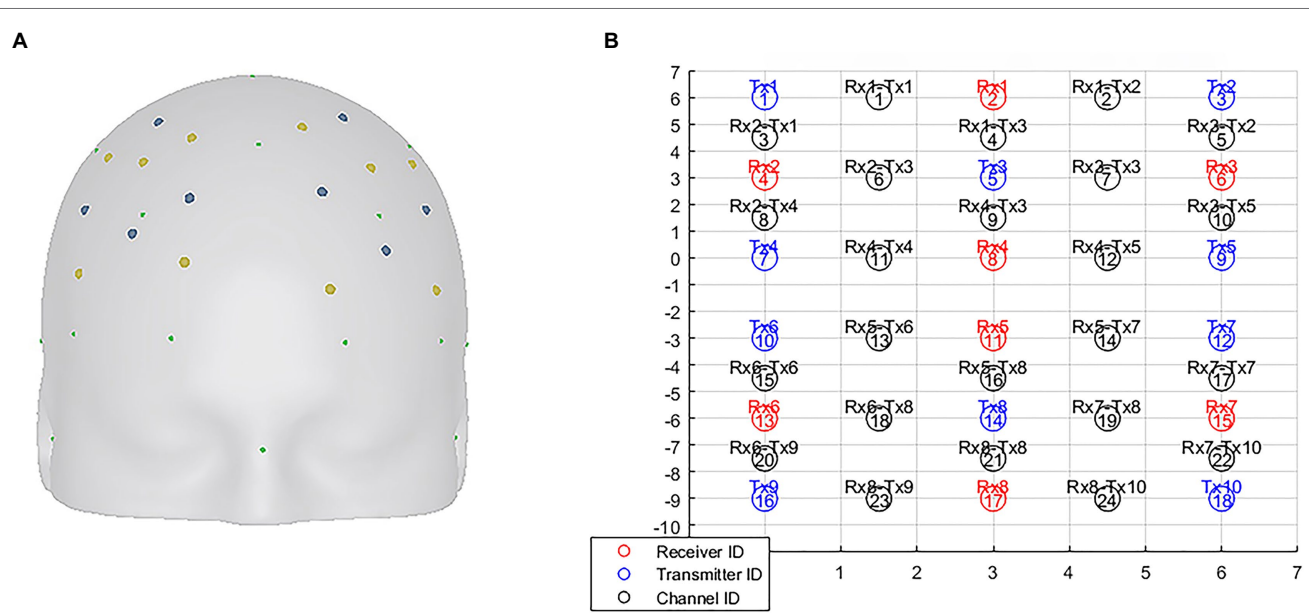

FIGURE 2 | The locations of the transmitters and receivers are shown in **(A)**, with the yellow dot being the transmitter and the blue dot being the receiver. The distribution of each channel is shown in **(B)**, with channels 1–12 distributed in the right hemisphere and channels 13–24 in the left hemisphere. Channels 4, 6, 7, and 9 were selected as analysis channels for the right hemisphere, and channels 16, 18, 19, and 21 were selected as analysis channels for the left hemisphere.

v1–v10. Next, for each participant's neural data, v1–v10 was compared with "rest" to calculate the beta value, which was named condition 1–condition 10, respectively. Finally, in order to investigate the dlPFC activation induced by ads at the group level, one-sample *t*-test was performed for all participants' beta values in condition 1–condition 10. Bonferroni correction was used to correct the *t*-test results. The ranking method of activation results refers to Kühn et al. (2016) and Gier et al. (2020). Channel 4, 6, 7, 9, 16, 18, 19, and 21 were selected as the comparison channels, and the highest value of corresponding *t*-value of the channels was selected as the ranking basis.

RESULTS

Behavioral Results

The decision-making session result data for each group was extracted from E-Prime 3 keylog ($M = 9.30$, $SD = 5.17$ for group A and $M = 7.8$, $SD = 4.13$ for group B), the results of which are shown in **Figure 3**. The various purchases of each product were ranked according to their purchase volume and ranked as follows: group A was v2, v10, v1, v9, v7, v6, v5, v8, v3, and v4; group B was v2, v9, v7, v6, v10, v5, v8, v3, v1, and v4. Independent samples *t*-test conducted with SPSS 20 was used to measure the difference between the groups. There was no significant difference in purchase volume between the two groups [$t_{(18)} = 0.253$, $p > 0.05$], but there was a large difference in purchase volume between the two groups for v1 and v10.

fNIRS Results

The peak *t*-values in the selected channels were used as the basis for ranking the degree of dlPFC activation, as shown in **Table 2**. The t-contrast activity map of each ad was sorted according to the peak value of the selected channel, as shown in **Figure 4**.

It is worth noting that while most of the ads in the behavioral and fNIRS results are largely consistent in rankings, there are still some differences. v1 and v10 ranked 3rd and 2nd in the behavioral results of Group A, but 8th and 3rd in the fNIRS results. While v1 and v10 ranked 9th and 5th in the behavioral results of Group B, and 10th and 7th in the fNIRS results, the rankings of the two results are closer. To find the reason for this phenomenon, 10 participants were randomly selected to be interviewed.

Interview Results

Compiling the interview transcripts revealed that almost all interviewees felt they were not familiar with the fruits introduced by v1 and v10. The origin of the carambola introduced in v1 and the roxburgh rose introduced in v10 are both very distant from the location of this experiment, and both fruits are very rare in the experimental location.

Interviewees felt they were more concerned about the taste of the fruits than the environment in which they were grown. In the ads, v10 introduced more about the taste of roxburgh rose, the way to consume and the deep processing products, while v1 focused more on the growing environment and the appearance of carambola. Moreover, because group A did not need to consider price when making decisions, almost all

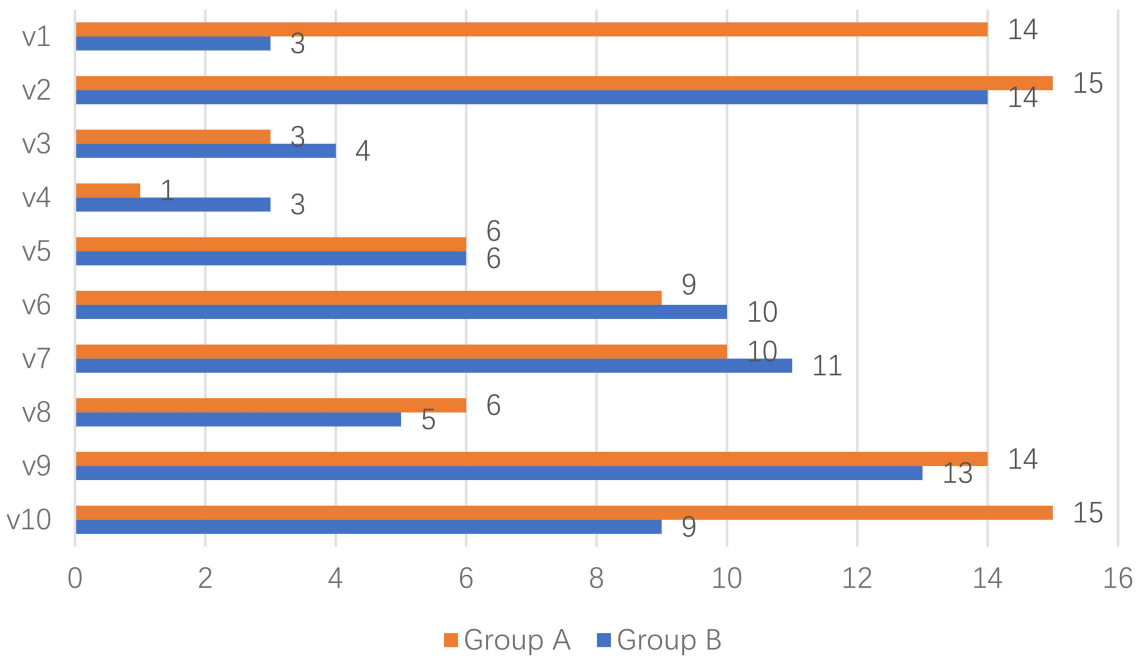

FIGURE 3 | Purchase data for each group.

TABLE 2 | The peak *t*-values of the selected channels.

Videos	Group A			Group B		
	T	*p*	Channel	T	*p*	Channel
v1	3.15	$p<0.01$	21	1.09	$p>0.05$	6
v2	7.67	$p<0.01$	16	8.32	$p<0.01$	21
v3	2.57	$p<0.05$	16	1.73	$p>0.05$	18
v4	1.63	$p>0.05$	18	1.46	$p>0.05$	19
v5	5.87	$p<0.01$	16	6.39	$p<0.01$	18
v6	6.33	$p<0.01$	16	6.69	$p<0.01$	16
v7	6.47	$p<0.01$	18	7.27	$p<0.01$	21
v8	5.54	$p<0.01$	16	4.97	$p<0.01$	16
v9	6.71	$p<0.01$	16	8.32	$p<0.01$	19
v10	6.62	$p<0.01$	21	2.63	$p<0.05$	6

participants chose to try unfamiliar products; in contrast, group B needed to consider price when making decisions, so most participants made choices based on their preferences. Thus, the situation emerged that v1 and v10 differed in the ranking of behavioral and neural outcomes in group A, while they were more similar in group B.

DISCUSSION

The purpose of this study was to investigate whether consumers' implicit awareness can predict the effectiveness of PSAs and help improve the effectiveness of PSAs. According to results, the neural activity collected by portable fNIRS accurately predicts the participants' decision-making behavior after they viewed the PSAs. At the group level, the higher the participants' dlPFC activation, the greater their purchase volume. This implies that activation of the dlPFC predicts the advertising effect of PSAs. This finding is consistent with the results of previous fMRI studies (Falk et al., 2012) and fNIRS studies (Gier et al., 2020). This means that the neuroimaging tool is not limited to anti-smoking PSAs, but can also be applied to other types of PSAs.

Activation of the dlPFC means that neural activity was significantly higher when participants viewed the PSAs compared to when they did not, implying that the PSAs had a significant effect on participants' decision-making processes. The dlPFC is the brain area associated with working memory, value assessment, willingness to pay, and decision-making (Karmarkar and Plassmann, 2019). Previous research has suggested that the more attractive the stimulus is to the participant, the higher the activation of dlPFC in their decision-making process (Meyerding and Mehlhose, 2020). In the present study, higher activation in the dlPFC meant that the PSAs had a greater impact on the participants and the ads were more effective. Therefore, we believe that the neural activity of dlPFC can predict the effectiveness of PSAs.

The products involved in v1 and v10 showed differences in the behavioral results of participants in group A and group B. This can be interpreted as viewers agreeing with the PSAs in their thoughts but not acting on them, consistent with the phenomenon mentioned by Kang et al. (2009). Combined with the interview results, we learned that this difference stems from the different content of the ads, which is consistent with the fact that ad content affects dlPFC activation (Wang et al., 2013). The different focus and presentation in the v1 and v10 resulted in different appeal of the ad content to participants, consistent with the findings of Shen (2015) on the effectiveness of sympathy appeals and fear appeals for anti-smoking ads. When people make decisions, they tend to value stimuli by using experiences and preferences as reference, showing activation of the dlPFC (Parnamets et al., 2020). From the interviews, we learned that the participants obtained some content of interest to them from v10, but did not obtain that from v1. Although the participants were unfamiliar with the fruits introduced by both v1 and v10, they had a reference in their value assessment because they got the information of interest from v10, as shown by the activation of the dlPFC, which was not the case with v1. It is noteworthy and interesting to note that most of the participants in group A bought the fruits presented in v1 and v10 out of curiosity and sympathy, because the anti-poverty project is a difficult and well-known project in China and most Chinese want to contribute to it. On advertising content alone, we believe that the activation of the dlPFC can be used as an indicator of the attractiveness of PSA content to enhance the advertising effect.

Although the results of this experiment are satisfactory, the shortcomings of this experiment still need to be addressed. The prediction method adopted in this experiment was within-sample prediction, and whether the experimental results can be applied to the overall population cannot be determined and still needs to be verified in future studies. Furthermore, although, we found that activation of the dlPFC can be used as an indicator of the effect of advertising, there are still some brain areas that we have not studied. McClure et al. (2004) suggested that vmPFC would assume a major role in decision-making and show greater activation when the decision is based on perception only; dlPFC would be more active when the information is more comprehensive. Wang et al. (2013) also suggested that difference in PSAs content can cause activation of the inferior frontal gyrus and precuneus. However, due to the limitation of the fNIRS observation range, we could not observe the neural activity of vmPFC, inferior frontal gyrus and precuneus. Whether advertising content affects emotion, whether emotion affects the decision-making process, and

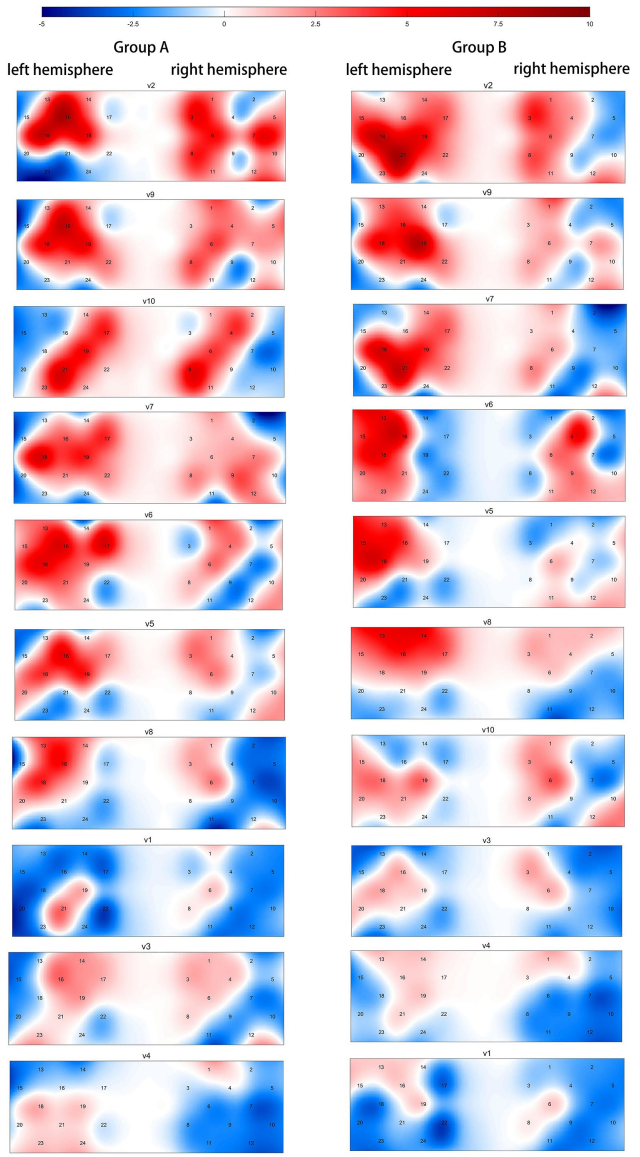

FIGURE 4 | v1–v10 are ranked according to the peak *t*-value of the selected channel, with red representing the activation of dorsolateral prefrontal cortex (dlPFC) compared to the resting state. Compared to the resting state, v4 in group A and v3, v4, and v1 in group B were insignificant.

whether advertising content can be better improved through other brain regions need to be investigated further in future research.

RESEARCH AND MANAGERIAL IMPLICATIONS

Studies have shown that most consumer purchases are impulsive, that 70% of purchases occur within 60 s (Rook and Fisher, 1995), and that better planning of advertising content to influence consumer decisions is the key to improving advertising effectiveness (Fisher et al., 2010). The same effect is true for PSAs. The more appealing the content of a PSA, the higher the likelihood that it will influence people. Nowadays, there are many types of PSAs, anti-gambling ads (Shead et al., 2011), and healthy diet ads (Phua, 2014). The method used by these studies is still to evaluate the effectiveness of PSAs based on the people's self-report. According to the results of this study, people's neural activity can predict the effectiveness of PSAs more accurately than self-report, and the rational use of neuroimaging tools can better influence people's behavior. The results of this study may provide a new approach for subsequent PSAs research to improve the effectiveness of advertising.

To change the bad social phenomenon and guide people's behavior, the preparation of PSAs needs to speed lots of time and money. Ineffective PSAs cannot achieve their purpose, can only waste a lot of resources. The results of this study provide a method to predict the effectiveness of PSAs before they are released. Meanwhile, the appeal of content can be adjusted according to the neural activity of viewers, so as to improve their influence and avoid the waste of social resources.

CONCLUSION

This study found that there was a positive correlation between the activation of dlPFC and the effectiveness of PSAs; The activation of dlPFC can also be used as an indicator of the attractiveness of the advertising content and help improve the effectiveness of PSAs. These findings imply that neuroimaging tools can be used not only in commercial advertising effectiveness and some PSA effectiveness studies, but also in PSA effectiveness studies in the remaining fields. Meanwhile, the findings of this study can serve as a primer for subsequent studies on the relationship between PSA effectiveness and neural activity. Before the PSAs are released, advertisers can predict the effect of the ads based on the audience's dlPFC neural activation, determine the content of the ads that can better influence the audience, improve the effectiveness of the ads, and avoid wasting resources.

In this study, only dlPFC was investigated as an observed brain region, but there are many other brain regions associated with advertising effects, such as vmPFC and insula, according to previous studies. Limited by the measurement depth of fNIRS, we were unable to measure these brain regions, which may also have indicators related to advertising effects. Future research could start with two aspects: first, whether the brain regions that were not observed in this study are related to improving the effectiveness of PSAs; and second, the neural mechanisms by which emotions influence audience behavior and how emotions affect PSA effectiveness.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because it was ensured to the participants that their data is

not available for third parties and it was guaranteed that participants can request the complete deletion of their datasets at any time. Requests to access the datasets should be directed to alixig@163.com.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by College of Economics and Management Ethics Committee, Zhengzhou University of Light Industry. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Pricing Analysis of Online Shopping Platforms Considering Consumer Information Levels

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To address the problem of frequent dishonest transactions by online shopping platform merchants, we developed monopoly and competitive platform pricing models based on two-sided market theory, which introduce consumer information levels. This article analyzes the incentives of the platforms to improve consumer information levels in platform pricing strategies. Monopoly online shopping platforms aim to maximize profits. The higher the consumer information level is, the lower the fees charged to merchants; this can lead to increased platform profits. The charging of consumers depends on cross-network externalities. Competitive online shopping platforms also aim at maximizing profits. Under the circumstance that the number of consumers remains the same, the higher the consumer information level is, the more merchants the platforms will attract. This reduces bilateral user fees, and platform profits will be lower. From the perspective of consumer information level, the article analyzes the impact of monopoly and competitive platforms adopting return measures to improve the level of consumer information on platform pricing, number of bilateral users, and profits.

Keywords: two-sided platform, information asymmetry, consumer information, cross-network externalities, return measures

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INTRODUCTION

The evolution of business involves overcoming information asymmetries and credit non-delivery. In the process, it reduces transaction costs, increases network density, and enhances transaction efficiency. Various online shopping platforms, such as eBay, Amazon, Taobao, JD, and Guazi, act as connecting intermediaries, enabling consumers and merchants to enact transactions across time and space, thereby enhancing convenience. Merchants have natural private information about goods (Daughety and Reinganum, 2008), resulting in information asymmetries for bilateral users, leading to dishonesty in online shopping platforms (such as for commodity quality), which is why consumers choose to leave the platform company. With cross-network externalities, the number of merchants is affected, and so is the pricing strategy of online shopping platforms (Rochet and Tirole, 2003; Armstrong and Wright, 2006; Feng et al., 2020).

In response to the dishonest behavior of merchants, the platform adopts prior mechanisms, such as merchant certifications, ratings, and interactive consumer reviews, to make merchants disclose more product information and improve consumer product information levels, which reduces bilateral user information asymmetries. To further improve the online transaction ex-post mechanism, the platforms have introduced diversified return services to enhance consumer information level. For example, employing 7 days of no-reason return service, the Tmall trading

platform has upgraded its return service for consumers who encounter problems with the quality of goods. It has successively launched a 360-warranty service, a 30-day no-worry-return service, and a 30-day warranty plus service. JD launched a 1-year warranty service and a 3-year warranty service to protect consumer rights.

Given the above background, as well as Armstrong's (2006) complete information pricing model and Hagiu and Hałaburda's (2014) incomplete information pricing model that considers the degree of user expectations, this study introduces the level of consumer information to build a platform pricing model with incomplete information. The primary goal is to analyze the effect of consumer information levels on online shopping platform pricing strategies under different market structures. We explain why platforms adopt measures (such as returns) to increase the level of consumer information and reduce the level of bilateral information asymmetry. The following questions are addressed: (1) what is the impact of consumer information level on pricing strategies of online shopping platforms with different market structures under the effect of cross-network externalities, and how does it increase profits?, and (2) what is the impact on pricing strategies when platforms adopt information level improvement services (such as return services)?

By platform profit maximization, we analyze the effect of consumer information level on platform pricing for bilateral users, number of bilateral users, and platform profit. We find that increasing the level of consumer information in the competitive platform reduces platform profits, resulting in less incentive for the competitive platform to increase the level of consumer information. In contrast, the monopoly platform has a greater incentive to increase the level of consumer information. Platforms set different return times for different product categories to improve consumer information levels and ensure consumer rights.

Other parts of this study are as follows. section Literature Review reviews the relevant literature. section Model Assumptions explains model construction. Section Model Analysis and Results analyzes the impact of consumer information level on optimal pricing, bilateral user size, and platform profit in different market structures. Section Discussion further discusses changes in the platform's pricing strategy when the platform adopts return measures to improve its information service level. Section Conclusion concludes the study with main conclusions and some recommendations for future research.

LITERATURE REVIEW

Our study is mainly related to three streams of existing research: two-sided market pricing, user expectation management, and platform governance mechanisms.

Bilateral platform pricing is largely based on the models of Rochet and Tirole (2003) and Armstrong (2006). There is one pricing model type for monopoly and competitive platforms from the perspective of the relationship between price and demand (Rochet and Tirole, 2002, 2003). A second type builds a pricing model of monopoly platforms and competitive platforms from the perspective of cross-network externalities (Armstrong, 2006). In early studies, platforms struggled to create cross-network effects because of high cost of consumers joining online platforms, leading to chicken-and-egg problems (Rohlfs, 1974; Caillaud and Jullien, 2003). There are two ways to address this. The first approach is that a platform uses price subsidies to increase independent values when consumers join a platform (Amelio and Jullien, 2012). With small marginal costs and high elasticity of demand on one side of the digital platform, to enable that side to have higher user participation, the platform implements price subsidies or free policies for users (Zhao et al., 2021). The second approach is that platforms adopt a vertical integration strategy to increase bilateral user interaction benefits (Hagiu and Spulber, 2013). For example, Google has introduced application development software for the Android platform (Wen and Zhu, 2019). As competition between platforms becomes more intense, bilateral platforms (such as those for dating, e-commerce, logistics, and media) emerge to meet the diverse needs of consumers. Platforms provide differentiated services or products for consumers, at which time bilateral users can either choose to join the platform with single- or multi-homing.

Bilateral market research under information asymmetry involves user expectation management. Maskin and Riley (1984) analyzed monopoly and competitive markets with incomplete information. In a study on the telecommunication market with network externalities, and the passive expectation concept of the unilateral network effect was proposed considering the rational expectation of consumers (Katz and Shapiro, 1985, 1986). Based on Katz and Shapiro's assumption of rational expectations, as followers enter, the position of the network leader is undermined, and market competition becomes more intense (Economides, 1996). In highly competitive markets, competitive platforms do not disclose advanced information to consumers and competitors from the perspective of profit and welfare maximization, although they increase expected network effects through advanced information strategies (Chellappa and Mukherjee, 2021). Only monopolistic platforms take advantage of information to improve pricing with the cross-network effect, and the platform pricing of passive expectation is lower than that of responsive expectation (Hagiu and Hałaburda, 2014; Hurkens and López, 2014). Such studies have studied platform pricing strategies with information asymmetry, but they did not consider which mechanisms could reduce information asymmetry and, thus, change platform pricing strategies.

Information asymmetry raises moral hazard and adverse selection problems (Akerlof, 1970; Stiglitz, 1983). To reduce information asymmetry, platform companies often adopt information disclosure, such as reputation mechanisms, margin mechanisms, and signaling. Airbnb improves consumer trust and facilitates bilateral user transactions through information disclosure methods, such as merchant response rate, merchant verification information, and overall consumer score (Xu et al., 2021). Online shopping platforms invest in developing information disclosure tools (Zhang et al., 2018) and establishing reputation feedback systems (Tadelis, 2016) to facilitate

consumer purchasing decisions. Crowdfunding platforms use media information and crowdfunding experience to reduce the degree of information asymmetry between sponsors and funders to achieve project funding objectives (Courtney et al., 2016). In addition, E-commerce platforms also provide different deposit policies to restrain dishonest transactions and improve trust in the platforms (Wang L. et al., 2021). Based on the transmission theory of labor markets (Spence, 1973), a platform can use advertising, full returns and prices to convey signals of high-quality products and reduce information asymmetry before and after transactions (Kihlstrom and Riordan, 1984; Moorthy and Srinivasan, 1995). In addition to the common mechanisms mentioned above, government regulation (Han, 2018) and technological progress of platform enterprises (Babich and Hilary, 2020; Wang Y. et al., 2021) can reduce information asymmetry. Although platform firms play a crucial role in reducing bilateral user information asymmetry by adopting these governance mechanisms, they do not consider platform network effects.

In sum, existing studies mainly focus on platform pricing with complete information and less research on platform pricing with incomplete information. In both response expectation and passive expectation scenarios, Hagiu and Hałaburda (2014) focus on the impact of user expectation changes on market equilibrium pricing and platform profits. In contrast to the study by Hagiu and Hałaburda (2014), we study the impact of consumer information level on platform pricing, number of bilateral users, and platform profits for monopoly online shopping platforms, competitive online shopping platforms, and incomplete competition online shopping platforms. Moreover, we further analyze pricing changes induced when platforms decrease information asymmetry of bilateral users (e.g., by adopting return measures).

MODEL ASSUMPTIONS

In this section, following Armstrong (2006) and Hagiu and Hałaburda (2014), we introduce consumer information levels and build monopoly and competitive platform pricing models. The following assumptions are made, and the notation needed for modeling is defined in **Table 1**.

Assumption 1. Extending the network externality theory of two-sided markets, several existing studies are used to simplify the model (Armstrong, 2006; Armstrong and Wright, 2006; Dou et al., 2020). Therefore, we assume that the scale of consumers and merchants is normalized to 1 and that there are cross-network externalities of platform bilateral users without considering intragroup network externalities. Each merchant generates utility for each consumer v ($v \in [0,1]$), and each consumer generates utility for each merchant φ ($\varphi \in [0,1]$).

Assumption 2. According to the information asymmetry theory, which is different from the theory on which the Armstrong (2006) model is based, we consider the heterogeneity of consumers in online trading platforms. To this end, we design two groups of consumers, informed and uninformed, to study platform pricing strategies (Chao and Derdenger, 2013; Hagiu and Hałaburda, 2014; Dou et al., 2020). When bilateral users are fully informed, the number of merchants expected by consumers is equal to the number of actual merchants, i.e., $N_s^e = N_s$; the number of consumers expected by merchants is equal to the number of actual consumers, i.e., $N_b^e = N_b$. The reason for this assumption is that, in reality, consumers, and merchants have asymmetric pricing information for each other. A merchant usually knows the pricing information of the platform with respect to consumers and the consumers' needs, i.e., $N_b^e = N_b$. However, consumers do not understand pricing information such as transaction fees and advertising fees, charged by a platform. Consumers can only expect merchants to enter based on their reputation, sales volume, and other information; therefore, when consumers have complete information about merchants, $N_s^e = N_s$.

TABLE 1 | Definition of notations.

Notations	Definition
v	Merchant-to-consumer network externalities ($v \in [0,1]$)
φ	Consumer-to-merchant network externalities ($\varphi \in [0,1]$)
V_0	The utility of the base services provided by the platform to consumers
θ	Consumer information level ($\theta \in [0,1]$)
c	The cost of goods or services provided by the merchant to the consumer
p_b, p_s	Membership fees charged to consumers and merchants in the monopoly platform
p_{ib}, p_{is}	Membership fees charged to consumers and merchants in the competitive platform i ($i = 1,2$)
N_b, N_s	Number of consumers and merchants in the monopoly platform
N_{ib}, N_{is}	Number of consumers and merchants in the competitive platform i ($i = 1,2$)
N_s^e, N_{is}^e	The number of merchants expected by consumers in the monopoly platform and competitive platform i(i = 1,2)
$\Pi_{pl}\Pi_{pli}$	Monopoly platform profit, competitive platform i ($i = 1,2$) profit

In the monopoly platform, the consumer utility function consists of payment of membership fees p_b by consumers and consumers getting the base service utility V_0 (e.g., the platform provides product browsing and accurate search results), and the merchant provides the informed consumer utility vN_s (uninformed consumer utilityvN_s^e), as shown in Equation (1):

$$U_{b(Informed)} = V_0 + vN_s - p_b, U_{b(Uninformed)} = V_0 + vN_s^e - p_b \quad (1)$$

When consumer utility $U_{b(i)}\left(i = Informed, Uninformed\right) \geq 0$, i.e., $\alpha \geq p_b - vN_s$, $\alpha \geq p_b - vN_s^e$, consumers choose to enter a platform transaction. Then, the number of informed and uninformed consumers entering the platform transaction is:

$$N_{b(Informed)} = 1 + vN_s - p_b, N_{b(Uninformed)} = 1 + vN_s^e - p_b \quad (2)$$

Because of information asymmetry between consumers and merchants, the consumer quantity function consists of two components, which are the θ proportion of informed consumers

and the $1-\theta$ proportion of uninformed consumers, as shown in Equation (3):

$$N_b = \theta\left(1+vN_s-p_b\right)+(1-\theta)\left(1+vN_s^e-p_b\right) \quad (3)$$

The higher the information service level provided by the platform, the more information (on product quality, sales volume, reputation, etc.) merchants can deliver to consumers; that is, the higher the consumer information level θ, the higher the proportion of informed consumers [$N_{b(Informed)}$] and the lower the proportion of uninformed consumers [$N_{b(Uninformed)}$].

Similarly, the merchant utility function consists of the membership fee p_s paid by merchants, the cost c of providing a product or service to consumers, and the utility φN_b brought by consumers to merchants, as shown in Equation (4):

$$U_s = \varphi N_b - p_s - c \quad (4)$$

A merchant chooses to enter a platform transaction only when merchant utility $U_s \geq 0$, i.e., $\varphi N_b - p_s \geq c$. Then, the function of the number of merchants entering platform transactions is calculated by Equation (5):

$$N_s = \varphi N_b - p_s \quad (5)$$

The monopoly platform profit function is shown in Equation (6):

$$\Pi_{pl} = p_b N_b + p_s N_s \quad (6)$$

In the competitive platform, we use the Hotelling model to describe the competition between symmetric platforms 1 and 2. The two platforms are located at the two ends of a line segment [0, 1], and bilateral users are distributed uniformly on the line segment. Considering that the unit search cost of bilateral users is not the focus of this model, the simplified unit search cost is 1.

In the competitive platform, because bilateral user information asymmetry, the consumer quantity function still consists of two components, which are the θ proportion of informed consumers and $1-\theta$ proportion of uninformed consumers, as shown in Equations (7) and (8):

$$N_{1b} = \theta\left(\frac{1}{2}+\frac{v\left(N_{1s}-N_{2s}\right)-\left(p_{1b}-p_{2b}\right)}{2}\right) + (1-\theta)\left(\frac{1}{2}+\frac{v\left(N_{1s}^e-N_{2s}^e\right)-\left(p_{1b}-p_{2b}\right)}{2}\right) \quad (7)$$

$$N_{2b} = 1 - N_{1b} \quad (8)$$

Here, $\frac{1}{2}+\frac{v(N_{1s}-N_{2s})-(p_{1b}-p_{2b})}{2}$ denotes the number of informed consumers in the competitive platform, and $\frac{1}{2}+\frac{v(N_{1s}^e-N_{2s}^e)-(p_{1b}-p_{2b})}{2}$ denotes the number of uninformed consumers in the competitive platform.

In the competitive platform, the merchants' number function consists of bilateral cross-network utilities and membership fees charged by the platform to merchants, as shown in Equations (9) and (10):

$$N_{1s} = \varphi N_{1b} - p_{1s} \quad (9)$$

$$N_{2s} = \varphi N_{2b} - p_{2s} \quad (10)$$

Then, the profit function of the competitive platform i is calculated with Equation (11):

$$\Pi_{pli} = p_{ib}N_{ib} + p_{is}N_{is} (i = 1, 2). \quad (11)$$

MODEL ANALYSIS AND RESULTS

Analyzing the Effect of Consumer Information Level in the Monopoly Platform

Result 1 The higher the consumer information level, the more the monopoly platform profits under the condition of cross-network externalities.

Proof Substituting Equation (5) into Equation (3) gives Equation (12):

$$N_b = \frac{1+(1-\theta)\,vN_s^e-\theta v p_s-p_b}{1-\theta\varphi v},$$
$$N_s = \frac{\varphi+(1-\theta)\,\varphi vN_s^e-p_s-\varphi p_b}{1-\theta\varphi\, v} \quad (12)$$

Substituting Equation (12) into Equation (6), first-order derivatives are taken for p_b and p_s, as shown in Equation (13):

$$\frac{\partial\Pi}{\partial p_b} = \frac{1+(1-\theta)\,vN_s^e-(\varphi+\theta v)\,p_s-2p_b}{1-\theta\varphi v},$$
$$\frac{\partial\Pi}{\partial p_s} = \frac{\varphi+(1-\theta)\,vN_s^e-(\varphi+\theta v)\,p_b-2p_s}{1-\theta\varphi\, v}. \quad (13)$$

Let $\frac{\partial\Pi}{\partial p_b}=0$ and $\frac{\partial\Pi}{\partial p_s}=0$. Under the$N_s = N_s^e$ equilibrium condition, the platform's optimal pricing for consumers and the platform's optimal pricing for merchants are given in Equation (14):

$$p_b^* = \frac{2-\varphi\,(\varphi+\theta v)}{4-(\varphi+v)\,(\varphi+\theta v)}, p_s^* = \frac{\varphi-\theta v}{4-(\varphi+v)\,(\varphi+\theta v\,)}. \quad (14)$$

Substituting Equation (14) into Equation (12), the platform's optimal number of bilateral users is given in Equation (15):

$$N_b^* = \frac{2}{4-(\varphi+v)\,(\varphi+\theta v)}, N_s^* = \frac{\varphi+\theta v}{4-(\varphi+v)\,(\varphi+\theta v\,)} \quad (15)$$

Substituting Equation (14) and Equation (15) into Equation (6), the monopoly platform's optimal profit is given in Equation (16):

$$\Pi_{pl}^* = \frac{4-(\varphi+\theta v)^2}{[4-(\varphi+v)\,(\varphi+\theta v)\,]^2} \quad (16)$$

The monopoly platform's optimal profit takes the first-order derivative for consumer information level, as shown in Equation (17):

$$\frac{\partial\Pi_{pl}^*}{\partial\theta} = \frac{8v^2\,(1-\theta)\,[4-(\varphi+v)\,(\varphi+\theta v)]}{[4-(\varphi+v)\,(\varphi+\theta v)]^4} > 0 \quad (17)$$

Equation (17) shows that the higher the consumer information level, the higher the monopoly platform profit. From Equation (16), when $\theta = 0$, there is highest level of asymmetry between consumers and merchants and the lowest proportion of informed consumers, the lowest profit of the monopoly platform is $\frac{4-\varphi^2}{[4-\varphi(\varphi+\nu)]^2}$; when $\theta = 1$, there is lowest level of asymmetry between consumers and merchants, and the highest proportion of informed consumers, and the highest profit of the monopoly platform is $\frac{4-(\varphi+\nu)^2}{\left[4-(\varphi+\nu)^2\right]^2}$.

It follows from result 1 that for the monopoly online shopping platform, the higher consumer information level, i.e., the lower bilateral user information asymmetry, the higher the online shopping platform profit.

Result 2 In the monopoly platform, the effect of consumer information level on platform-to-consumer pricing is decided by the magnitude of cross-network externalities; the higher the consumer information level, the lower the platform-to-merchant pricing.

Proof Bilateral user pricing in monopoly platforms takes the first-order derivative for consumer information level, as shown in Equation (18):

$$\begin{aligned}\frac{\partial p_b^*}{\partial \theta} &= \frac{2\nu\left(\nu-\varphi\right)}{\left[4-\left(\varphi+\nu\right)\left(\varphi+\theta\nu\right)\right]^2},\\ \frac{\partial p_s^*}{\partial \theta} &= \frac{\left[2\varphi\left(\varphi+\nu\right)-4\right]\nu}{\left[4-\left(\varphi+\nu\right)\left(\varphi+\theta\nu\right)\right]^2} < 0\end{aligned} \tag{18}$$

Equation (18) shows that if merchant network externality is greater than consumer network externality, the higher the consumer information level and the higher the monopoly platform's pricing to consumers; if merchant network externality is less than consumer network externality, the higher the consumer information level, the lower the monopoly platform's pricing to consumers. When consumer information level increases, the monopoly platform pricing to merchants decreases.

Result 3 The higher the consumer information level, the more the platform attracts bilateral users to join under cross-network externalities of the monopoly platform.

Proof In the monopoly platform, the number of bilateral users takes the first-order derivative for consumer information level, as shown in Equation (19):

$$\begin{aligned}\frac{\partial N_b^*}{\partial \theta} &= \frac{2\nu\left(\nu+\varphi\right)}{\left[4-\left(\varphi+\nu\right)\left(\varphi+\theta\nu\right)\right]^2} > 0,\\ \frac{\partial N_s^*}{\partial \theta} &= \frac{4\nu}{\left[4-\left(\varphi+\nu\right)\left(\varphi+\theta\nu\right)\right]^2} > 0\end{aligned} \tag{19}$$

With cross-network externalities, Equation (19) shows that as consumer information level increases, the number of monopoly platform bilateral users increases, and that consumers and merchants are more willing to transact on the platform.

According to result 2 and result 3, Equation (18) and Equation (19) are subtracted, as shown in Equation (20).

$$\frac{\partial p_b^*}{\partial \theta} - \frac{\partial N_b^*}{\partial \theta} < 0, \frac{\partial p_s^*}{\partial \theta} - \frac{\partial N_s^*}{\partial \theta} < 0 \tag{20}$$

From Equation (20), the effect of consumer information level on the number of monopoly platform bilateral users is greater than the effect on bilateral user pricing. Therefore, regardless of cross-network externality magnitude, increasing consumer information levels will eventually lead to increase in platform profits.

In sum, the monopoly platform aims at maximizing profit given cross-network externalities. It increases consumer information levels and brings increased benefits to consumers, merchants, and the platform, which improves overall social welfare. Therefore, the monopoly platform has an incentive to increase consumer information level.

Analyzing the Effect of Consumer Information Level in the Competitive Platform

Result 4 With cross-network externalities of the competitive platform, the lower the consumer information level, the higher the platform profits.

Proof Substituting Equation (8), Equation (9), and Equation (10) into Equation (7) yields Equation (21).

$$N_{1b} = \frac{1-\theta\nu\left(\varphi+p_{1s}-p_{2s}\right)+\left(1-\theta\right)\nu\left(N_{1s}^e-N_{2s}^e\right)+p_{2b}-p_{1b}}{2\left(1-\theta\varphi\nu\right)} \tag{21}$$

Substituting Equation (9) and Equation (21) into Equation (11) yields Equation (22):

$$\begin{aligned}&\Pi_{pl1} = \left(p_{1b}+\varphi p_{1s}\right)\\ &\frac{1-\theta\nu\left(\varphi+p_{1s}-p_{2s}\right)+\left(1-\theta\right)\nu\left(N_{1s}^e-N_{2s}^e\right)+p_{2b}-p_{1b}}{2\left(1-\theta\varphi\nu\right)}\\ &-{p_{1s}}^2\end{aligned} \tag{22}$$

In Equation (22), platform profit takes the first-order derivative separately for bilateral user pricing, as shown in Equation (23):

$$\begin{aligned}\frac{\partial \Pi_{pl1}}{\partial p_{1b}} &= \frac{1-\theta\nu\left(\varphi+p_{1s}-p_{2s}\right)+\left(1-\theta\right)\nu\left(N_{1s}^e-N_{2s}^e\right)+p_{2b}-2p_{1b}-\varphi p_{1s}}{2\left(1-\theta\varphi\nu\right)},\\ \frac{\partial \Pi_{pl1}}{\partial p_{1s}} &= \frac{\varphi\left(1-\theta\nu\right)\left(\varphi+p_{1s}-p_{2s}\right)+\left(1-\theta\right)\varphi\nu\left(N_{1s}^e-N_{2s}^e\right)+\varphi\left(p_{2b}-p_{1b}\right)-\theta\nu\left(p_{1b}+\varphi p_{1s}\right)}{2\left(1-\theta\varphi\nu\right)} - 2p_{1s}\end{aligned} \tag{23}$$

Let $\frac{\partial \Pi_{pl1}}{\partial p_{1b}} = 0$ and $\frac{\partial \Pi_{pl1}}{\partial p_{1s}} = 0$. According to the Armstrong (2006) model, because of the symmetry of the platform, platform

pricing for bilateral users satisfies $p_{1b} = p_{2b}$ and $p_{1s} = p_{2s}$ under the $N_{is} = N_{is}^{e}$ equilibrium condition, and we obtain competitive platform optimal pricing for consumers and optimal pricing for merchants, as shown in Equation (24):

$$p_b^* = \frac{4 - 3\theta\varphi\nu - \varphi^2}{4}, p_s^* = \frac{\varphi - \theta\ \nu}{4}. \tag{24}$$

Substituting Equation (24) into Equation (7), Equation (8), Equation (9), and Equation (10) gives the optimal number of consumers and merchants for the competitive platform, as shown in Equation (25):

$$N_b^* = \frac{1}{2}, N_s^* = \frac{\varphi + \theta\nu}{4}. \tag{25}$$

Substituting Equation (24) and Equation (25) into Equation (11) gives the optimal profit of the competitive platform, as shown in Equation (26):

$$\Pi_{pl}^* = \frac{8 - \varphi^2 - 6\theta\varphi\nu - \theta^2\nu^2}{16}. \tag{26}$$

The competitive platform profit takes the first-order derivative for consumer information level, as shown in Equation (27):

$$\frac{\partial \Pi_{pl}^*}{\partial \theta} = \frac{-6\varphi\nu - 2\theta\nu^2}{16} < 0 \tag{27}$$

From Equation (27), under the effect of cross-network externalities, the higher the consumer information level, the lower the competitive platform profit. From Equation (26), when $\theta = 0$ with the highest level of asymmetry between consumers and merchants and the lowest proportion of single-homing informed consumers, then the highest competitive platform profit is $\frac{8-\varphi^2}{16}$; when $\theta = 1$ with lowest level of asymmetry between consumers and merchants and highest proportion of single-homing informed consumers, then the lowest competitive platform profit is $\frac{8-\varphi^2-6\varphi\nu-\nu^2}{16}$.

From result 4, the lower the consumer information level, the higher the competitive online shopping platform profit.

Result 5 With cross-network externalities of the competitive platform, the lower the consumer information level, the higher the platform pricing for bilateral users.

Proof Competitive platform pricing for bilateral users takes the first-order derivative for consumer information level, as shown in Equation (28):

$$\frac{\partial p_b^*}{\partial \theta} = \frac{-3\varphi\nu}{4} < 0, \frac{\partial p_s^*}{\partial \theta} = \frac{-\nu}{4} < 0 \tag{28}$$

Result 6 With cross-network externalities of the competitive platform, consumer information level does not affect the number of consumers; the higher the consumer information level, the more merchants that want to join.

Proof The number of consumers and number of merchants in the competitive platform take the first-order derivative for consumer information level, as shown in Equation (29).

$$\frac{\partial N_b^*}{\partial \theta} = 0, \frac{\partial N_s^*}{\partial \theta} = \frac{\nu}{4} > 0 \tag{29}$$

The general intuition is that two online shopping platforms compete to attract bilateral users to join the platform by reducing the information asymmetry of the bilateral users. The platform decreases pricing for bilateral users, which makes the competing platforms more profitable. However, this conclusion is the opposite of result 4. Based on calculations in Equation (28) and Equation (29), the competitive platform exploits the information asymmetry of bilateral users to increase profits. The competitive platform maximizes profits by increasing the information asymmetry of bilateral users and decreasing pricing to bilateral users.

In the above analysis, the competitive platform aims to maximize profits by reducing consumer information level and increasing the fees charged to bilateral users under cross-network externalities. Therefore, the competitive platform has no incentive to raise consumer information level.

Analyzing the Effect of Consumer Information Level in the Mixed Market Structure

Online trading platforms include both head market platforms (e.g., Taobao and JD) and many segmented market platforms (e.g., Mogu and Beibei). Therefore, there is a hybrid state of imperfectly competitive markets between duopoly market structure and monopoly market structure, and this hybrid market structure is dynamic. The consumer quantity function in the hybrid market structure is shown in Equation (30) and Equation (31). The merchant quantity function is given in Equation (9) and Equation (10); the profit function is still calculated using Equation (11):

$$\begin{aligned} N_{1b} = \theta & \left[\gamma \left(\frac{1}{2} + \frac{\nu\left(N_{1s} - N_{2s}\right) - \left(p_{1b} - p_{2b}\right)}{2} \right) \right. \\ & \left. + (1-\gamma)\left(1 + \nu N_{1s} - p_{1b}\right) \right] + (1-\theta) \\ & \left[\gamma \left(\frac{1}{2} + \frac{\nu\left(N_{1s}^{e} - N_{2s}^{e}\right) - \left(p_{1b} - p_{2b}\right)}{2} \right) + (1-\gamma) \right. \\ & \left. \left(1 + \nu N_{1s}^{e} - p_{1b}\right) \right] \end{aligned} \tag{30}$$

$$\begin{aligned} N_{2b} = \theta & \left[\gamma \left(\frac{1}{2} - \frac{\nu\left(N_{1s} - N_{2s}\right) - \left(p_{1b} - p_{2b}\right)}{2} \right) \right. \\ & \left. + (1-\gamma)\left(1 + \nu N_{2s} - p_{2b}\right) \right] + (1-\theta) \\ & \left[\gamma \left(\frac{1}{2} - \frac{\nu\left(N_{1s}^{e} - N_{2s}^{e}\right) - \left(p_{1b} - p_{2b}\right)}{2} \right) + (1-\gamma) \right. \\ & \left. \left(1 + \nu N_{2s}^{e} - p_{2b}\right) \right] \end{aligned} \tag{31}$$

Here, γ denotes market competition level, and different values of γ indicate market structures at varying times. When $\gamma = 0$, the platform has a monopoly market structure, as in case 4.1; when $\gamma = 1$, the platform has a duopoly market structure, as in case 4.2.

Proof Similar to the proof of 4.2, the solution of the joint cubic Equation (9), Equation (10), Equation (30), and Equation (31) can be obtained as$N_{1b}(\theta,\gamma)$, $N_{2b}(\theta,\gamma)$, $N_{2s}(\theta,\gamma)$, and $N_{2s}(\theta,\gamma)$. Next, we substitute $N_{1b}(\theta,\gamma)$, $N_{2b}(\theta,\gamma)$, $N_{1s}(\theta,\gamma)$, and $N_{2s}(\theta,\gamma)$ into the profit function and take the first-order

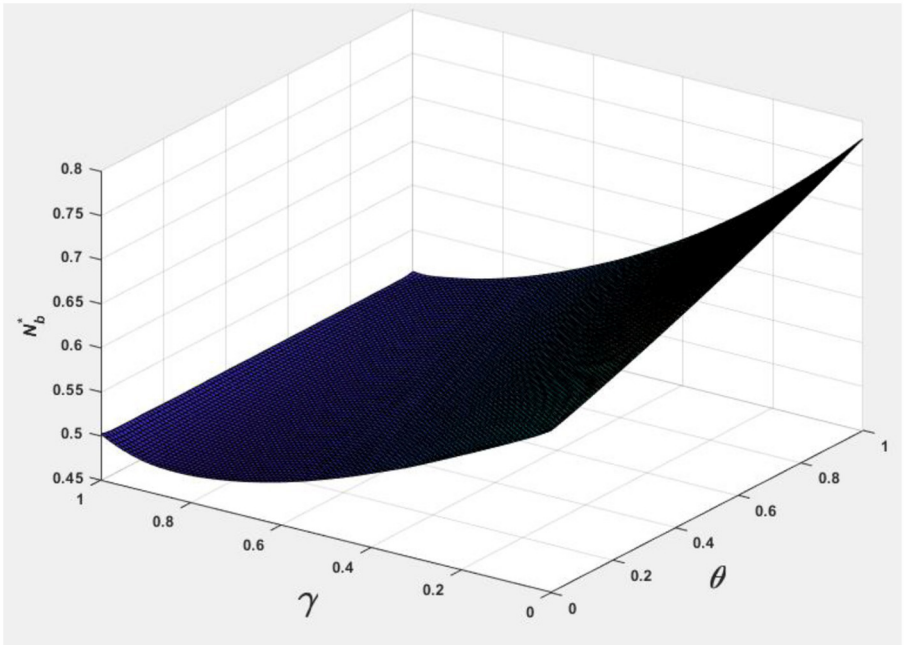

FIGURE 1 | Effect of θ, γ on N_b^*.

derivative for the profit function. Let $N_{1s}^e = N_{2s}^e = N_s^e$. We can obtain p_b^*, p_s^*, N_b^*, N_s^*, and Π_{pl}^*, as shown in Equation (32):

$$p_b^* = \frac{BC - \varphi AC}{H}; p_s^* = \frac{AC}{H}; N_b^* = \frac{ABC}{H}; N_s^* = \frac{\varphi ABC - AC}{H};$$
$$\Pi_{pl}^* = \frac{AB^2C^2 - A^2C^2}{H^2} \quad (32)$$

Here, $A = \frac{2-\gamma-2(1-\gamma)\theta\varphi v}{2[1-(1-\gamma)\theta\varphi v](1-\theta\varphi v)}, B = \frac{2}{\varphi-\theta v}, C = \frac{2-\gamma}{2[1-(1-\gamma)\varphi v]}, D = \frac{1-\gamma}{1-(1-\gamma)\varphi v}, and\ H = AB + (v-\varphi)\,AD + BD$

To facilitate analyzing the effects of consumer information level θ and the market competition level γ on p_b^*, p_s^*, N_b^*, N_s^*, and Π_{pl}^*, we let $v = 0.5$ and $\varphi = 0.7$, and the following **Figures 1**–**5** are obtained by referring to the assignment of Hagiu and Hałaburda (2014).

From **Figures 1**, **2**, it can be seen that to occupy a larger market share, eBay, Taobao, JD, Guazi, and other online shopping platforms provide better differentiated return services to improve consumer information levels, such as Tmal (with a 30-day warranty service) and Nike (with a 30-day no-reason return service) (Choi, 2013). JD has launched 1 and 3-year warranty services. Guazi provides a 30-day comprehensive warranty, a 7-day no-reason return, a 7-day no-reason exchange, a 259 safety inspection, and other services to protect consumer rights.

From **Figure 3**, to obtain greater profits, if the market competition level is lower, platforms have more incentive to improve consumer information level. In contrast, when market competition level is higher, platforms have less incentive to improve the level of information services. Therefore, the market generally adopts a 7-day no-reason return service for most competitive goods in online shopping platforms.

From **Figures 4**, **5**, it can be seen that to improve consumer information level, the more competitive the platform is, the lower the membership fees charged to consumers and merchants. We see Taobao and JD, for example, give consumers red packet allowances to improve the size of transactions s. They also give different forms of subsidies such as technical service fees and free store decorations to merchants.

DISCUSSION

The Armstrong (2006) model introduces cross-network externalities, and explains why online shopping platforms adopt skewed pricing strategies to subsidize consumers. Hagiu and Hałaburda (2014) introduce expectation factors and changes in cross-network externalities under different expectation formation mechanisms, leading to different responses in platform pricing, which ultimately lead to differences in platform profits. In the monopoly platform, profits of responsive expectations are higher than those of passive expectations; in the competitive platform, platform profits of passive expectations are higher than those of responsive expectations. Based on Armstrong (2006) and Hagiu and Hałaburda (2014), our research develops an imperfect information pricing model considering the level of consumer information to explain why online shopping platforms adopt measures to reduce the level of bilateral information asymmetries. This section further examines the effect of the platform increasing consumer information level

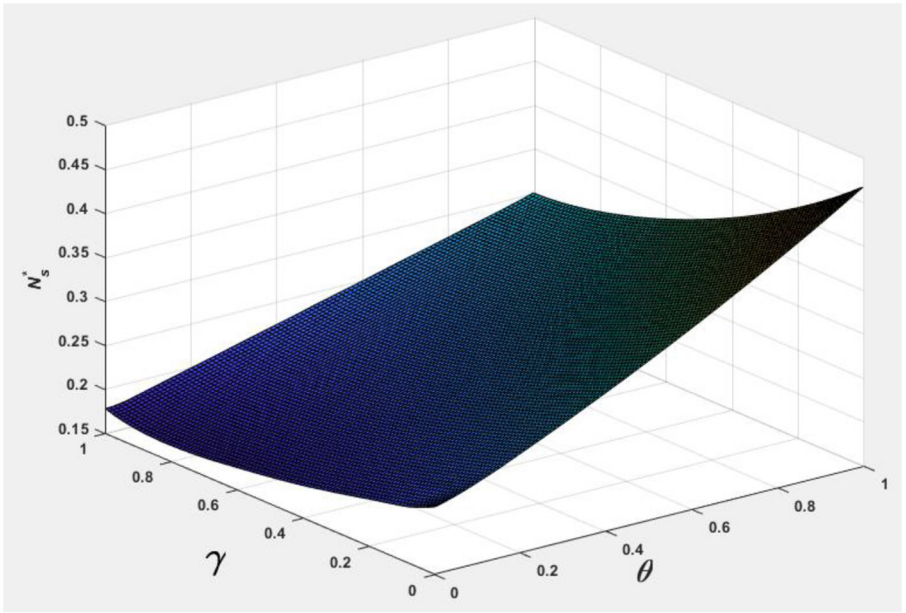

FIGURE 2 | Effect of θ, γ on N_s^*.

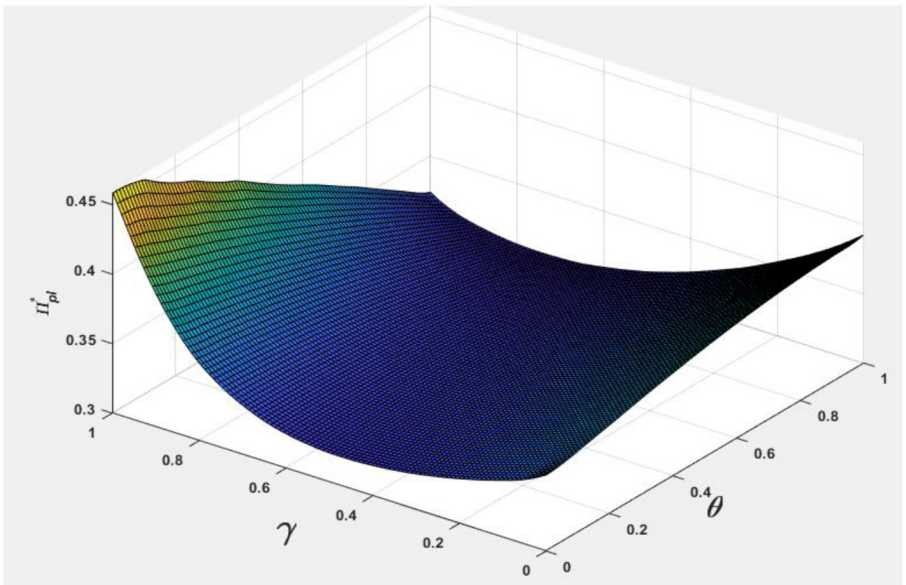

FIGURE 3 | Effect of θ, γ on Π_{pl}^*.

(e.g., adopting return measures) on platform pricing, the number of bilateral users, and platform profits.

Guazi, eBay, Taobao, JD, and other online trading platforms provide a basic level of information to consumers. The platforms adopt return measures to release buyers and sellers from the contract to protect consumers' rights and maximize profits. This approach motivates merchants to disclose more private information about their goods, reduces the information asymmetry of bilateral users, and acts as a disincentive for dishonest merchants to trade. When the platform adopts return measures, the consumer information level function is shown as Equation (33):

$$\theta = k\omega(t) + \theta_0 \tag{33}$$

Here, $k > 0$, k denotes the conversion coefficient between platform return service level and consumer information level; $\omega(t)$ ($\omega(t) \in [0, 1]$) denotes platform return service level, and

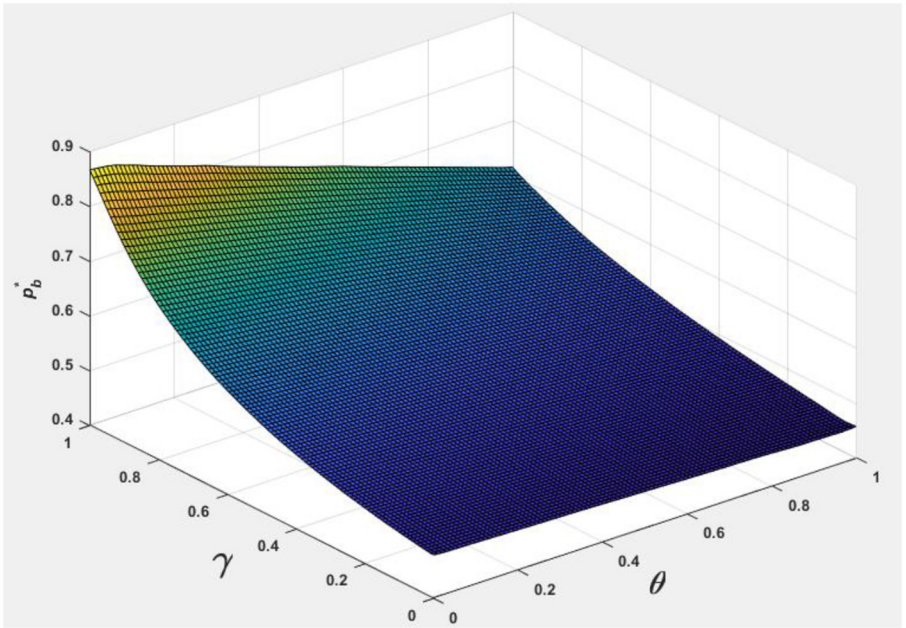

FIGURE 4 | Effect of θ, γ on p_b^*.

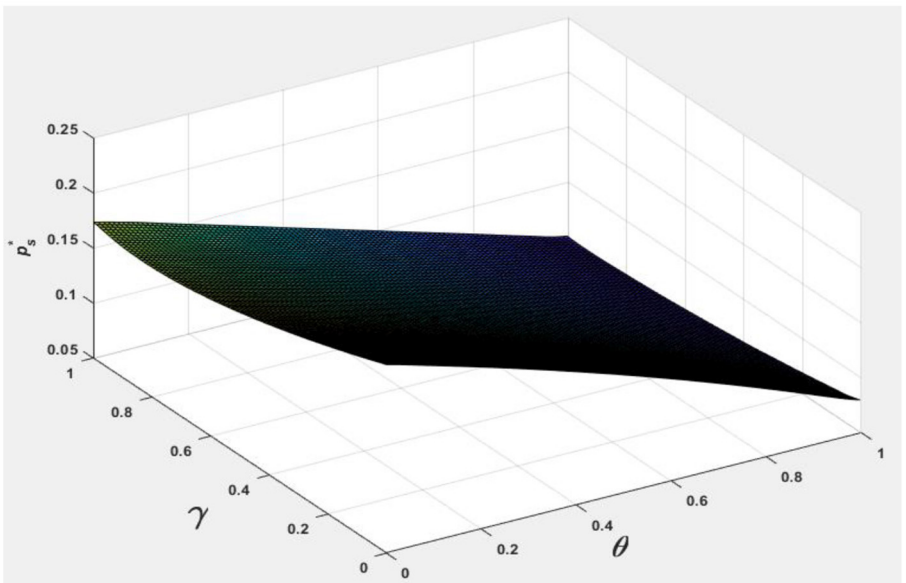

FIGURE 5 | Effect of θ, γ on p_s^*.

when$\omega(t) = 0$, the online shopping platform does not adopt return measures. This study assumes that the longer the return time provided by the platform, the higher the platform return service level when consumers return goods purchased that do not meet their expectations, i.e., $\frac{\partial \omega(t)}{\partial t} \geq 0$.

To facilitate transactions, merchants in online shopping platforms use pictures, text, videos, live streaming, and other forms to convey product information to consumers on the product display page. However, consumers have different levels of information about each type of goods before a purchase. Nelson (1970) divided goods into two categories: search goods and experience goods. On the premise that consumer information level and conversion coefficient remain unchanged, consumers have more information about search goods (such

as clothes, pants, and shoes) than experience goods (such as cars and food) before shopping, i.e., $\theta_{0(Search\ goods)} > \theta_{0(Experience\ goods)}$. When consumers return goods that do not meet their expectations, the platform sets the return time for search goods shorter than that for experience goods. For example, eBay has different return times for fashion, health and beauty, home and garden, media and other goods, and return times are at least 30 or 60 days.

Analyzing the Role of the Monopoly Platform When Adopting Return Measures

From Equation (14), when no return measures are adopted, the monopoly platform pricing for consumers and merchants is given, as shown in Equation (34):

$$p_b^1 = \frac{2-\varphi\left(\varphi+\theta_0 v\right)}{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)}, p_s^1 = \frac{\varphi-\theta_0 v}{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)} \quad (34)$$

From Equation (15), when no return measures are adopted, the number of consumers and merchants is given in the monopoly platform, as shown in Equation (35):

$$N_b^1 = \frac{2}{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)}, N_s^1 = \frac{\varphi+\theta_0 v}{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)} \quad (35)$$

From Equation (16), we can obtain monopoly platform profit when no return measures are adopted, as shown in Equation (36):

$$\Pi_{pl}^1 = \frac{4-\left(\varphi+\theta_0 v\right)^2}{\left[4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)\right]^2} \quad (36)$$

Substituting Equation (33) into Equation (14), we obtain the pricing for consumers p_b^2 and pricing for merchants p_s^2 when the monopoly online shopping platform adopts return measures and then compare them with the pricing for consumers p_b^1 and pricing for merchants p_s^1 when no return measures are adopted, as shown in Equation (37):

$$\frac{p_b^2}{p_b^1} = \frac{8-4\varphi\left(\varphi+\theta_0 v\right)-2\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)+\varphi\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)\left(\varphi+\theta_0 v+k\omega v\right)-4\varphi k\omega v}{8-4\varphi\left(\varphi+\theta_0 v\right)-2\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)+\varphi\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)\left(\varphi+\theta_0 v+k\omega v\right)-2\left(\varphi+v\right)k\omega v}$$
$$\frac{p_s^2}{p_s^1} = \frac{4\left(\varphi-\theta_0 v\right)-\varphi\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)+v\left(\varphi+v\right)\theta_0\left(\varphi+\theta_0 v+k\omega v\right)+\left[\varphi\left(\varphi+v\right)-4\right]k\omega v}{4\left(\varphi-\theta_0 v\right)-\varphi\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)+v\left(\varphi+v\right)\theta_0\left(\varphi+\theta_0 v+k\omega v\right)-\varphi\left(\varphi+v\right)k\omega v} < 1 \quad (37)$$

From Equation (37), when merchant-to-consumer network externalities are greater than consumer-to-merchant network externalities, $\frac{p_b^2}{p_b^1} > 1$ is given. When the monopoly online shopping platform adopts return measures, it raises charges to consumers (e.g., reduces subsidies). Conversely, the monopoly online shopping platform reduces charges to consumers (e.g., the platform will subsidize consumers on top of original charges). When the monopoly online shopping platform adopts return measures (increasing consumer information level), the platform will reduce charges to merchants.

Substituting Equation (33) into Equation (15), we obtain the number of consumers N_b^2 and the number of merchantsN_s^2 when the monopoly online shopping platform adopts return measures and then compare them with the number of consumers N_b^1 and the number of merchants N_s^1 when return measures are not adopted, as shown in Equation (38):

$$\frac{N_b^2}{N_b^1} = \frac{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)}{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v+k\omega v\right)} > 1, \quad (38)$$
$$\frac{N_s^2}{N_s^1} = \frac{4\left(\varphi+\theta_0 v\right)-\varphi\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)-v\left(\varphi+v\right)\theta_0}{\left(\varphi+\theta_0 v+k\omega v\right)-\varphi\left(\varphi+v\right)k\omega v+4k\omega v} > 1$$
$$\frac{4\left(\varphi+\theta_0 v\right)-\varphi\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)-v\left(\varphi+v\right)\theta_0}{\left(\varphi+\theta_0 v+k\omega v\right)-\varphi\left(\varphi+v\right)k\omega v}$$

From Equation (38), when the monopoly online shopping platform adopts return measures, it attracts more consumers to enter the platform to trade. With cross-network externalities, it attracts more merchants to trade on the platform.

Substituting Equation (33) into Equation (16), we obtain the profit Π_{pl}^2 when the monopoly online shopping platform adopts return measures and then compare it with the profit Π_{pl}^1 when the return measure is not adopted, as shown in Equation (39):

$$\frac{\Pi_{pl}^1}{\Pi_{pl}^2} = \frac{4-\left(\varphi+\theta_0 v\right)^2}{4-\left(\varphi+\theta_0 v+k\omega v\right)^2} * \left[\frac{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v+k\omega v\right)}{4-\left(\varphi+v\right)\left(\varphi+\theta_0 v\right)}\right]^2 < 1 \quad (39)$$

From Equation (39), when the monopoly online shopping platform adopts return measures, it can promote the growth of platform profits.

Analyzing the Role of the Competitive Platform When Adopting Return Measures

From Equation (24), when no return measures are adopted, the competitive platform pricing for consumers and merchants is given, as shown in Equation (40):

$$p_b^3 = \frac{4-3\theta_0\varphi v-\varphi^2}{4}, p_s^3 = \frac{\varphi-\theta_0 v}{4} \quad (40)$$

From Equation (25), when no return measures are adopted, the number of consumers and merchants is given in the competitive platform, as shown in Equation (41):

$$N_b^3 = \frac{1}{2}, N_s^3 = \frac{\varphi+\theta_0 v}{4} (41). \quad (41)$$

From Equation (26), we can obtain competitive platform profit when no return measures are adopted, as shown in Equation (42):

$$\Pi_{pl}^3 = \frac{8-\varphi^2-6\theta_0\varphi v-\theta_0{}^2 v^2}{16} \quad (42)$$

Substituting Equation (33) into Equation (24), we obtain the pricing for consumers p_b^4 and pricing for merchants p_s^4 when the competitive online shopping platform adopts return measures, and then we subtract, respectively, the pricing for consumers p_b^3 and pricing for merchants p_s^3 when the competitive online shopping platforms do not adopt return measures, as shown in Equation (43):

$$p_b^4 - p_b^3 = \frac{-3k\omega\varphi v}{4} < 0, p_s^4 - p_s^3 = \frac{-k\omega v}{4} < 0 \quad (43)$$

From Equation (43), when the competitive online shopping platform adopts return measures, the platform reduces consumer and merchant charges.

Substituting Equation (33) into Equation (25), we obtain the number of consumers N_b^4 and the number of merchants N_s^4 when the competitive online shopping platform adopts return measures, and then subtract, respectively, the number of consumers N_b^3 and the number of merchants N_s^3 when the competitive online shopping platform does not adopt return measures, as shown in Equation (44):

$$N_b^4 - N_b^3 = 0, N_s^4 - N_s^3 = \frac{k\omega v}{4} > 0. \quad (44)$$

From Equation (44), the competitive online shopping platform maintains consumer size and attracts more merchants to join platform transactions when it adopts return measures.

Substituting Equation (33) into Equation (26), we obtain the profit Π_{pl}^4 when the competitive online shopping platform adopts return measures, and then subtract the profit Π_{pl}^3 when the competitive online shopping platform does not adopt return measures, as shown in Equation (45):

$$\Pi_{pl}^4 - \Pi_{pl}^3 = \frac{-6k\omega\varphi v - (k\omega)^2 v^2 - 2k\omega\theta_0 v^2}{16} < 0 \quad (45)$$

From Equation (45), when the competitive online shopping platform adopts return measures, it sacrifices part of its profit to subsidize merchants and consumers, maintaining the number of consumers and expanding the number of merchants.

CONCLUSION

Online shopping platforms bring convenience to consumers, but there are still dishonest trading problems, such as mismatches between transaction price and expected quality of goods purchased. For long-term development, online shopping platforms, such as Taobao and JD, often adopt 7-day no-reason return services; likewise, 30-day no-reason return measures are used by Nike (Choi, 2013). Also, cash-on-delivery, word-of-mouth reviews, merchant ratings, and other measures reduce bilateral user information asymmetry level and govern dishonest transactions. In this study, based on previous research (Armstrong, 2006; Hagiu and Hałaburda, 2014), we constructed a pricing model for online shopping platforms, which introduces consumer information level, and we analyze pricing strategies of monopoly and competitive online shopping platforms. Furthermore, we examined the role of online shopping platforms when adopting return measures. To assess the robustness of the findings, we study the pricing strategies of online shopping platforms under imperfect competition conditions in the market. We obtain the following conclusions under the consideration of network effects.

(1) In the monopoly online shopping platform, the lower the bilateral user information asymmetry level, merchants and consumers that are attracted to trade, and platform profits are higher. Therefore, monopoly platforms have an incentive to improve consumer information level when they pursue profit maximization.

When the monopoly online shopping platform increases consumer information level (e.g., adopting return measures), the platform can reduce charges to merchants. The platform subsidizes merchants on original charges, e.g., by reducing merchant registration fees, reducing technical service fees, providing free store decorations, or similar measures. Thus, the platform can attract more merchants and consumers to trade and can realize platform profit growth.

(2) The higher the consumer information level in the competitive online shopping platform, the lower the fees charged to merchants and consumers. The platform sacrifices some of its profits to attract more merchants to join and to maintain a number of consumers. Therefore, relative to the monopoly platform, the competitive platform has relatively little incentive to increase consumer information level while pursuing profit maximization.

Since competitive online shopping platforms have little incentive to improve consumer information level, market regulators should adopt a 14-day return time (or longer) to protect consumer rights. When a competitive online shopping platform increases consumer information level (e.g., by adopting return measures), it can expand the number of merchants and maintain the number of consumers by reducing charges for bilateral users. For consumers, the platform can issue red packets, discount coupons, etc.; for merchants, the platform can provide free value-added services and other similar benefits.

(3) Since consumers have different levels of information about various goods, online shopping platforms adopt different high-quality return services to reduce bilateral user information asymmetry level, and the return time of experience goods is greater than that of search goods.

The study also has some shortcomings. For example, merchants assume complete information about consumers, and consumers do not adjust their decisions based on available information. We further study platform pricing strategies with bilateral information uncertainty between merchants and consumers.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

HC: conceptualization, methodology, visualization, investigation, supervision, and writing (original draft). WX: software, data curation, validation, and writing (review and editing). PX: conceptualization, project administrations, supervision, validation, and writing (review and editing). All authors contributed to the article and approved the submitted version.

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How Are Consumers Affected by Taste and Hygiene Ratings When Ordering Food Online? A Behavioral and Event-Related Potential Study

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With the rapid development of the take-out industry, taste and hygiene ratings as social-based information have been frequently used by online food-ordering platforms to facilitate consumer purchases. The present study aims to uncover the effects of taste and hygiene ratings on online food-ordering decision by incorporating behavioral and neural approaches. The behavioral results showed that a high taste rating induced a higher ordering intention than a low taste rating, and that a high hygiene rating induced a higher ordering intention than a low hygiene rating. The effect of hygiene rating on ordering intention was moderated by taste rating. Hygiene rating had a greater impact on ordering intention when the taste rating was high (vs. low). In addition, inconsistency between taste and hygiene ratings increased the cognitive load and took more time for decision-making. The event-related potential (ERP) data revealed that consumers paid more attention to a high (vs. low) taste rating in the early cognitive process, which was reflected by a larger P2. Subsequently, a more negative N2 was elicited by conflicting ratings than consistent ratings when the taste rating was low. In the relatively late decision-making process, a larger P3 was evoked by consistent than conflicting ratings, suggesting that consumers had more confidence in their decisions for consistent ratings. These findings could help restaurants understand the roles of taste and hygiene rating cues in affecting consumer behavior and prompt those restaurants to adopt effective measures to increase online sales.

Keywords: taste rating, hygiene rating, food, cue diagnosticity theory, event-related potentials

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INTRODUCTION

With the development of e-commerce, online restaurant ordering, and take-out service have become important parts of daily life. In particular, the outbreak of the COVID-19 pandemic has stimulated the development of the so-called at-home economy since 2020. Consumers could simply browse the information of foods and restaurants at home and order take-outs using mobile food-ordering applications. This process is convenient and efficient for consumers. However, consumers face difficulties in inferring food quality because the foods and restaurants can not be directly observed and physically experienced during online purchase. Since consumer-generated comments

and ratings exert informational and social influences on consumer behavior (Utz et al., 2012; Kuan et al., 2014; Tang and Song, 2019), ratings about food taste and hygiene have been increasingly used by the online take-out industry to facilitate consumer decision-making.

Prior research has identified taste and health as important factors that influence food consumption (Vadiveloo et al., 2013). Taste provides information about food quality and is perhaps one of the most important determinants of food preference (Pirastu et al., 2012). Though unable to obtain direct physical experience about taste during online food-ordering, consumers could form taste perception by referring to the reviews posted by other consumers. Hygiene is an important characteristic linked to food safety and consumer health (Kang, 2015). Food manufacturers and restaurants have been trying to brand their healthy image and sell their products through a hygiene perspective (Chandon and Wansink, 2007). The ease of identifying healthful (or hygienic) food has a positive effect on food choice (Liu et al., 2012; Rogers et al., 2016). Not surprisingly, ratings about food taste and hygiene in e-commerce provide crucial information about food quality. Numerous studies have shown that product rating has a notable influence on consumer attitude and can reflect whether the sellers are reliable (Lee et al., 2008). But little empirical research to date has endeavored to understand how taste and hygiene ratings affect consumer choice. It is suggested that the informational social influence of others is highly salient in the context of food consumption (Cruwys et al., 2015). Therefore, we infer that taste and hygiene ratings have positive effects on consumer decision-making during online food-ordering.

According to the cue utilization theory, shopping websites deliver a series of cues which can be divided into intrinsic cues and extrinsic cues, and consumers use both intrinsic and extrinsic cues to assess product quality (Olson and Jacoby, 1972; Dimoka et al., 2012). Intrinsic cues are associated with the direct physical attributes of the product (e.g., ingredients, taste, and smell), whereas extrinsic cues are usually associated with indirect aspects of the product (e.g., product price, brand reputation and online reviews) (Richardson et al., 1994). When consumers are unable to experience intrinsic product cues directly, they tend to make use of extrinsic cues to assess product quality (Wells et al., 2011). Previous research has indicated that extrinsic cues in online stores provide important guidance for consumers' decisions (Parboteeah et al., 2009; Hu et al., 2010). Since consumers can not directly observe the intrinsic cues of food from mobile food-ordering applications, they are more likely to apply extrinsic cues (i.e., online comments) to assessing food quality. Moreover, building on cue utilization theory, cue-diagnosticity theory suggests that when consumers are faced with multiple extrinsic cues in an online market, they are inclined to prioritize them based on their diagnosticity (Slovic and Lichtenstein, 1971; Skowronski and Carlston, 1987). Diagnosticity refers to the ability of a cue in assisting product evaluation and decision making (e.g., quality assessment and categorization) (Skowronski and Carlston, 1987; Feldman and Lynch, 1988). A more diagnostic cue is given more importance and is more likely to be utilized in product evaluation compared to a less diagnostic cue (Feldman and Lynch, 1988; Purohit and Srivastava, 2001). When multiple cues coexist, the effectiveness of a less diagnostic cue in affecting product evaluation is prone to be enhanced when the more diagnostic cue has a positive valence and inhibited when the more diagnostic cue has a negative valence (Purohit and Srivastava, 2001). For example, Wang et al. (2016) investigated the joint influence of product rating and sales cues on purchase decision and observed that product rating (a more diagnostic cue) had a more pronounced impact on purchasing rate than sales (a less diagnostic cue). When the product rating is high, sales has a positive effect on purchasing rate; but when the product rating is low, sales has no effect on purchasing rate (Wang et al., 2016). In a study examining the joint influence of online rating and product price on purchase decision, it is found that product rating as a more diagnostic cue can positively moderate the effect of price (a less diagnostic cue) on purchase intention (Tang and Song, 2019). However, it is still unknown about the difference of diagnosticity between taste rating and hygiene rating cues. In the present study, taste rating might be perceived with a higher level of diagnosticity compared to hygiene rating given that taste is a key determinant of food quality (Pirastu et al., 2012). It remains to be explored whether these two types of ratings could be interactive in affecting consumer decision-making. According to extant literature on cue diagnosticity, we expect that taste rating would be prioritized in decision making and would moderate the effect of hygiene rating on consumer responses.

Given that neuromarketing approaches are conducive to understanding consumer information processing and decision-making (Yuan et al., 2007; Wang et al., 2016, 2020; Hsu, 2017; Shang et al., 2020), the event-related potential (ERP) method can be used to provide neural evidence for the mechanisms underlying the impact of taste and hygiene rating cues and to understand the priority of information processing between these two factors. Compared with self-report, ERP method can open the black box of the brain and explore the corresponding information processing activities (Dimoka et al., 2012; Kuan et al., 2014). Furthermore, the use of self-reported data is often blamed for bring about subjective biases (Kuan et al., 2014). Therefore, the current study adopted ERP method and behavioral method to examine the underling neural mechanism by considering the effects of two extrinsic rating cues in online food-ordering decision. On the basis of prior studies on information processing and purchase decision-making (Ma et al., 2014; Wang et al., 2016), P2, N2, and P3 were of particular interest to us in the current study.

P2 is a relatively early positive ERP component over frontal regions (Polezzi et al., 2008). It is an attention-associated component that represents early rapid automatic activity, which is followed by the progressive recruitment of slow, elaborative and semantic processing under voluntary control (Correll et al., 2006; Thomas et al., 2007; Ma et al., 2014). Thomas et al. (2007) suggests that P2 reflects the rapid and automatic evaluation of the stimulus in early cognitive stages, and the amplitude of P2 indicates the attention resources invested in the stimulus. The attention resources invested by decision makers are positively correlated with P2 amplitude (Mercado et al., 2006). Therefore, in this study, we speculate that a cue with a high level of diagnosticity (i.e., taste rating) might be

prioritized in information processing and grab attention in the relatively early processing stage, which would be indicated by a noticeable P2 component.

N2, another frequently studied ERP component in decision-making research, typically appears after the presence of a stimulus over anterior scalp regions (Folstein and Van Petten, 2008). Unlike P2, N2 belongs to the conscious cognitive processing stages, during which more complex stimuli features could be detected and processed (Yuan et al., 2007). Previous studies have consistently demonstrated that the N2 amplitude is positively associated with conflict detection and cognitive control (Yeung et al., 2004; Yang et al., 2007; Wang et al., 2020). A high degree of conflict induces a more negative N2 amplitude than a low degree of conflict (Yang et al., 2007). For instance, individuals show higher N2 amplitudes when faced with a mismatch between price cues, which suggest the presence of heightened cognitive and decisional conflict (Fu et al., 2019). In the current study, we expect that a low consistency between taste and hygiene ratings would result in greater cognitive conflicts than a high consistency between them.

P3 is a positive ERP component that is maximal over parietal sites and arises at approximately 300–600 ms after stimulus onset (Polich and Kok, 1995). It is associated with conscious evaluation, such as decision difficulty, decision confidence and preference, at the relatively late processing stage of decision making (Nieuwenhuis et al., 2005; Salti et al., 2012). Task-related factors (e.g., task difficulty, task relevance and stimulus probability) have a strong impact on the cognitive processes in decision-making and may result in the variation of P3 amplitude (Jost et al., 2004; Sawaki and Katayama, 2007; Holroyd et al., 2008). In contrast to easy tasks, difficult tasks make individuals more equivocate, decrease their confidence in their judgments, and thus result in a decrease in P3 amplitude (Kok, 2001). Finnigan et al. (2002) demonstrated that the amplitude of P3 was sensitive to decision accuracy and confidence, as a greater P3 amplitude was induced when decision accuracy or confidence was high (vs. low) (Finnigan et al., 2002). Therefore, P3 amplitude reflects task difficulty and decision confidence during decision making (Hillyard et al., 1971). In this study, participants were required to make decisions according to taste and hygiene ratings. We speculate that when taste and hygiene ratings provide consistent predictions, consumers' confidence in decision making will be enhanced and a larger P3 will be elicited compared to when the ratings provide conflicting predictions.

Taken together, the current study is aimed to reveal how consumers process different types of rating cues in online food-ordering by using behavioral and ERP measures. Taste and hygiene ratings, as two important extrinsic cues, might affect consumers' perception of the food and the final ordering decision. P2, N2, and P3, three ERP components associated with the evaluation processes, were examined. The findings of this study would contribute to a better understanding of how consumers make online food-ordering decisions when faced with multiple extrinsic cues and help online restaurants to make better use of online ratings to attract potential consumers.

STUDY 1: A BEHAVIORAL EXPERIMENT

In Study 1, we used a behavioral experiment to examine the joint effects of taste rating (high vs. low) and hygiene rating (high vs. low) on online food-ordering decisions. A 2 (taste rating: high vs. low) × 2 (hygiene rating: high vs. low) between-subjects design was employed in Study 1. Therefore, four conditions were created, i.e., high taste rating & high hygiene rating (hereafter HT & HH), high taste rating & low hygiene rating (hereafter HT & LH), low taste rating & high hygiene rating (hereafter LT & HH), and low taste rating & low hygiene rating (hereafter LT & LH).

Participants

A total of 277 native Chinese (92.4% ranging from 18 to 30 years old, 6.1% ranging from 31 to 40 years old, 1.5% older than 41 years old; 57.4% females) from Hefei University of Technology participated in this experiment online. All participants had online food ordering experience, and they were randomly assigned to one of the four conditions. Specifically, 72 participants were subjected to the HT & HH condition, 69 participants were subjected to the HT & LH condition, 68 participants were subjected to the LT & HH condition, and 68 participants were subjected to the LT & LH condition.

In order to eliminate the confounding effects of personal characteristics (e.g., gender, age, education, and online food ordering frequency), we conducted ANCOVA or chi-square test. The results showed that there were no significant differences of gender ($\chi^2(3) = 5.368$, $p > 0.1$), age [$F_{(3,273)} = 0.596$, $p > 0.1$], education ($\chi^2(12) = 9.07$, $p > 0.1$), and online food ordering frequency [$F_{(3,273)} = 1.284$, $p > 0.1$] among four conditions.

Experimental Stimuli

In Study 1, we designed a simple smartphone application interface for ordering food online. Four restaurants with different levels of taste and hygiene ratings were created, with restaurant name (using serial numbers), picture (only containing tables and chairs), location (same address for four restaurants), sales (around 500 a month) and restaurant per capita consumption (around 70 Chinese yuan per capita) strictly controlled. Based on the findings of Wang et al. (2016), ratings ranging from 2.00 to 2.25 were classified as low ratings, and ratings ranging from 4.75 to 5.00 were classified as high ratings (1.00 and 5.00 corresponded to the lowest and highest rating scores, respectively). therefore, in the present study, rating scores for the HT & HH condition were set as 4.95 and 4.85, for the HT & LH condition were 4.95 and 2.15, for the LT & HH condition were 2.25 and 4.85, and for the LT & LH condition were 2.05 and 2.15.

Procedures

The experiment was conducted on wjx.com, which was a professional data collection website in China. Prior to the experiment, participants were informed that the purpose of the research was to understand consumers' online restaurant ordering behavior. Participants were asked to imagine that "You plan to order take-out through a mobile application. Now you open the food-ordering application and check the information of a restaurant as shown in the following picture." After reviewing

the restaurant information, participants reported how likely they would be to order take-out from this restaurant in a 7-point Likert scale (1 = very unlikely, 7 = very likely). Considering the high internal consistency (α = 0.951), we used the average to form consumer attitude index.

Results

A 2 × 2 ANCOVA was conducted with ordering intention as the dependent variable. It revealed significant main effects of taste rating [$F_{(1,273)}$ = 114.38, $p < 0.001$, η^2 = 0.30] and hygiene rating [$F_{(1,273)}$ = 31.76, $p < 0.001$, η^2 = 0.10]. A high taste rating (M = 4.59, S.E. = 0.11) led to a higher ordering intention than a low taste rating (M = 2.88, S.E. = 0.12). Similarly, a high hygiene rating (M = 4.19, S.E. = 0.11) led to a higher ordering intention than a low hygiene rating (M = 3.28, S.E. = 0.11). More importantly, there was a significant interaction effect between taste rating and hygiene rating [$F_{(1,273)}$ = 22.56, $p < 0.001$, η^2 = 0.08]. Under the high taste rating condition, participants showed higher ordering intention for a high hygiene rating (HT & HH: M = 5.43, S.E. = 0.16) than for a low hygiene rating (HT & LH: M = 3.76, S.E. = 0.16; $p < 0.001$). However, under the low taste rating condition, there was no significant difference for ordering intention between a high hygiene rating (LT & HH: M = 2.95, S.E. = 0.16) and a low high hygiene rating (LT & LH: M = 2.80, S.E. = 0.16) ($p > 0.1$) (see **Figure 1**).

Discussion

The behavioral experiment in Study 1 was conducted to examine the joint effects of taste rating and hygiene rating as two extrinsic cues on consumers' online food ordering intention. The results revealed that consumers indicated a higher ordering intention from a restaurant with a high taste rating (high hygiene rating) than one with a low taste rating (low hygiene rating), indicating that high ratings for taste or hygiene signaled better restaurant quality and experience. In addition, the effect of hygiene rating on ordering intention was dependent upon taste rating. Hygiene rating had a positive effect on ordering intention when the taste rating was high. whereas hygiene rating did not make a difference when the taste rating was low. According to the cue diagnosticity theory, the effect of a less diagnostic cue on product evaluation is contingent on the valence of the more diagnostic cue when multiple cues coexist (Purohit and Srivastava, 2001; Wang et al., 2016). The findings of Study 1 indicated that taste rating was perceived to be more diagnostic than hygiene rating during online restaurant evaluation and decision making, and thus the effect of the hygiene rating on restaurant online ordering behavior was moderated by taste rating.

Study 1 provided initial evidence for the joint effects of two extrinsic cues on online food ordering intention. However, it remains to be explored about how consumers process the information of taste rating and hygiene rating on the time course and its underlying cognitive mechanism. Therefore, Study 2 investigated the joint effects of taste and hygiene ratings further by examining the brain activities associated with information processing and decision making by employing ERP method.

STUDY 2: AN EVENT-RELATED POTENTIAL EXPERIMENT

Participants

Through posting information about the experiment on the campus bulletin board system, we recruited 21 healthy right-handed students (10 females) from Guangdong University of Technology to participate in the experiment. All participants were native Chinese speakers with normal or corrected-to-normal visual acuity and without any history of neurological disorders or mental diseases. They all had experience in ordering food online. The experiment complied with the Declaration of Helsinki and was approved by the Internal Review Board of the Laboratory of Neuromanagement and Decision Neuroscience, Guangdong University of Technology. Before the experiment, all participants provided written informed consent regarding the experiment and the protection of personal privacy, health, safety and dignity. Participants were paid 50 Chinese yuan (approximately 7 USD) after the experiment. The EEG data from two participants were discarded because of excessive recording artifacts (i.e., less than 30 valid trials were remained per condition), leaving valid data from 19 participants (9 females) for the final data analysis. Their age ranged from 19 to 23 years (mean age = 20.5 ± 1.07 years).

Experimental Stimuli

We collected 200 local restaurant names from popular food-ordering platforms[1,2] and allowed the participants to browse them prior to the ERP experiment. A serial number was assigned to each restaurant. To avoid different degrees of familiarity with the restaurants, only the serial number was used to represent each restaurant in the ERP experiment. Moreover, the experiment employed a 2 (taste rating: high vs. low) × 2 (hygiene rating: high vs. low) within-subjects design. That is, the experiment consisted of the same four experimental conditions as Study 1. According to the findings of Wang et al. (2016), ratings ranging from 2.00 to 2.25 were classified as low ratings, and ratings ranging from 4.75 to 5.00 were classified as high ratings. Consequently, five scores were selected from each range to represent high or low ratings in the experiment. The same ten scores were used to manipulate taste and hygiene ratings. The taste and hygiene rating scores were paired randomly, resulting in 100 pairs of ratings. Each pair of ratings was presented twice in the experiment, resulting in 200 trials altogether and 50 trials in each condition. To eliminate the possible confounding effect of reading order, the vertical positions of taste and hygiene ratings were counterbalanced.

Experimental Procedures

Participants were comfortably seated on a chair in a dimly lit, sound-proof room. The stimuli were presented centrally on a 19-inch computer monitor (1,280 × 1,024 pixels, 60 Hz) against

[1]www.Dianping.com

[2]www.Meituan.com

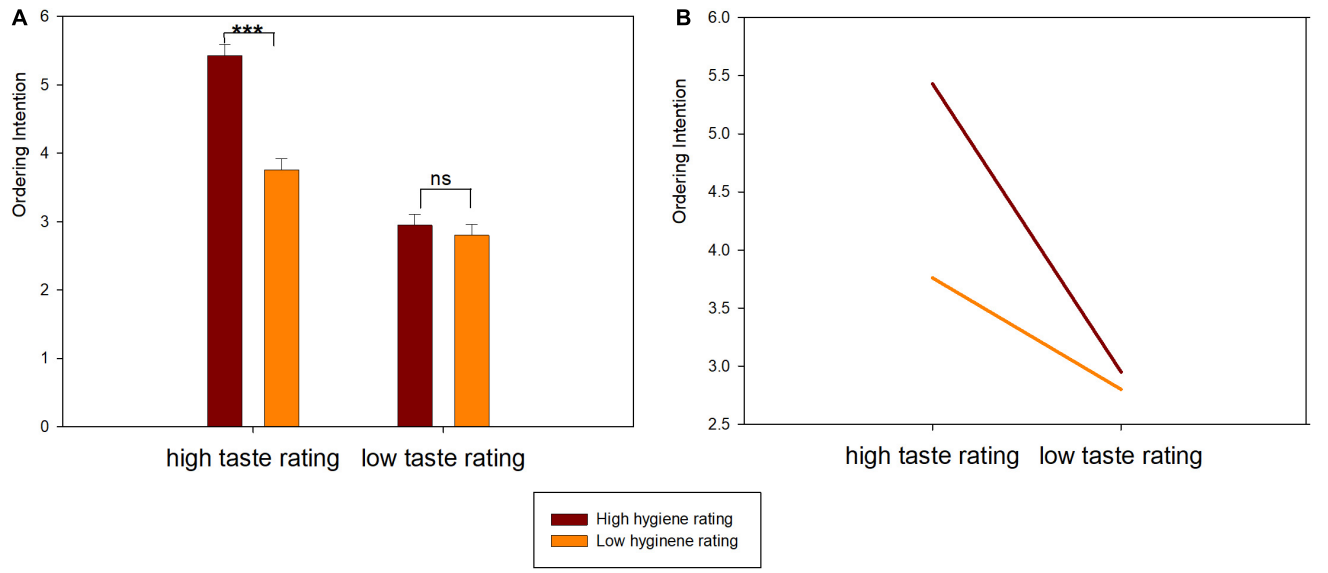

FIGURE 1 | Ordering intention results in Study 1. **(A)** Bar graph. **(B)** Linear graph. ***$p < 0.001$, ns $p > 0.05$.

a gray background at a distance of 90 cm in front of each participant. E-Prime 2.0 software (Psychology Software Tools Inc., Pittsburgh, PA, United States) was used to present the stimuli randomly, and a keypad was provided for participants to provide responses.

Before the ERP experiment started, each participant was given the following introduction: "Imagine that now it is near meal time and you want to order take-out through mobile applications (e.g., Dianping or Meituan). You could see a list of restaurants and check consumer ratings of taste and hygiene about each of the restaurant. You have to decide whether you would like to order food from the restaurant or not after reading the information about the restaurant." Each participant performed ten practice trials to get familiar with the task. The formal experiment was composed of four blocks, each containing 50 pairs of stimuli. As **Figure 2** shows, each trial began with a central fixation cross (+) against a gray background for 600–800 ms, which was followed by a restaurant number (S1) for 1,000 ms. Next, a blank screen was displayed for 400 to 600 ms. After that, a picture with taste and hygiene rating scores (S2) was presented with a duration of 3,000 ms. Participants were asked to decide whether they would like to order food from the restaurant as soon as possible after viewing S2, which would disappear when participants made a response. The response-to-hand assignments were counterbalanced across all participants. Finally, a blank screen was presented for 800 to 1,000 ms before the next trial began. After each block, participants were able to rest for several minutes. The experiment lasted approximately 15 min.

After the ERP experiment, participants were asked to assess the perceived diagnosticity of taste and hygiene ratings on a five-point Likert scale ranging from 1 (very low) to 5 (very high). One item was adapted from Qiu et al. (2012)'s study to measure the perceived diagnosticity of each cue, i.e., to what degree do you think the taste (hygiene) rating is useful for food evaluation and restaurant choice?

Event-Related Potential Recording and Analysis

The EEG data were recorded with an eego amplifier by using a Waveguard EEG Cap with 64 Ag/AgCl electrodes mounted according to the extended international 10–20 system (both manufactured by ANT Neuro, Enschede, Netherlands). The cephalic (forehead) location in the middle of FPz and Fz served as the ground, and the left mastoid was used as an online reference. Channel data were recorded at a sampling rate of 500 Hz, with online band-pass-filtering from 0.1 to 100 Hz. The electrode impedance was kept below ten kΩ throughout the experiment.

During off-line data analyses, EEG data were analyzed in ASALab 4.10.1 software (ANT Neuro, Enschede, Netherlands). EEG data were re-referenced to the average of the left and the right mastoids off-line. Ocular artifacts were identified and corrected with the eye movement correction algorithm in the ASALab program. The EEG data were digitally filtered with a low-pass filter at 30 Hz (24 dB/octave). For the ERP, the time windows of 200 ms before S2 onset and 800 ms after S2 onset were segmented, with the activity from −200 to 0 ms serving as the baseline. Trials containing amplifier clipping, bursts of electromyography activity or peak-to-peak deflection that exceeded ± 100 mV were excluded from the final averaging. More than 30 sweeps remained in each condition for each participant, which was adequate for achieving stable and reliable measurements of P2, N2, and P3 (Luck, 2005). For each participant, the recorded EEGs over each recording site were grand averaged across each experimental condition. The current experiment examined four conditions varying in taste rating (high vs. low) and hygiene rating (high vs. low).

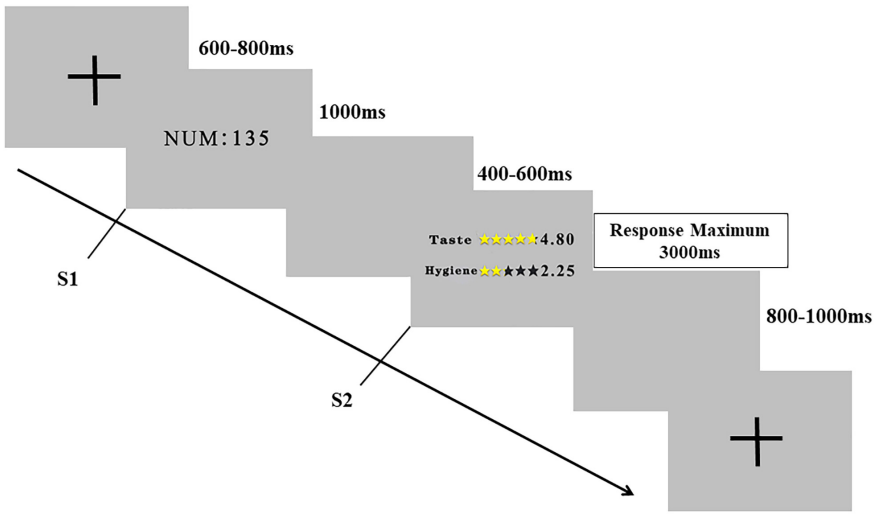

FIGURE 2 | Schematic illustration of one trial in the experimental task of Study 2. Participants were instructed to make a "choose" or "not choose" decision after the presentation of S2 along with taste and hygiene rating information.

On the basis of the visual inspection of the grand averaged waveforms and relevant studies on decision-making (Ma et al., 2014; Wang et al., 2016), P2, N2, and P3 components were analyzed. We selected the time windows of 150–190 ms after the onset of S2 for P2, 270–330 ms for N2, and 360–560 ms for P3. According to the brain locations of the ERP components described in the introduction, six electrodes (FC3, FCZ, FC4, C3, CZ, and C4) in the fronto-central and central areas were used for P2 and N2 analyses, and nine electrodes (C3, Cz, C4, CP3, CPz, CP4, P3, Pz, and P4) were used for P3 analysis. Repeated measure analyses of variance (ANOVAs) were conducted separately for P2, N2, and P3. The Greenhouse-Geisser correction was used when necessary (uncorrected df is reported with the ε and corrected *p*-values), and Bonferroni correction was used for multiple paired comparisons. Simple effect analyses were performed when the interaction effect was significant.

Results

Behavioral Data

Ordering Rate

Only trials that registered responses in <3 s after S2 onset were included in the behavioral data analyses. Considering the binary decision paradigm in our ERP study, the percentage at which participants decided to order from the restaurant online was called ordering rate, which has similar meaning with ordering intention. The ordering rate and the reaction time (RT) were analyzed separately by repeated-measure ANOVAs with taste rating (high vs. low) and hygiene rating (high vs. low) as within-subject factors. It showed significant main effects of taste rating [$F_{(1,18)} = 78.77$, $p < 0.001$, $\eta^2 = 0.81$] and hygiene rating [$F_{(1,18)} = 28.12$, $p < 0.001$, $\eta^2 = 0.61$] on ordering rate (see **Figure 3A**). A high taste rating ($M = 0.75$, S.E. = 0.05) led to a higher ordering rate than a low taste rating ($M = 0.13$, S.E. = 0.04). Similarly, a high hygiene rating ($M = 0.63$, S.E. = 0.04) led to a higher ordering rate than a low hygiene rating ($M = 0.26$, S.E. = 0.05). Furthermore, the differentiated rate (the difference of ordering rate between high and low rating conditions) of the taste rating ($M = 0.62$, S.E. = 0.07) was marginally larger than that of the hygiene rating ($M = 0.37$, S.E. = 0.07) ($t_{(18)} = 1.77$, $p < 0.1$). Interestingly, a marginally significant interaction effect was observed between taste and hygiene ratings [$F_{(1,18)} = 4.09$, $p < 0.1$, $\eta^2 = 0.19$] (see **Figure 3B**). Simple effect analyses showed that under the high taste rating condition, the ordering rate for a high hygiene rating (HT & HH: $M = 0.99$, S.E. = 0.05) was higher than that for a low hygiene rating (HT & LH: $M = 0.51$, S.E. = 0.10; $p < 0.001$). Under the low taste rating condition, the ordering rate for a high hygiene rating (LT & HH: $M = 0.27$, S.E. = 0.08) was also higher than that for low hygiene rating (LT & LH: $M = 0.003$, S.E. = 0.002) ($p < 0.01$). But the difference between high and low hygiene ratings was marginally larger when the taste rating was high (vs. low) (0.48 vs. 0.27, $p < 0.1$).

Reaction Time

All RTs were longer than 300 ms, therefore no extremely fast RTs were found and included in the analysis. The ANOVA showed insignificant main effects of taste and hygiene ratings, but a significant interaction effect between them [$F_{(1,18)} = 45.63$, $p < 0.05$, $\eta^2 = 0.70$]. Simple contrasts showed that under the high taste rating condition, the RT for a high hygiene rating (HT & HH: $M = 758.68$, S.E. = 39.23) was significantly shorter than that for a low hygiene rating (HT & LH: $M = 1144.54$, S.E. = 80.67) ($p < 0.001$). Under the low taste rating condition, the RT for a high hygiene rating (LT & HH: $M = 1178.40$, S.E. = 88.24) was significantly longer than that for a low hygiene rating (LT & LH: $M = 797.31$, S.E. = 46.80) ($p < 0.001$) (**Figure 4**).

Perceived Diagnosticity

A paired *t*-test was performed to compare the perceived diagnosticity of different types of ratings. It demonstrated that

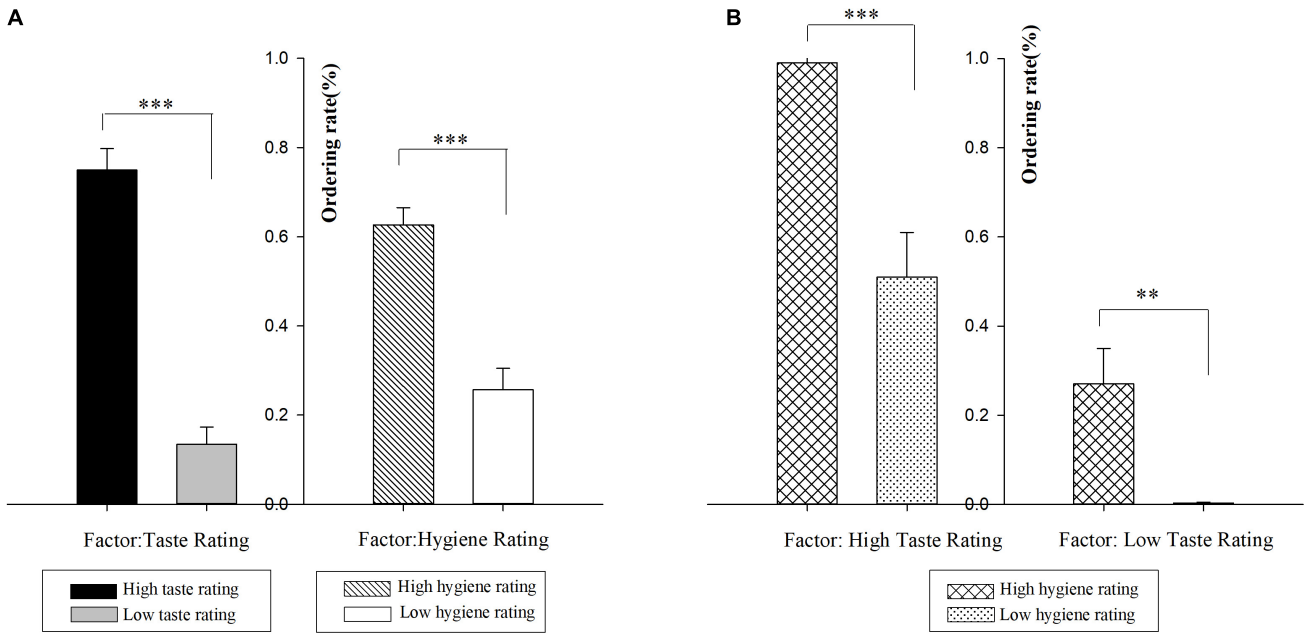

FIGURE 3 | Ordering rate results in Study 2. **(A)** The ordering rates organized according to one factor (taste rating or hygiene rating). **(B)** The ordering rates for all four experimental conditions. The error bars indicate standard error of the mean. $^{**}p < 0.01$ and $^{***}p < 0.001$.

the perceived diagnosticity of taste rating (M = 4.16, S.E. = 0.21) was significantly higher than that of hygiene rating (M = 3.32, S.E. = 0.24; $t_{(18)} = 2.109$, $p < 0.05$).

Event-Related Potential Data

The stimulus-locked grand-average ERP across four conditions at four representative midline electrodes are shown in **Figure 5**.

Three-way 2 (taste rating: high vs. low) × 2 (hygiene rating: high vs. low) × 6 (electrodes: FC3, FCZ, FC4, C3, CZ, and C4) within-subject ANOVA for P2 in the time window from 150 to 190 ms was conducted. A significant main effect of taste rating [$F_{(1,18)} = 7.02$, $p < 0.05$, $\eta^2 = 0.28$] was observed, as a high taste rating evoked a larger P2 (M = 4.05, S.E. = 0.43) than a low taste rating (M = 3.51, S.E. = 0.47). But the main effect of hygiene rating and the interaction between taste and hygiene ratings were not significant.

To further explore the informational conflict effects of taste and hygiene ratings, we conducted an ANOVA on N2 amplitude between 270 and 330 ms. It revealed insignificant main effects of taste and hygiene ratings, but a significant interaction effect between taste and hygiene ratings [$F_{(1,18)} = 4.88$, $p < 0.05$, $\eta^2 = 0.21$]. When the taste rating was high, the amplitude of N2 did not differ between a high hygiene rating (HT & HH: M = 0.52, S.E. = 0.50) and a low hygiene rating (HT & LH: M = 1.2, S.E. = 0.63; $p > 0.1$). However, when the taste rating was low, the amplitude of N2 for a high hygiene rating (LT & HH: M = −0.04, S.E. = 0.61) was marginally larger than that for a low hygiene rating (LT & LH: M = 0.69, S.E. = 0.67; $p < 0.1$). We also conducted a 2 (rating consistency: consistent vs. conflicting) × 6 (electrodes: FC3, FCZ, FC4, C3, CZ and C4) within-subject repeated ANOVA for N2 amplitude. When the taste and hygiene ratings gave consistent predictions, the situation was defined as a consistent condition (including HT & HH and LT & LH); otherwise, it was defined as a conflicting condition (including HT & LH and LT & HH). The results showed a significant main effect of rating consistency [$F_{(1,18)} = 4.89$, $p < 0.05$, $\eta^2 = 0.21$], as

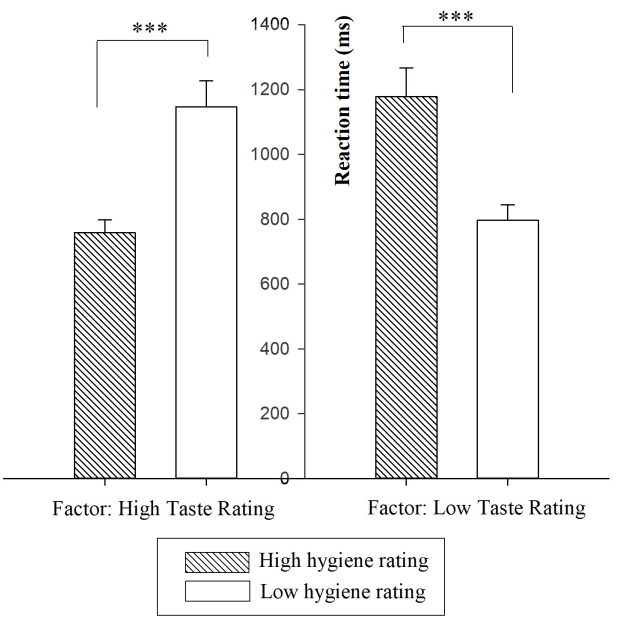

FIGURE 4 | Reaction time (RT) results for all experimental conditions in Study 2. The error bars indicate standard error of the mean. $^{***}p < 0.001$.

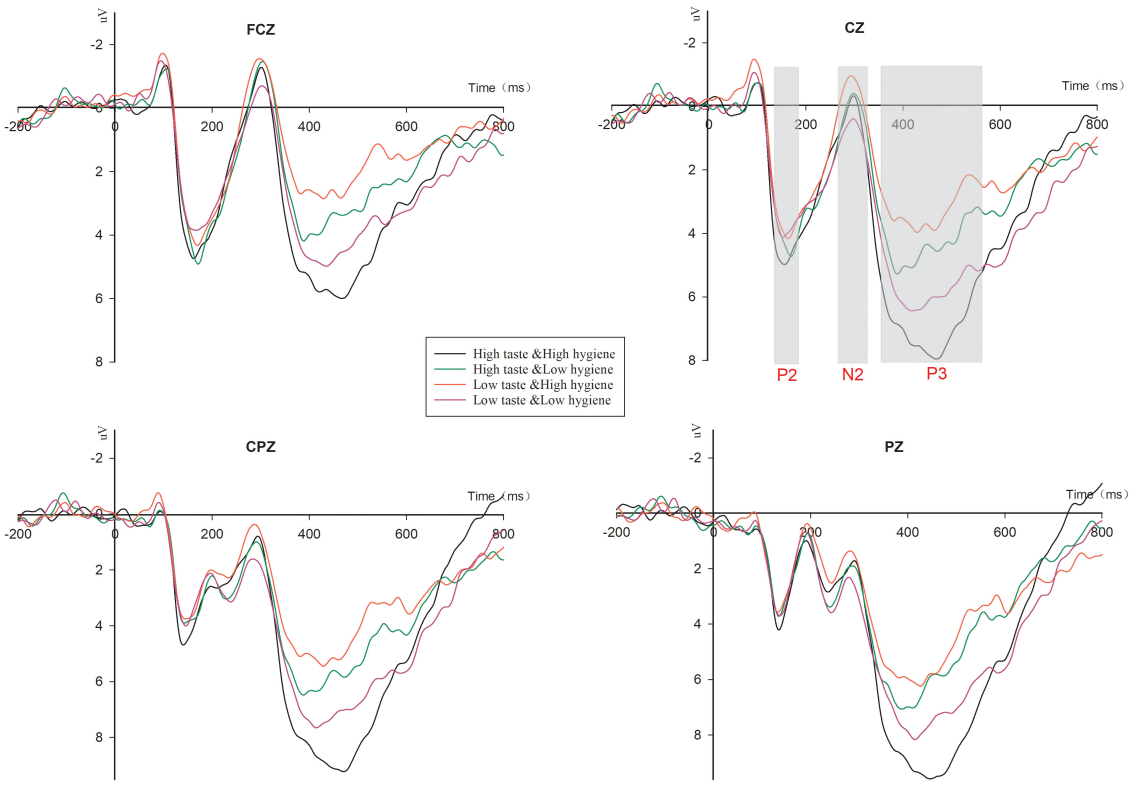

FIGURE 5 | Event-related potential (ERP) results in Study 2. Grand-average ERP waveforms of the frontal, fronto-central, and central regions recorded from the FCz, Cz, CPz, and Pz electrodes.

the conflicting condition (M = 0.07, S.E. = 1.17) elicited a more negative N2 than the consistent condition (M = 1.21, S.E. = 1.07).

Regarding the P3 component, an ANOVA was performed on P3 amplidute in the time window from 360 to 560 ms. The results revealed a significant main effect of taste rating [$F_{(1,18)}$ = 8.37, p = 0.010, η^2 = 0.317], but no salient main effect of hygiene rating. The P3 amplitude for a high taste rating (M = 6.16, S.E. = 0.730) was larger than that for a low taste rating (M = 5.22, S.E. = 0.66). In addition, a significant interaction effect was observed between taste and hygiene ratings [$F_{(1,18)}$ = 48.38, $p < 0.001$, η^2 = 0.73]. Simple effect analyses showed that when the taste rating was high, a high hygiene rating (HT & HH: M = 7.53, S.E. = 0.85) evoked a greater P3 amplitude than a low hygiene rating (HT & LH: M = 4.80, S.E. = 0.67, $p < 0.001$); but when the taste rating was low, a high hygiene rating (LT & HH: M = 4.20, S.E. = 0.57, p = 0.000) evoked a smaller P3 amplitude than a low hygiene rating (LT & LH: M = 6.23, S.E. = 0.82, p = 0.010). In other words, the consistent ratings evoked greater P3 amplitudes than the conflicting ratingss (i.e., HT & HH > HT & LH, LT & LH > LT & HH). We also conducted a 2 (rating consistency: consistent vs. conflicting) × 9 (electrodes: C3, Cz, C4, CP3, CPz, CP4, P3, Pz, and P4) within-subject repeated ANOVA for P3 amplitude. The results showed a significant main effect of rating consistency [$F_{(1,18)}$ = 48.38, $p < 0.001$, η^2 = 0.73]. The consistent condition (M = 6.88, S.E. = 0.79) elicited a more positive amplitude of P3 than the conflicting condition (M = 4.498, S.E. = 0.591).

Discussion

The ERP experiment of Study 2 was conducted to reveal the brain activities associated with information processing of taste rating and hygiene rating when ordering food online. Behaviorally, the ordering rate and RT were examined. Neurally, the ERP components of P2, N2 and P3 were examined, which provided neural evidence for understanding how taste and hygiene ratings affect consumer responses in the brain.

At the behavioral level, a high taste rating (high hygiene rating) induced a higher ordering rate than a low taste rating (low hygiene rating). According to cue utilization theory, our findings indicate that high ratings for both taste and hygiene dimensions signal better restaurant quality than low ratings. Furthermore, the differentiated rate (the difference of ordering rate between a high rating and a low rating) of the taste rating was marginally greater than that of the hygiene rating, indicating that a change in taste rating had a larger impact on consumer behavior than that in hygiene rating. More importantly, we found a marginally significant interaction between taste and hygiene ratings on ordering rate. The difference between high and low hygiene ratings was marginally larger when the taste rating was high (vs. low), suggesting that hygiene rating had a greater impact on ordering rating under the high taste rating condition.

In terms of RT, the HT & LH condition led to a longer RT than the HT & HH condition, and the LT & HH condition led to a longer RT than the LT & LH condition. Prior studies

have shown that task completion time is associated with task difficulty and cognitive load, and the greater the task difficulty, the higher the cognitive load perceived by participants (Leuthold et al., 2011; Wang et al., 2016; Jin et al., 2017). It generally requires a longer time for more in-depth cognitive processing. In the current study, longer RTs were observed when the two types of ratings provided conflicting (vs. consistent) predictions. In line with prior studies, the longer RTs for the conflicting (vs. consistent) conditions reveals a greater level of cognitive load experienced in decision-making.

At the brain level, three ERP components, P2, N2, and P3, were identified in this study. A greater P2 amplitude was observed for the high taste rating condition than for the low taste rating condition. P2 is an early ERP component that is associated with the attention resources invested in the stimulus, and a larger P2 amplitude could be induced when more attention was allocated to the stimulus in the automatic evaluation process (Mercado et al., 2006; Thomas et al., 2007; Ma et al., 2014). In this study, participants might automatically evaluate taste rating in the relatively early stage of information processing and devote more attention resources to a high taste rating than a low taste rating. However, no clear difference in P2 amplitude was found between high and low hygiene ratings. According to cue-diagnosticity theory, we speculate that taste rating might be processed with priority during early cognitive processing since it is more diagnostic of food quality than hygiene rating. The finding of P2 was in consonance with the behavioral result, which demonstrated that taste rating was more impactful than hygiene rating in consumer decisions.

Following P2, a more negative N2 component was observed for conflicting ratings (i.e., a combination of HT & LH and LT & HH) than consistent ratings (i.e., a combination of HT & HH and LT & LH). N2 is positively associated with conflict detection and cognitive control (Yang et al., 2007; Forster et al., 2011; Spapé et al., 2011). The larger N2 for the conflicting ratings suggests a stage of informational conflict detection when consumers encountered extrinsic cues with inconsistent predictions. In other words, conflicting ratings induced a higher level of cognitive conflict and required the exertion of more cognitive control than consistent ratings. Furthermore, the salience of the conflict was contingent upon taste rating. When the taste rating was low, a high hygiene rating (conflicting condition) evoked a more negative N2 amplitude than a low hygiene rating (consistent condition). However, when the taste rating was high, no significant difference was found in N2 amplitude between a high hygiene rating (consistent condition) and a low hygiene rating (conflicting condition). Given that a high taste rating captures more attention resource than a low taste rating, as reflected by P2, less attention might be paid to hygiene rating when the taste rating was high. Hence the difference between the HT & HH and HT & LH conditions might be overlooked in this cognitive stage. In contrast, when the taste rating was low, more attention could be allocated to hygiene rating. Hence the conflict between taste and hygiene ratings could be well detected, resulting in a larger N2 for the LT & HH (vs. LT & LH) condition.

Regarding P3 component, this study revealed a greater P3 amplitude for the high (vs. Low) taste rating condition. P3 has been associated with task difficulty and individuals' confidence in decision-making (Nieuwenhuis et al., 2005; Salti et al., 2012). When an individual has a high (vs. low) degree of confidence in judgment or decision-making tasks, a greater P3 amplitude will be evoked (Finnigan et al., 2002). Thus, the larger P3 for the high (vs. low) taste rating might indicate that participants had a higher degree of confidence when the restaurant has a high taste rating. More importantly, the significant interaction between taste and hygiene ratings showed that consistent ratings triggered larger P3 amplitudes than conflicting ratings (i.e., HT & HH > HT & LH, and LT & LH > LT & HH). These findings suggest that consumers encounter less difficulty and are more confident in their decisions when consistent (vs. conflicting) ratings are presented to them. The RT results also provide support for the notion that LPP is representative of decision difficulty and/or decision confidence, as a shorter time was required to make a decision when the ratings provided consistent (vs. conflicting) predictions (i.e., HT & HH < HT & LH, and LT & LH < LT & HH).

GENERAL DISCUSSION

Key Findings

This study investigated the joint effects of two extrinsic cues, i.e., taste and hygiene ratings, on online food-ordering decisions. By incorporating behavioral and ERP approaches, we found taste and hygiene ratings are weighed differently in online food-ordering decisions, and we also uncovered the brain activities associated with information processing and decision making.

First, a high taste rating (high hygiene rating) had more positive influence on online food-ordering decision than a low taste rating (low hygiene rating). More importantly, taste rating is perceived to be more diagnostic than hygiene rating during online food-ordering decision making, and the effect of hygiene rating on online food purchase behavior is moderated by taste rating. The behavioral data collected by Study 1 and Study 2 provided consistent supports for the above conclusion. The results were not entirely consistent with the findings of Hu et al. (2010) and Miyazaki et al. (2005), which suggested that when extrinsic cues were inconsistent, negative, but not positive, cues tended to dominated consumer evaluation (Miyazaki et al., 2005; Hu et al., 2010). In the current study, the effect of high (positive) or low (negative) hygiene rating cues was modulated by the valence of taste rating. The findings of the present study are concordant with cue dianosticity theory, which suggests that the effect of a less diagnostic cue on product evaluation is contingent on the valence of the more diagnostic cue when multiple cues coexist (Purohit and Srivastava, 2001; Wang et al., 2016). Take Purohit and Srivastava (2001)'s study as an example, they reported that product warranty (a less diagnostic cue) had a positive impact on consumer response when brand reputation (a more diagnostic cue) was high and had no effect when brand reputation was low. Furthermore, in a study examining the joint influence of online rating (a more diagnostic cue) and product price (a less diagnostic cue) on purchase decision, it is found

that product rating positively moderates the effect of price on purchase intention (Tang and Song, 2019). In Study 2, the self-reports collected after the ERP experiment confirms that taste rating is perceived to be more diagnostic than hygiene rating during product evaluation and decision making. Therefore, it's not surprising that taste rating has a larger impact on ordering rate than hygiene rating, and the effect of the hygiene rating on ordering rate is moderated by taste rating.

Second, taste rating is weighed more heavily than hygiene rating in consumer information processing and decision making, which is supported by ERP data collected from Study 2. The ERP component of P2 was more sensitive to taste rating than hygiene rating in the relatively early automatic cognitive stage, suggesting that taste rating is prioritized during information processing. The effect of hygiene rating on conflict-related N2 component was dependent upon taste rating, as the difference between high and low hygiene ratings was only present when the taste rating was low (vs. high). Moreover, a main effect of taste rating on P3 component was observed instead of hygiene rating. Consumers are more confident in their decisions when the taste rating is high (vs. low). In line with the cue-diagnosticity theory, we suggest that taste rating is more diagnostic and is weighed more heavily than hygiene rating in consumer information processing and decision making.

Implication for Practice

The rapid advance in electronic commerce as well as the ongoing COVID-19 pandemic have made online food-ordering increasingly prevalent. The extrinsic cues provided by online food-ordering platforms reduce the asymmetry of information between sellers and consumers and largely facilitate consumer decision-making. By addressing how two types of extrinsic cues (i.e., taste and hygiene ratings) affect online food-ordering decision, the findings of the present study may be of great interest to online food-ordering platforms and restaurants. First, they should realize the importance of boosting taste and hygiene ratings, since both ratings positively predict ordering rate. E-sellers of take-out service should take advantage of these two extrinsic rating cues to exert positive social influence. Second, taste rating should be enhanced with priority when the resources that a restaurant could utilize are limited. Taste rating has a larger impact on consumer responses and the effect of hygiene rating on consumer responses is dependent upon taste rating. Therefore, when online marketing resources are limited for restaurants, they should pay more attention to improving the taste or texture and innovating flavors of food in the first place, with the aim of improving the taste rating. Last but not least, it's recommended that consistent positive ratings are provided to the consumers, as consistent ratings lower the difficulty of decision making and increase consumers' confidence in their decisions. In a fast-paced era of mobile internet, online sellers have to strive to make it easier for consumers to make a fast and right decision.

Limitations and Future Research

This work has some limitations that should be acknowledged. First, the online food-ordering decision scenario in the study 2 was simplified compared to real life decision making, because ERP experiments must follow strict requirements for environment, equipment and materials. Second, most participants were college students. Examining participants with different demographic backgrounds would provide a more comprehensive and generalized understanding of the brain activities of general consumers in the decision-making process in online ordering and a greater sample size may increase the robustness of the current results. Third, this work only considered two types of ratings (i.e., taste and hygiene ratings) on online food-ordering platforms, leaving opportunities for investigating other types of ratings (e.g., ratings about food appearance and delivery service) and other characteristics of online reviews (e.g., reviewer reputation and expertise) in future research.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Internal Review Board of the Laboratory of Neuromanagement and Decision Neuroscience, Guangdong University of Technology. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CW, YL, and HF conceived and designed the two experiments and performed the ERP experiment. YL, ZY, and GD performed the behavioral experiment. YL, XL, and ZY analyzed the data. CW, YL, XL, and HF wrote and refined the article. All authors contributed to the article and approved the submitted version.

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Driving Mechanism for Manufacturer's Decision of Green Innovation: From the Perspectives of Manager Cognition and Behavior Selection

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From the perspectives of manager cognition and behavior selection, this paper analyzes the cognitive basis of manufacturer's green innovation and discovers that the embodied cognition of the manager has an important influence on the selection of green innovation behavior. Next, the behavior activation in the four stages of manufacturer's green innovation, namely, initiation, termination, change, and solidification, was analyzed, and two behavior selections were proposed: the adaptive legitimacy with institutional logic as the cognitive starting point and the strategic legitimacy with efficiency logic as the cognitive starting point. On this basis, the authors examined four types of manufacturer decisions of green innovation (compliance, selection, creation, and control) driven by manager cognition and behavior selection. The examination reveals how should the manager, facing the growing environmental pressure, form a correct cognition, select the right behavior, and make the proper green innovation decision, which promotes the green, sustainable development of manufacturers.

Keywords: manufacturer, green innovation, decision, mechanism, embodied cognition, behavior selection

INTRODUCTION

Green innovation achieves sustained economic and environmental performance by reducing the full-lifecycle eco-environmental effects of products (Chen, 1999; Xiang et al., 2002). It is an innovation that significantly benefits the environment (Driessen and Hillebrand, 2002). Despite enabling enterprises to form dynamic green capacity (Huang et al., 2015), green innovation faces problems, such as heavy investment cost, long return period, and high risks (Li, 2019). As a result, manufacturers are often caught in a dilemma, when they make the decision on whether to adopt green innovation.

On the driving factors of corporate green innovation, most scholars held that external forces play an important role in the corporate decision of green innovation, such as market drivers and

government environmental regulations. In the real world, green innovation drivers also exist within the enterprises (Xie et al., 2019). These internal factors fall on the organizational level and individual level (Peng and Huang, 2013; Zhao and Zhang, 2019; Wei, 2020). The existing studies have provided a series of meaningful results on how manufacturers make green innovation decisions under the joint effect of internal and external drivers. However, there are two main defects: (1) some studies fail to classify the target industries and (2) the studies rarely consider the mechanism of individual cognition and behavior logic of the manager acting on the decision of a manufacturer about green innovation. In fact, the decision of a manufacturer about green innovation is closely associated with the cognitive level and behavior selection model of corporate managers (senior executives). Therefore, this paper explores the driving mechanism for manufacturer's decision of green innovation, from the angles of manager cognition and behavior selection. The research results provide a reference for manufacturers to realize high-quality development through green innovation.

COGNITIVE BASIS OF MANUFACTURER'S GREEN INNOVATION

Manager Cognition

The manager cognition refers to the knowledge combination underpinning the decision of the corporate managers (Borkent, 2015), which supports the decision of a manager through information identification, interpretation, and action. In cognitive psychology, individual's cognition is usually explained in the following aspects by the concept of embodiment (Borkent, 2015), which in the body is an important factor that affects individual's cognition, and the body acts as the carrier of individual behavior. Each individual has a unique perception and experience of the surrounding environment. Thus, the embodiment of physical experience leads to the difference in individual's cognition (Ye, 2014). The various events and physical processes in the external environment are the cognitive resources of subjective initiative (Spackman and Yanchar, 2014). In the presence of these cognitive resources, individuals are willing to find solutions based on the existing resources in a particular situation. Whether to possess resources, whether they are willing to use resources, and how to utilize resources depend on the previous experience of the individuals.

In fact, the individual's cognition formed in a certain environment tends to stagnate, unless disruptive changes take place in the environment (North, 1990). As a result, corporate managers easily ignore changes in the environment, making it difficult for enterprises to make suitable decisions in the face of various dynamic environmental changes.

Manufacturer's Green Innovation

Green innovation has a positive impact on the sustainability of manufacturers. In general, manufacturer's green innovation can be divided into green process innovation and green product innovation (Xie and Zhu, 2021). The former is mainly the innovation of the production end. The latter targets the entire production cycle. The focus of manufacturer's green innovation varies with the innovation orientations. To reduce the environmental pollution and resource waste of the production process, green process innovation of manufacturers stresses the reform of the local production model of enterprises. In essence, green process innovation attempts to eliminate or reduce pollution throughout the production process and ensure that corporate development is in line with environmental policies. Green product innovation of manufacturers emphasizes the reform of the value chain. In essence, green product innovation aims to produce greener and more environment friendly products and to bring differentiated advantages for enterprise products.

Manufacturer's Green Innovation Under Manager Cognition

In the market economy, an enterprise has two attributes, namely, economic man and moral man (Zhu, 2014). An externality exists through the production and operation of enterprises. Hence, there might be contradictions and conflicts of interest between the profit-seeking nature of enterprises and the social benefits (e.g., eco-environmental protection) (Xu, 2021). It is a major challenge for enterprises to realize harmonious coexistence with the environment. For manufacturers, the handling of the challenge is closely associated with the cognition of the manager (especially senior executive): whether green innovation is considered in decision-making and whether the enterprise would carry out green innovation activities. The reason is that the previous experience of production and operation shapes the personal cognition of corporate managers (especially senior executives), which determines their thinking pattern, and ability to accept and judge information. The personal cognition helps corporate managers (especially senior executive) to recognize and determine the external environment of the enterprise and promotes them to change or adjust the production and operation field or direction of the enterprise, according to the variation in the external environment.

During the change or adjustment, the cognition of the corporate managers (senior executives) also changes. However, the change is bounded by the limitation of the embodied cognition of corporate managers (senior executives) (Ye, 2014). That is, the decision path and behavior pattern are still based on the previous cognitive architecture, without breaking the original thinking pattern or cognitive system. In the face of green innovation, which demands conceptual reform, the manufacturer must fundamentally change its original operation philosophy. Meanwhile, the embodied manager (senior executive) of the manufacturer, which is seamlessly integrated into the environment, needs to break away from the innate cognition and realize the importance of reducing negative environmental impacts through green innovation under the interaction between internal psychology and external

environment (Zhang and Li, 2021). In this way, the manager (senior executive) will be more willing to pursue green innovation and promote the manufacturer make behavior selection to put green innovation into practice. Therefore, the manufacturer's behavior selection of green innovation depends heavily on the environmental cognition of the manager (senior executive).

BEHAVIOR SELECTION ANALYSIS OF MANUFACTURER GREEN INNOVATION

Activation Process of Manufacturer's Green Innovation Behavior

The analysis in section Manufacturer's Green Innovation Under Manager Cognition shows that manufacturer's green innovation requires the corporate managers (senior executives) to transform the original cognition, establish the corresponding cognition of the environment, and further convert the cognition into green innovation practice. That is, the manager must complete the shift from the self-enhancement model to problem-solving model. The psychological features of the latter model promote the managers to reform their cognition (Shang et al., 2014). The shift covers four stages.

(1) Initiation stage: The changes in external environment activate the cognitive reform of the management. The cognition reform of the manager starts from the changes in the external environment of the enterprise. The environmental factors exert constitutive effects on the embodied cognition of the manager (Ye, 2014). Based on the perception of the external environment and the *status quo* of corporate development and operation, the manager evaluates the living environment and potential opportunities or risks facing the enterprise. If the other similar enterprises in the same industry respond and adjust timely (e.g., adopting green innovation) to cope with environmental pressure, the manager will realize that the living environment of the enterprise has been fundamentally changed. Bearing this in mind, the managers will regulate their mental state and change their cognition, break away from the original thinking pattern, and try to find the right solutions from different angles and directions. Meanwhile, the manager will incorporate the following into individual cognitive systems: the concerns of environmental changes and the understanding of problems of external stakeholders, who are affected by organizational decision and behavior. Hence, the changes of the external environment, which is critical to the survival and development of the enterprise, could stimulate the managers to complete the psychological shift toward the problem-solving model and reform their cognition of green innovation.

(2) Termination stage: The management denies its own cognition and triggers trial-and-error learning. Once the cognition reform of green innovation is activated, the behavior of the manager will change: an exploration will begin concerning the direction of corporate green innovation. However, this does not exceed the original scope of manager cognition. Only when problems are detected through the exploration, the managers will doubt and deny their perception of green innovation. It signifies the termination of the originally embodied cognition. In other words, when profound changes of the external environment bring severe challenges and major problems to the enterprise, the manager tends to look for pertinent solutions, e.g., green innovation practice, to problems of corporate development, based on the scope of the original cognition. If negative feedbacks occur, the managers will attribute the failure to the bias and even incorrectness of the original cognitive scope, deny embodied cognition, and become willing to reform their cognition of green innovation.

(3) Change stage: The management constructs green innovation cognition through trial-and-error learning. When the manager tries to solve the corporate development problems brought by external environmental pressure through green innovation, the managers would continuously examine the specific causes of new problems arising during the solution of the current problem and adjust their cognition accordingly. Meanwhile, new attempts are made to solve the new problems. The trial-and-error and learning process are implemented iteratively until all problems are truly solved. Each round of trial-and-error and learning reshapes the original cognition of the manager. Through continuous adjustment, the embodied cognition of the manager rises in a spiral. In this process, the originally embodied cognition of the manager is gradually phased out, and a new cognition is constructed to ease external environmental pressure and implement green innovation. The new cognition paves the way to green innovation decision by the manufacturer.

(4) Solidification stage: The management forms a new cognition theory and externalization. Through a loop of trial-and-error learning of the third stage, the new embodied cognition formed in the change stage is natural legitimacy and compliance. Therefore, the manager will solidify the new embodied cognition through theorization. At the same time, after the completion of the reform of embodied cognition, and the solidification of green innovation cognition, new changes take place in the management behaviors around corporate green innovation. It is necessary for the manager to implement the green innovation cognition in practice. Putting the cognition into practice promotes manufacturer's green innovation, turning green innovation into a habit of the enterprise.

Behavior Selection of Manufacturer's Green Innovation

Based on the organizational level, the green innovation behavior of manufacturers manifests the corporate compliance with the concept of green development. The behaviors are in line with

the values, goals, norms, concepts, and needs of ecology first and green development and conducive to the harmonious coexistence between the enterprise and the eco-environment. In this way, the enterprise can solicit the support and recognition of the government, the market, and consumers, by virtue of its legitimacy. This proactive green innovation behavior could be affected by the embodied cognition of the manager (especially senior executive). Under different embodied cognitions, the manufacturer selects different green innovation behaviors to win legitimacy. There is the adaptive legitimacy with institutional logic as the cognitive starting point (Xie and Zhu, 2021), and the strategic legitimacy with efficiency logic as the cognitive starting point (Xie and Zhu, 2021).

The adaptive legitimate behavior selection for green innovation emphasizes that manufacturers implement green innovation out of compliance and believes that the survival and development of manufacturers depend on the market and their institutional environment (Scott, 1995). Complying with the institutional environment is the only source of legitimacy of the enterprise. On this basis, manufacturers will mainly follow the institutional logic (Xie and Zhu, 2021) in green innovation behavior. To pursue legitimacy, the enterprise would adopt a passive strategy dominated by the compliance with institutional control. The strategy highlights the compliance with industry regulations and codes of conduct. In the end, all enterprises in the industry will adopt the same logical strategy, i.e., their behaviors will converge. The positive signals conveyed during the period enable enterprises to gain recognition from external stakeholders and provide them with the resources needed for innovation. Then, the enterprises can transform resources, information, knowledge, institutions, and norms into green innovation capacity and pursue green innovation under the incentive of institutional logic, thereby alleviating the pressure of the external environment.

The strategic legitimate behavior selection for green innovation emphasizes that enterprises carry out green innovation by their subjective initiative and believes that the continuous growth of the manufacturer depends on its resource integration capacity. The enterprise should effectively integrate its own resources with externally acquired resources, overcome its resource limitation, and seek new opportunities to promote rapid development. On this basis, manufacturers will mainly follow the efficiency logic (Xie and Zhu, 2021) in green innovation behavior. That is, the enterprise will use legitimacy as an important means of obtaining resources. Besides obeying environmental laws and regulations, the enterprise will actively exert its own initiative and take a proactive approach to obtain resources as soon as possible. Then, the resources will be integrated and optimized to maximize the resource advantage. In this way, the enterprise can lead competitors by a wide margin and receive the environmental premium. In this process, the manufacturer actively performs related environmental and social responsibilities and provides green products, which are expensive yet attractive to consumers, aiming to gain a sustainable competitive advantage.

Hence, legitimacy provides the criterion of corporate managers (especially senior executives) to judge and choose embodied cognition and determines the behavior selection for manufacturer green innovation.

MANUFACTURER'S DECISION OF GREEN INNOVATION DRIVEN BY COGNITION-BEHAVIOR SELECTION

The previous analysis shows that, firstly, managers (especially senior executives) form corresponding embodied cognition under the pressure of the external environment. Secondly, the cognition is transformed into green innovation behavior selection of a different manufacturer (adaptive legitimacy and strategic legitimacy). On this basis, finally the difference in behavior selection results in varied green innovation decisions. Even if the behavior selection is the same, the green innovation decision may vary, owing to the disparity in the problem-solving method and process (green product innovation or green process innovation). **Figure 1** shows the manufacturer's decision of green innovation driven by cognition-behavior selection.

As shown in **Figure 1**, the managers (especially senior executives), after selecting adaptive legitimate behavior of green innovation under the cognition of institutional logic, will make one of the two different green innovation decisions, namely, compliance and selection, in view of their cognition of institutional pressure, during the acquisition of relevant resources and maintaining legitimacy through green innovation. Specifically, compliance is the green innovation decision of the manager, upon perceiving strong pressure from external environmental changes. The manager decides to obey government systems and industry practices. Under the premise of respecting nature and making full use of natural resources, the manufacturer will work to reduce the environmental pollution that may occur during the product lifecycle, and new green products of a manufacture that meet environmental requirements and are harmless or minimally harmful to the environment. Selection is the green innovation decision of the manager, after fully considering the institutional pressure in the environment and the situation of corporate development. Without sacrificing the production capacity, the enterprise chooses to optimize and adjust some links in the production process, trying to reduce the production pollution and the generation of hazardous waste, lower the pollution discharge to the level below relevant laws, regulations, and standards, and achieve clean and up-to-standard production. Under the cognition of institutional logic and the selection of adaptive legitimate green innovation behavior, the manufacturer tends to align its behavior with government systems or social expectations and decide to pursue green innovation, with the aim to alleviate its development pressure. This decision helps to win government supports in technology, personnel, capital, and taxation and wins the recognition of shareholders.

It can also be seen from **Figure 1** that, the manager (especially senior executive), after selecting strategic legitimate behavior of green innovation under the cognition of efficiency logic, will make one of two different green innovation decisions, namely, creation and control, in view of the scope of resource

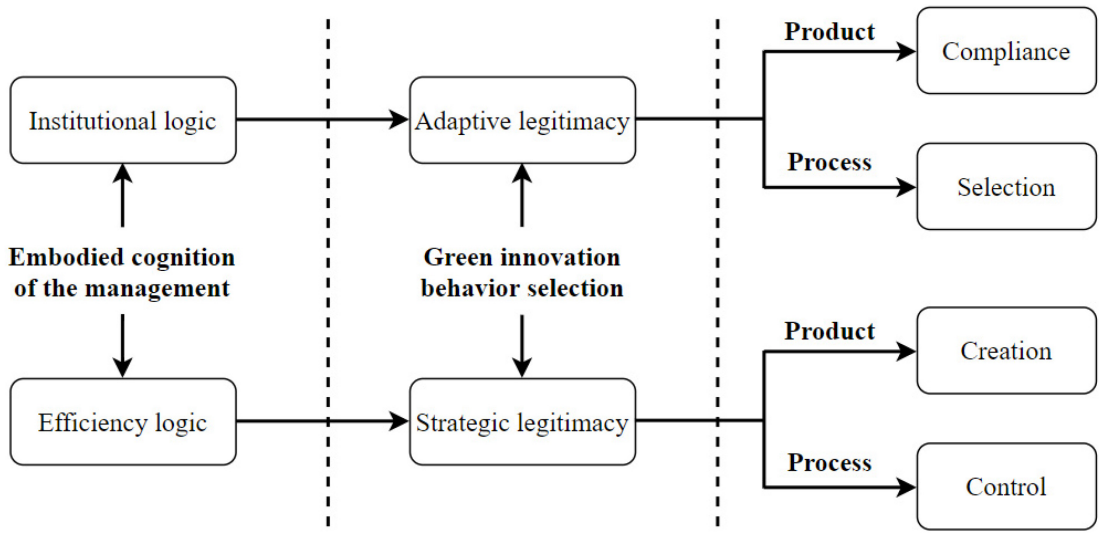

FIGURE 1 | Manufacturer decision of green innovation driven by cognition-behavior selection.

optimization and integration, as the enterprise takes the subjective initiative to perform its social and environmental responsibilities through green innovation. Specifically, creation is the green innovation decision of the manager that influences and partially reshapes the existing environmental systems, industry norms, and public perception by optimizing and integrating the resources controlled by the enterprise. In this case, the enterprise mainly builds a green recycling system for product manufacturing and relies on the system to serve consumers. The environmental operations will win the recognition from consumers and stakeholders and give the enterprise a sustainable competitive advantage. Control is the green innovation decision of the manager that seeks to fundamentally reform the existing environmental systems, industry norms, and public perception by rationalizing the allocation, optimization, and integration of internal and external resources of the enterprise, according to its embodied cognition. In this case, the manufacturer pursuing green innovation no longer eyes profit growth alone, but tries to replace the traditional non-ecological production model with a model that harmoniously coexists with the environment, while meeting the consumer demand for ecological stability. In addition, the enterprise will actively convey its own values, concepts, and progress of green innovation to the society. This would drive the green transformation of the whole industry and promote the low-carbon development of the whole industry chain. Under the cognition of efficiency logic and the selection of strategic legitimate green innovation behavior, the manufacturer tends to exert its subjective initiative and actively implement its social and environmental responsibilities, when manufacturer makes the decision on green innovation. During the pursuit of green innovation, the enterprise would organically integrate its own resources and externally acquired resources and occupy an advantageous position by its resource advantage. In this way, the enterprise could become a leader in green innovation and substantially enhance its core competitiveness.

CONCLUSION AND SUGGESTIONS

Through the research, it can be found that personal differences lead to varied embodied cognition of manager, which could affect the behavior selection of manufacturer green innovation. Driven by cognition-behavior selection of the manager, the manufacturer will make different green innovation decisions. Therefore, the following suggestions are proposed. The first is to integrate manager's embodied cognition and green innovation behavior selection under its effect to make suitable green innovation decisions. The second is to gradually shift the cognition of manager (especially senior executives) from institutional logic to efficiency logic and then make the strategic legitimate behavior selection for green innovation exerting their subjective initiative. On this basis, making matching green innovation decisions so as to realize sustainable development through green innovation.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

MH: contribution rate 57% including the overall idea of the manuscript, formulation of overarching research goals and aims, development of methodology, writing original draft, and writing review and editing. DZ: contribution rate 40% including writing original draft, writing editing, and visualization presentation of research results (drawing picture).

DG: contribution rate 3% including material and sorting, references review, collection, sorting out, and manuscript format. All authors contributed to the article and approved the submitted version.

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The Impact of the Scale of Third-Party Logistics Guaranteeing Firms on Bank Credit Willingness in Supply Chain Finance: An ERP Study

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Supply chain financing guaranteed by third-party logistics (3PL) firms is an effective way to solve the financing difficulties of small and medium-sized enterprises (SMEs). Studies have explored factors that affect the willingness of supply chain financial credit providers under guarantee of 3PL firms (e.g., the scale of financing enterprises and credit). However, whether the scale of 3PL firms will affect the bank's credit decision has not been studied, as well as the neural processing of credit decisions. To clarify these issues, this study extracted behavioral and event-related potentials (ERPs) data when participants performed a selection task of judging whether to grant credit to guaranteed financing-seeking enterprises according to the large or small scale of the 3PL guaranteeing firms. The behavioral results showed that under the condition of a large-scale 3PL guaranteeing firm, the willingness to provide credit to SMEs was higher than that under the condition of a small-scale 3PL guaranteeing firm. This finding indicates there was credit scale discrimination against 3PL guaranteeing firms in supply chain finance. The ERP results showed that compared with the condition of a large-scale 3PL guaranteeing firm, a greater N2 amplitude was induced under the condition of a small-scale 3PL guaranteeing firm, which indicated that credit decision makers experienced greater perceived risk and more decision-making conflict. In contrast, a larger LPP amplitude was detected under the condition of a large-scale 3PL guaranteeing firm (as opposed to a small-scale firm), which indicated that large-scale 3PL guaranteeing firms received more positive comments and more positive emotions from credit decision makers than small-scale 3PL guaranteeing firms. Based on these results, this study reveals the cognition process of credit decision makers regarding the impact of the 3PL guaranteeing firm scale on the willingness to provide credit in supply chain finance and explains the theory of credit scale discrimination from the perspective of decision neuroscience.

Keywords: credit decision, third-party logistics guarantor financing, scale of guaranteeing firm, ERP, N2, LPP

INTRODUCTION

Financial constraints are widespread worldwide. Compared with large companies, it is more difficult for small and medium-sized enterprises (SMEs) to obtain financing from banks and other financial institutions, and they are subject to greater financing constraints (Xavier, 2006; Ryan et al., 2013; Seo, 2013; Song et al., 2021). This difficulty not only severely restricts the development of such enterprises but also affects the income of other members of the supply chain and the supply chain overall. Guarantor financing is an effective way to resolve financing difficulties for SMEs (Randall and Farris, 2009; Martinez et al., 2020). Third-party logistics (3PL) guarantor financing has become one of the main methods to overcome such difficulties (Wang and Wang, 2019; Chakuu et al., 2020) by helping reduce banks' risk perception and enhance their credit willingness. With the good credit of guaranteeing logistics firms', SMEs in the same supply chain are more likely to obtain bank loans. That is, the risk of banks is greatly reduced in this situation, and they are more willing to lend.

To date, related studies on supply chain finance have mainly focused on innovation in the operation mode, benefit distribution mechanism, risk prevention (Caniato et al., 2016), and smart technology application (Rijanto, 2021) but have ignored the potential impact of the 3PL guaranteeing firm scale on credit willingness in supply chain finance. In reality, firm scale is an important factor that restricts various aspects of firm operation, which indicates its strength, capital, and future development prospects (Beck et al., 2005). Similarly, 3PL guaranteeing firm scale indicates that it is still solvent in the condition of a default by the guaranteed enterprise, which may have a significant impact on banks' credit willingness in supply chain finance and thus requires further research. In the practice of supply chain finance, credit decision making is a complex process affected by many factors (Hofmann and Belin, 2011; Lekkakos and Serrano, 2016). Due to "information asymmetry, "the bank implements credit rationing and cannot meet the loan requirements of SMEs to avoid serious adverse selection (Joseph and Weiss, 1981; Kirschenmann, 2016). The application of smart technologies such as blockchain (Rijanto, 2021) and well-trained loan officers can minimize the impact of these factors. However, the supply chain finance credit is ultimately determined by the loan officer based on the materials submitted by the enterprise. Thus, this study focus on the decisions made by loan officers as an agency of bank decisions. It has been established that loan officers often pay attention to the scale of financing-seeking enterprises in supply chain finance when deciding whether to provide loans (Cenni et al., 2015; Ali, 2021). However, whether the scale of 3PL firms will affect the bank's credit decision has not been studied, as well as the neurocognitive process and cognitive mechanism behind this behavior have not been fully studied. As a background against which to investigate these phenomena, this study examines how an enterprise seeking financing obtains bank credit under two conditions: when the guaranteeing firm is large-scale 3PL firm and when the guaranteeing firm is a small-scale 3PL firm.

To better to understand the impact of the scale of 3PL guaranteeing firms on banks' credit willingness in supply chain finance, event-related potential (ERP) technology is applied (Plassmann et al., 2012; Pozharliev et al., 2015). ERPs are an important research method of decision-making neuroscience. The method offers the advantage of high time resolution, which can reflect different cognitive processes by observing the components affected by various experimental conditions through recording the potential on the scalp surface (Ma et al., 2012). A large number of neuroscience studies on decision making have shown the value of this approach to exploring potential conflict perception, emotional arousal, motivation, and stimulus evaluation in risk decisions, such as financial decision making (Frydman et al., 2014; Razi et al., 2016; Gianmario et al., 2017; Wuke et al., 2019). Thus, the method provides a foundation for us on which to conduct an ERP study on the impact of the scale of 3PL guaranteeing firm on the credit decision making of banks by revealing the cognitive processes that occur in the brains of loan officers. The findings of this study can provide insight into the implicit motivation of credit decision makers and serve as a supplement or explanation for results reported elsewhere (Ahlert et al., 2006; Yoon et al., 2006).

THEORETICAL BACKGROUND AND HYPOTHESIS DEVELOPMENT

Behavioral Hypothesis

Banks face various risks of the implementation of supply chain finance, such as supply risk, interruption risk, credit risk, market risk, and operational risk (Tsai, 2008; Shashank and Thomas, 2009; Chen et al., 2021). Due to the serious information asymmetry between banks and enterprises, banks implement credit rationing to SMEs to avoid risks (Xavier, 2006; Seo, 2013; Cenni et al., 2015). Adverse selection coming with the asymmetric information makes credit rationing a rational choice for banks (Stiglitz and Weiss, 1981). It has been widely believed that in the traditional Stiglitz–Weiss model, firm size plays an important role in influencing credit rationing (Wang et al., 2019). For example, some scholars conducted quantitative research using the data of Chinese listed companies from 2009 to 2015 and came to the following conclusions: Compared with large enterprises, SMEs obtained less credit financing and higher costs, that is, the phenomenon of credit scale discrimination does exist (Wei et al., 2019). This kind of situation that credit funds are tilted toward large-scale enterprises has seriously affected the growth of enterprises and their contribution to the economy (Beck et al., 2005). Some studies have found that the scale of financing enterprises in supply chain finance is an important factor affecting the implementation of supply chain finance (Ali, 2021). However, SMEs can enhance their image and reduce the information asymmetry between banks and such enterprises through the guarantee of 3PL firms (Randall and Farris, 2009; Bai, 2019). Thus, the existence of 3PL guaranteeing firms can effectively reduce the bank's credit risk and increase its enthusiasm to support SME financing (Hofmann, 2005; Lamoureux and Evans, 2011; Wuttke et al., 2016). When

a 3PL firm plays the role of guarantor in the supply chain finance of SMEs, to a certain extent, the scale of the 3PL guaranteeing firm represents in the view of the bank the firm's ability to remain solvent in the event of a default (Deng et al., 2016). Therefore, the larger that the 3PL guaranteeing firm is, the smaller the bank's perceived risk and the higher its willingness to grant credit; conversely, the lower its willingness to grant credit (Vousinas, 2018). Based on the preceding analysis, this article proposes the following hypothesis.

H1: The willingness of banks to provide credit to SMEs under the large-scale 3PL guaranteeing firm condition is higher than under the small-scale condition.

ERP Hypotheses

Based on the described decision-making pattern, it is possible that the existence of 3PL guaranteeing firms reduces the perceived uncertainty and risk of credit personnel of financial institutions. Especially in the case of a large 3PL guaranteeing firm, the uncertainty and risk of credit perceived by financial institution personnel are low. Therefore, their evaluation of SMEs applying for loans is relatively high, which improves the credit willingness of the financial institution. This evaluation involves a value-based classification process. Thus, when studying the neural basis of the influence of the size of the guaranteeing 3PL firm on the credit decision making of financial institutions in supply chain finance, this study focuses on two ERP components that are often studied in decision-making research and are closely related to decisional conflict and risk perception (i.e., N2) and evaluation classification (i.e., LPP).

N2

The N2 component is a negative potential that peaks at 200 and 400 ms after stimulation. It is mainly distributed among the frontal area, frontal central joint area, and central area of the brain. It is an ERP component often studied in decision-making research (Nagy et al., 2003; Handy, 2005; Wuke et al., 2019). A considerable number of studies had consistently suggested that N2 is a conflict-related component and whose amplitude is positively correlated with decisional conflict (Yang et al., 2007; Larson et al., 2012; Han et al., 2015; Wang et al., 2018; Yu et al., 2020). Recently, studies have begun to show that when experimental subjects are faced with information flows from different sources, their perceived conflicts of decision-making risks are reflected by the amplitude of the N2 component (Ma et al., 2015; Meng and Xiu, 2018), which indicates that higher perceived risk attracts greater attention resources and increases the difficulty of decision making (Wang et al., 2018; Wuke et al., 2019). For example, the N2 amplitude in the decision making of high-risk PPP financing projects is significantly higher than that of low-risk projects, and the N2 amplitude increases with the increase in conflicts in risk management decisions (Meng and Xiu, 2018).

Generally, the 3PL firms that provide guarantees of supply chain finance is relatively stronger and larger enterprises (Abbasi et al., 2017; Wang and Wang, 2019). Firm size has a positive relationship of supply chain finance practices (Uyar, 2009; Ali, 2021). It has been established that loan officers often pay attention to the scale of financing-seeking enterprises and 3PL guarantor firms in determining whether to provide loans (Cenni et al., 2015; Ali, 2021). We have speculated in the behavioral hypothesis that the loan officers are likely to believe that under the guarantee of the large-scale 3PL guaranteeing firm, it is a good choice to grant credit to financing-seeking enterprises in supply chain finance. Conversely, while the 3PL guaranteeing firm is small-scale, loan officers are likely to believe that granting credit to the financing-seeking enterprises is accompanied by more uncertainty and risk, and cannot assure it is a good choice. In other words, the size of 3PL guaranteeing firms is directly related to the risk perception of credit decision makers. Higher risk perception will attract more attention resources and increase the difficulty of decision making, it will cause a larger N2 amplitude (Wang et al., 2018; Wuke et al., 2019). Specifically, we hypothesize the following.

H2: The N2 amplitude of the supply chain financial credit decision under the conditions of the participation of a large-scale 3PL guaranteeing firm will be smaller than under the condition of a small-scale guaranteeing firm.

LPP

LPP (late positive potential) is a late positive-going component that mainly distributes over the central-parietal regions and peaks at approximately 600 ms after the onset of stimuli (Herring et al., 2011). Previous studies consistently show that the magnitude of LPP reflects the allocation of attention resources. The more attention resources that subjects obtain, the greater the amplitude of LPP (Dolcos, and F., 2006). Studies on decisions have recently reported that LPP may reflect the cognitive process of assessment classification (Chen et al., 2010; Wang et al., 2016; Wuke et al., 2019). These studies suggest that an increase in LPP amplitude is associated with better evaluation and classification of stimuli (Chen et al., 2010; Wang et al., 2016; Wuke et al., 2019). For example, product descriptions that imply lower risk and better future performance lead to a greater amplitude of LPP (Wang et al., 2016; Wuke et al., 2019).

Studies have shown that banks make credit decisions based on the group characteristics of the credited companies (Riley, 1987; Brandt and Li, 2002). In practice, 3PL guaranteeing firms in supply chain finance are all large-scale companies. Banks believe that large 3PL guaranteeing firms have advantages in terms of information acquisition, industry experience, and solvency (Zhou et al., 2020; Hua et al., 2021). Therefore, it is reasonable to say banks evaluate a large 3PL guaranteeing firm better than a small one. In the current study, we assume that banks granting credit to a large-scale 3PL guarantee financing enterprise is with less uncertainty and risk than those granting credit to a small 3PL guarantee financing enterprise. As increased LPP amplitude is positively related to higher evaluation categorization (Wang et al., 2016; Wuke et al., 2019),

we speculate that financing-seeking enterprises guaranteed by a large 3PL guaranteeing firm, rather than a small 3PL guaranteeing firm, will lead to a better evaluation, which will be reflected in a greater LPP amplitude. Thus, the following hypothesis is proposed.

> *H3*: The amplitude of LPP under the condition of the participation of a large-scale 3PL guaranteeing firm will be greater than under the condition of a small-scale 3PL guaranteeing firm.

MATERIALS AND METHODS

Participants

The experiment recruited 30 Chinese students (16 females) from senior or graduate students majoring in finance-related subjects in Ningbo University, aged 19–28 years ($M = 20.53$ years, SD = 2.177 years) as paid volunteers. All participants were native Chinese speakers, right-handed, and had normal or corrected vision without a history of psychological or mental illness. Prior to the experiment, all participants were informed of the experimental procedures and other relevant details and signed a written informed consent form, indicating their voluntary participation in the experiment. The research was conducted in accordance with the Declaration of Helsinki (WMA, 2013). After the experiment, the participants were paid 40 RMB. In the formal experiment, the data of four subjects were discarded due to excessive ERP artifacts. Therefore, the final analysis included 26 active participants. The experiment was approved by the Ethics Committee of the School of Neuroeconomics and Neuromanagement of Ningbo University.

Stimulus Materials and Stimulus Selection

This research investigates 3PL firms of different sizes that provide financing guarantees on behalf of SMEs. The study examines two loan decision-making situations (large vs. small 3PL guaranteeing firm).

To determine the scale of the guaranteeing logistics firms, a questionnaire survey was conducted on the names of the guaranteeing logistics firms investigated in the experiment, the 30 participants (16 women) were asked to rate 50 companies with the same name length using a 5-point Likert score (1 = minimum scale; 5 = maximum scale). Ten small 3PL guaranteeing firms with an average scale of less than 2.53 points and 10 large 3PL guaranteeing firms with an average scale of greater than 4.55 points were selected. Subsequently, the same method was used to select financing enterprises of different sizes as stimulus materials. Thus, in the formal experiment, 8 financing-seeking enterprises and 20 3PL guaranteeing firms (10 large and 10 small) were combined to create 160 trials. The stimulus material was displayed in the middle of a gray screen of a size of 270*360 pixels. The 28 displayed company names were the same in length, with a font of 30 points, and corresponding symbols were used to indicate the size of the company under the company name. The symbols were used for both the financing-seeking companies and the 3PL guaranteeing firms (i.e., 1 or 2 ☆ = small; 4 or 5 ☆ = large). All stimuli were randomly divided into 4 blocks, each with 40 trials. In each block, 40 trials were performed in pseudorandom order.

Procedures

First, participants were informed that they must observe the names and scales of the financing-seeking companies and 3PL guaranteeing firms in turn. Next, they were to imagine that they, as credit decision makers, were determining whether they were willing to grant credit to each financing-seeking company and to score their willingness to provide credit on a continuum from 1 (very reluctant) to 7 (very willing). The participant was seated comfortably in a sound-reduced room, approximately 100 cm from a computer-controlled monitor (1,280 × 1,024 pixels) with a refresh rate of 60 Hz, the stimulus material was displayed in the middle of the screen. The participants were instructed to make their decisions using a wireless keyboard.

As shown in **Figure 1**, at the beginning of each test, a fixed cross appeared for 500 ms, followed by a blank screen that appeared for 400–600 ms. Then, the name of the financing-seeking enterprise (with a fixed length) appeared for 2,000 ms, followed by a blank screen that appeared for 600–800 ms. Next, the name of a 3PL guaranteeing firm (fixed length; 2,000 ms) and the number of stars representing its scale were displayed, followed by a blank screen that appeared for 600–800 ms. Finally, the participants were asked to rate their intentions of granting credit to the financing-seeking enterprise according to the scale of the 3PL guaranteeing firm. The triggers for stimulation and recording were presented using the E-Prime 2.0 software package (Psychology Software Tools, Pittsburgh, PA, United States). The participants were also asked to minimize blinking, eye movement, and muscle movement during the experiment. The formal experiment commenced after 6 practice trials.

Electroencephalogram Recordings and Data Analysis

EEG recording involves the use of a cap with 64 Ag/AgCl electrodes whose potential distribution is in accordance with the international 10–20 system standard. The sampling frequency was set to 500 Hz, the online bandpass filter frequency was set to an eego amplifier of 0.1–100 Hz (all produced by ANTNeuro, Enschede, Netherlands). A pair of electrodes placed 10 mm above and below the right eye were used to record the vertical electrooculograms, while another pair of electrodes placed 10 mm to the right of the right eye and 10 mm to the left of the left eye were used to record the horizontal electrooculograms. The forehead position was used as the ground, and the left mastoid was used as a reference. The impedance of the tested scalp was maintained below 5 kΩ to ensure good data quality.

The left mastoid reference was transferred to the arithmetic mean of the bilateral mastoid as the offline reference. The method proposed by Semlitsch was used for ocular artifact correction (Semlitsch et al., 2010). A 30 Hz (24 dB/Octave) low-pass filter was used to digitally filter the average ERP. The 200 ms prior to the onset of stimulus (i.e., the name and scale of the financing-seeking company or the guaranteeing company) and the 800 ms

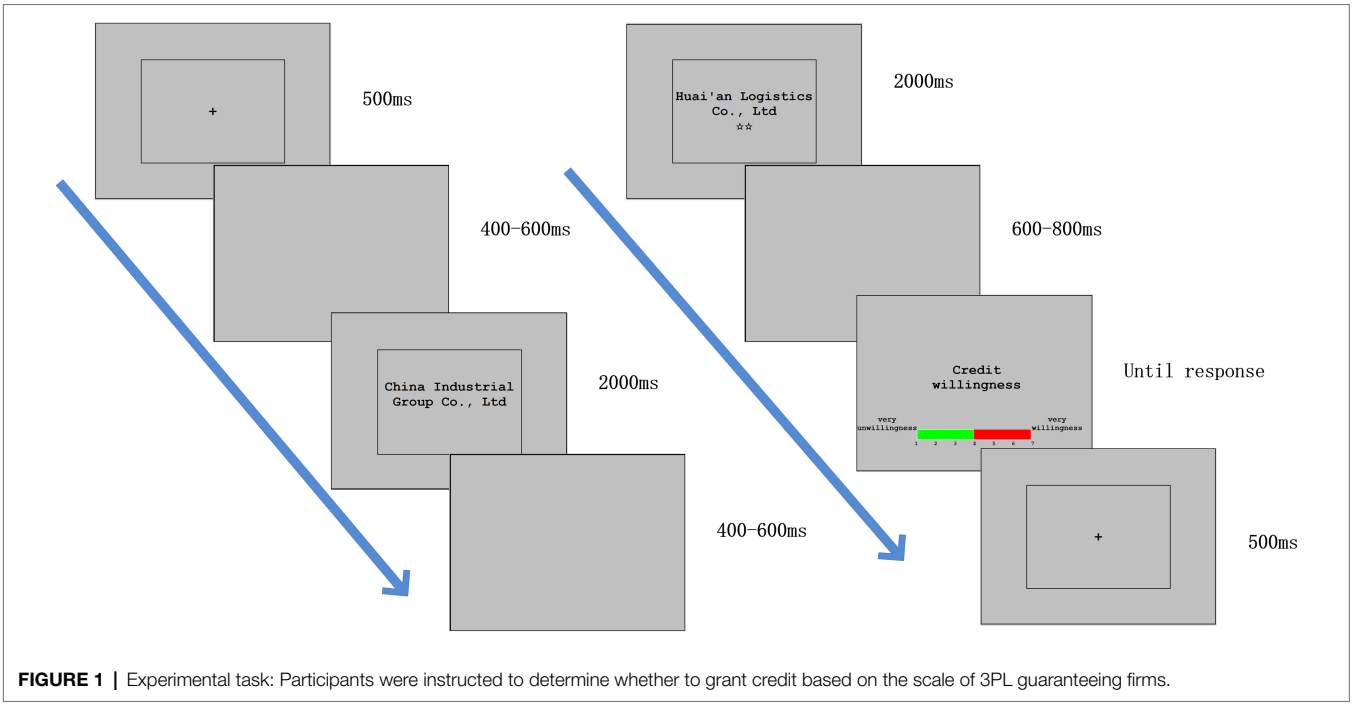

FIGURE 1 | Experimental task: Participants were instructed to determine whether to grant credit based on the scale of 3PL guaranteeing firms.

after this onset were used as the epochs, and the 200 ms prior to the onset of stimuli was used as the baseline. The data collected after the stimulus presentation were compared with the corrected baseline value. EEG data whose amplitude exceeded ±100 μm were removed to improve the quality of the statistical data.

This study adopted a within-subjects experimental design; therefore, repeated-measures ANOVA within the subjects was used for the data statistics, Greenhouse–Geisser correction (Greenhouse and Geisser, 1959) and Bonferroni correction were used for correction according to the experimental conditions, and partial eta-squared values (η_p^2) are reported to demonstrate the effect sizes in the ANOVA models (Cohen, 1988). Based on previous research and visual observation of the scalp distribution of the large average waveform in our research, 9 electrodes (F1, Fz, F2, FC1, FCz, FC2, C1, Cz, and C2) were selected for N2 component analysis, and another 9 electrodes (C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2) were used for LPP component analysis. In addition, the time windows for responding to the N2 and LPP components were 190–240 ms and 400–550 ms, respectively. Then, a 2 (3PL guaranteeing firms: large vs. small) × 9 (electrodes: F1, Fz, F2, FC1, FCz, FC2, C1, Cz, and C2) ANOVA was conducted for the mean amplitude of the N2 component, while a 2 (3PL guaranteeing firms: large vs. small) × 9 (electrodes: C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2) ANOVA was performed for the mean amplitude of the LPP component.

RESULTS

Behavioral Results

According to the research hypotheses, statistical analysis was performed on the credit willingness of the 26 subjects. The *t*-test results of the paired samples show that the main effect of the difference in the willingness to provide credit of the financial institutions under the conditions of 3PL guaranteeing firms of different sizes is significant, and the participants displayed higher willingness to grant credit under the condition of a large-scale 3PL guaranteeing firm [$M_{big} = 5.5067$, $SE = 0.128$; $M_{small} = 3.1804$, $SE = 0.104$; $t(1,25) = 19.145$, $p = 0.000$]. Therefore, H1 is supported.

ERP Results

N200 (190–240 ms)

We conducted a two-way 2 (3PL guaranteeing firms: large vs. small) × 9 (electrodes: F1, Fz, F2, FC1, FCz, FC2, C1, Cz, and C2) repeated measure ANOVA for the mean N2 amplitude. The results reveal that the main effect of different scale 3PL guaranteeing firms is significant [$F(1, 25) = 26.796$, $p = 0.000$, $\eta_p^2 = 0.517$], which indicates that the average amplitude (negative polarity: when the voltage value is small, the amplitude is larger) under the condition of a small-scale 3PL guaranteeing firm ($M_{small} = 0.138$ μV, $SE = 0.579$) is larger than under the condition of a large-scale 3PL guaranteeing firm ($M_{big} = 1.636$ μV, $SE = 0.524$; **Figure 2**).

The N2 analysis results support H2. We select three midline electrodes (Fz, FCz, and Cz) to illustrate their neural dynamic activity under the conditions of different sizes of 3PL guaranteeing firm (**Figure 3A**). In addition, the brain map shows the main differences between the two conditions from the frontal lobe to the central region (**Figure 3B**).

LPP (400–550 ms)

We conducted a two-way 2 (3PL guaranteeing firms: large vs. small) × 9 (electrodes: C1, Cz, C2, CP1, CPz, CP2, P1, Pz, and P2) repeated measure ANOVA for the mean LPP amplitudes.

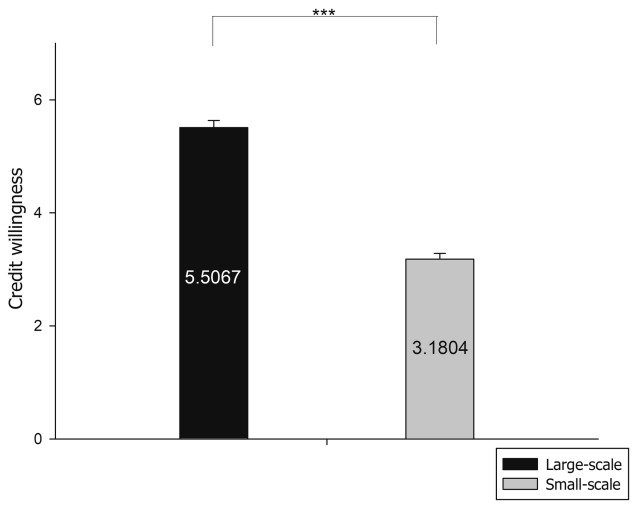

FIGURE 2 | Behavioral results for the willingness to provide credit (large-scale vs. small-scale). ***$p<0.001$.

The results revealed that the main effect is significant [$f(1,25) = 9.197$, $p = 0.006$, $\eta_p^2 = 0.269$], which indicates that the average amplitude of LPP under the condition of a large-scale 3PL guaranteeing firm ($M_{big} = 5.375\,\mu V$, $SE = 0.677$) is larger than under the condition of a small-scale 3PL guaranteeing firm ($M_{small} = 3.921\,\mu V$, $SE = 0.756$; **Figure 3**).

The LPP result supports H3. Three intermediate electrodes (Cz, CPz, and Pz) were selected, and their neural dynamic activity under the conditions of different sizes of 3PL guaranteeing firm is illustrated in **Figure 4A**. In addition, the brain topographic map shows the main differences between the two conditions in the central-to-parietal region (**Figure 4B**).

Correlation Analysis Between EEG Data and Behavior

A correlation analysis of the average amplitudes of N2 and the decision-making behavior revealed a significant positive correlation between the average amplitudes of N2 at the Cz electrode and the behavior ($r = 0.306$, $p < 0.05$; **Figure 5A**). In addition, we analyzed the correlation between decision-making

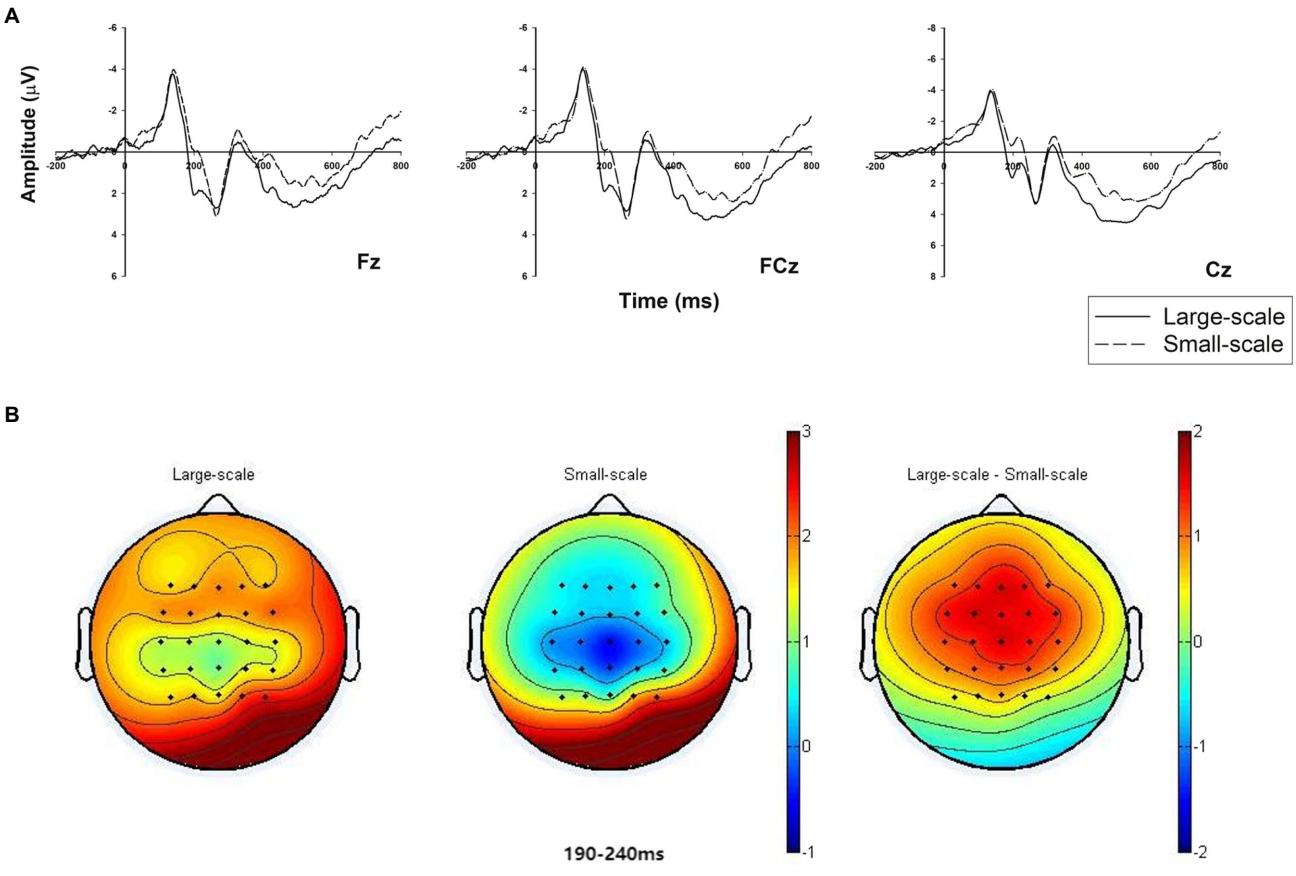

FIGURE 3 | Grand-averaged event-related potential (ERP) waveforms of N2 in the frontal-to-central region with three electrodes and related brain topography. **(A)** The N2 amplitude comparison under the two conditions of 3PL guaranteeing firms (large-scale vs. small-scale) at representative electrodes (Fz, FCz, and Cz). **(B)** Brain topography of the two conditions and a contrast at the N2 time window of 190–240 ms.

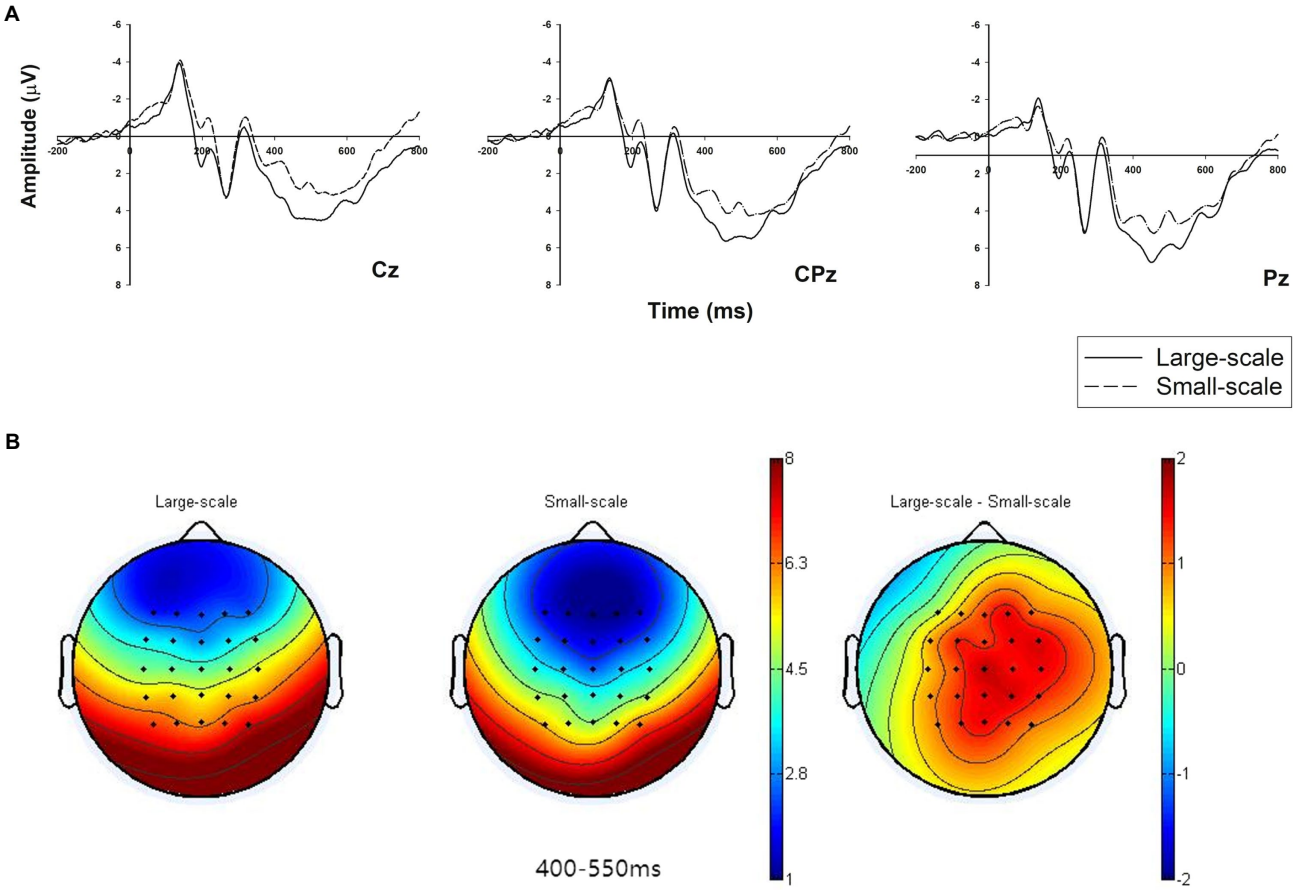

FIGURE 4 | Grand-averaged event-related potential (ERP) waveforms of LPP in the central-to-parietal region with three electrodes and related brain topography. **(A)** The LPP amplitude comparison of the two conditions of 3PL guaranteeing firms (large-scale vs. small-scale) at representative electrodes (Cz, CPz, and Pz). **(B)** The brain topography of the two conditions and a contrast at the LPP time window of 400–550 ms.

behavior and the average amplitude of LPP. The results revealed a significant positive correlation between the average amplitude of LPP at the Pz electrode and behavior ($r = 0.353$, $p < 0.05$; **Figure 5B**).

DISCUSSION

Key Findings

This study used ERPs to investigate the influence of the size of a 3PL guaranteeing firm on bank credit decision making in supply chain finance and its potential neural mechanism. To the best of our knowledge, this study is the first to apply the neuroscience method of ERPs to study credit decision making in supply chain finance. Significant effects were observed at both the behavioral and neural levels. First, the behavioral results showed that loan officers had a higher willingness to grant credit under the condition of a large-scale 3PL guaranteeing firm than under the condition of a small-scale firm. Regarding response time, there was no significant difference between large 3PL guaranteeing firm and small firm. The ERP results showed that supply chain financial decision making when a large 3PL guaranteeing firm is involved results in a smaller N2 amplitude. This outcome indicates that credit decision makers perceive a relatively low risk and thus reduced conflict and difficulty in decision making. In addition, the participation of a large 3PL guaranteeing firm in supply chain finance results in a larger average amplitude of LPP than a small guaranteeing firm participates. This outcome indicates that the involvement of a large 3PL guaranteeing firm leads to higher positive evaluation.

Behavior Result: Credit Scale Discrimination Occurs in Supply Chain Financial Credit Decision Making

The behavioral results reveal that credit decision makers have a higher willingness to provide credit under the condition that the 3PL guaranteeing firm is large. It is found that banks discriminate against 3PL firms that offer guarantees for SME financing enterprises. Previous studies have shown that under the condition of incomplete information, it is difficult for banks to monitor the possible default motives of SMEs (Ray, 1998), resulting in scale discrimination in SME credit financing (Gertler and Gilchrist, 1994; Kudlyak and Sánchez, 2016).

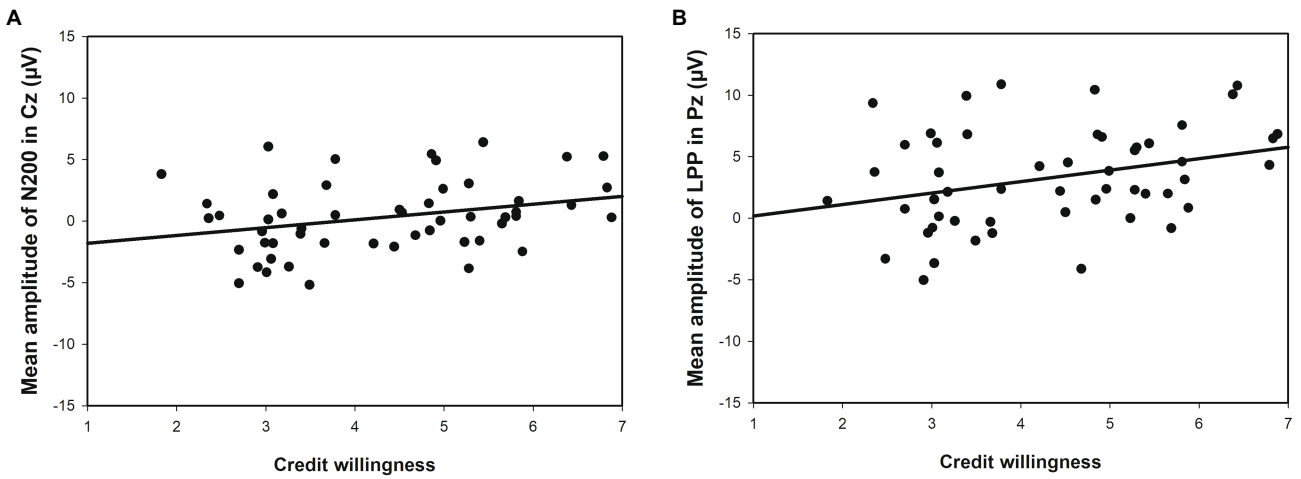

FIGURE 5 | Correlation between amplitudes of N2 or LPP and credit willingness: **(A)** Linear correlation between the mean amplitude of N2 at the Cz electrode and credit willingness; **(B)** Mean amplitude of LPP at the Pz electrode and credit willingness.

Behavioral finance theory holds that information asymmetry causes banks to have cognitive biases on financing companies, leading to biased credit decision making (credit rationing; Joseph and Weiss, 1981; Stiglitz and Weiss, 1981). Some studies have proved that collateral (i.e., "hard information") and corporate reputation (i.e., "soft information") can effectively alleviate the problem of information asymmetry in credit rationing (Bester, 1987; Diamond, 1989). However, SMEs have few collaterals, lack effective "hard information," and it is difficult to obtain "soft information" such as high corporate reputation. The characteristics of risk bundling and information sharing in supply chain finance can reduce the degree of information asymmetry between banks and SMEs and greatly reduce the risk and monitoring cost of commercial banks providing loan services for such enterprises (Yang et al., 2021). However, in certain cases, banks still face the risk caused by SMEs, which reduce the willingness of banks to perform supply chain financing. In this study, although we provided credit decision makers with information on the 3PL firms offering guarantees for the credit-seeking SMEs, these decision makers remained unsure whether credit for the SMEs was the right choice. After all, the scale of 3PL guaranteeing firms indicates solvency in the event of a default by the guaranteed SME. Large-scale 3PL guaranteeing firms have strong solvency which can reduce the risk of supply chain finance. And small-scale 3PL guaranteeing firms do not have the corresponding debt-paying ability which cannot reduce the risks brought by SMEs in supply chain finance. Thus, the scale of 3PL guaranteeing firms has a significant impact on banks' willingness to grant credit in supply chain finance. Credit decision makers may (in part) make decisions based on the scale of the 3PL firms that provide guarantees for SMEs. The scale of the 3PL guaranteeing firm is small, bankers may think that granting an SME credit is a dangerous choice and not conducive to increasing the bank's income, they refuse to take the risk. In contrast, if a large 3PL firm offers to guarantee, the bankers may think that credit for the SME is a good choice.

Neural Mechanism: Decisional Conflicts and Evaluation Classifications Exist in the Supply Chain Financial Credit Decision Process

The results of event-related potential revealed that large-scale 3PL guaranteeing firms induce smaller N2 amplitudes and larger LPP amplitudes than small-scale firms. These results are explained as follows. Banks are more inclined to provide credit to SMEs affiliated with large, well-developed and leading 3PL logistics firms (Vousinas, 2018). Credit decision makers believe that enterprise size has a positive relationship of supply chain finance practices (Uyar, 2009; Ali, 2021). In contrast, they tend to think it is dangerous to provide financing to enterprises affiliated with small-scale 3PL guaranteeing firms. The higher perceived risk of the decision-making processes increases the difficulty of decision making and further aggravates decision-making conflict (Wang et al., 2018; Wuke et al., 2019). Under the condition of a small-scale 3PL guaranteeing firm, decision conflict is greater, the N2 amplitude is greater. Therefore, a small 3PL guaranteeing firms lead to higher perceived risk, which explains the theory of credit scale discrimination from a new perspective.

We also find that the participation of large-scale 3PL guaranteeing firms in supply chain finance results in a greater LPP amplitude than that of small-scale firms. A large number of studies have found that LPP components may reflect the neurophysiological mechanism of classification processing (Chen et al., 2010; Wang et al., 2016; Wuke et al., 2019). These studies suggest that an increase in LPP amplitude is associated with better evaluation of classified stimuli (Chen et al., 2010; Wang et al., 2016; Wuke et al., 2019). Many researchers believe that enterprise size is positively related to the proportion of

bank credit in total assets (Rajan and Zingales, 1998). That is, the larger that the scale of an enterprise is, the better its access to bank credit. The participants in this study may have more highly evaluated the financing-seeking enterprises guaranteed by large-scale 3PL firms and classified them in better evaluation categories (compared with small-scale 3PL guaranteeing firms), reflecting the larger amplitude of LPP. Thus, large 3PL guaranteeing firms obtained more positive comments and more positive emotions from the credit decision makers.

Theoretical Contribution and Implications for Practice

The findings of this study have significance for industry practitioners. First, it is the first attempt to study supply chain finance from the perspective of cognitive neuroscience, the study reveals that scale discrimination occurs in supply chain financial credit decision making with respect to 3PL guaranteeing firms. Many scholars believe that guarantor financing is an effective way to solve the financing problems of SMEs (Randall and Farris, 2009). However, this study found that banks discriminate against 3PL firms that guaranteeing for SME financing enterprises. Thus, the credit willingness of bank is reduced. Therefore, supply chain finance does not proceed smoothly in practice not because there is no guarantor but likely because there is no strong guaranteeing firm to reduce the information asymmetry between banks and the financing-seeking enterprises. Furthermore, participants did not bear the loss of high risk of the selected study, choosing the high-risk option may be more prominent than in the real world (Nieuwenhuis, 2011). Based on the findings of this study, we should further to examine the causes of such discrimination in supply chain finance to avoid the decision-making bias of credit decision makers as much as possible. Second, neurocognitive tools can be applied for financial decision making. Credit decision makers occasionally cannot explain why they exhibit specific behavior (Dijksterhuis, 2004; Berns and Moore, 2012; Plassmann et al., 2015) or do not know their own thoughts and feelings (Chamberlain and Broderick, 2007; Thayer, 2010; Pozharliev et al., 2015). In this study, decisional conflicts and evaluation classifications exist in the supply chain financial credit decision process. 3PL guaranteeing firm affects the credit decision makers' perception matching degree and subsequently affects a series of psychological processes, such as the attention to enterprise scale and emotional attitude, finally affecting their credit decision making regarding guaranteed enterprises seeking financing. This paper reveals the cognition of credit decision makers regarding the scale of 3PL guaranteeing firms and the psychological mechanism of credit decision making for guaranteed financing-seeking enterprises, which can provide insight into the implicit motivation of credit decision makers and serve as a supplement or explanation for results reported elsewhere.

Limitations and Future Research

There are some limitations that should be acknowledged. First, there are limitations in the research sample. In this study, college students were selected to participate in the experiment, considering the control of individual factors, experimental efficiency, experimental cost control, and the convenience of data acquisition. Because the selection of this kind of experimental object can well control the interference factors, which is conducive to explore the general law. However, it will have more extensive value if we can take the real loan officer as the research object. The professional knowledge, bank, and business environment of the credit decision maker may affect the credit decision making. Therefore, if we can recruit real bank credit officers as participants, it will enhance the comprehensive understanding of supply chain financial credit decision making and the generalization of research conclusions. Second, other decision types in supply chain finance are also not considered in this study. Supply chain financial decision making may involve many complex problems (Rijanto, 2021), which requires professionally trained loan officers to support decision making. Therefore, it is not clear whether the loan officers' credit decision-making choices specifically refer to their business expertise. Third, it is possible that the ERP components related to the neural mechanism behind the credit decision of supply chain finance have not been fully discovered. Some studies have examined P3 ERP components and early error detection ERP components (FRN, ERN, and MFN) elicited following risk-related decisions or task feedback (Dilushi et al., 2018). However, these components were not found in this study, which may be related to specific decision-making situations, and future research needs to further explore. SMEs credit institutions and loan officers should be fully aware of their limitations. On the whole, one should be careful when generalizing the conclusions of this work to larger populations or real-world decisions.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of the Academy of Neuroeconomics and Neuromanagement at Ningbo University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XW made substantial contributions to the research, participated in all aspects of manuscript production, conducted experiments, analyzed the data, and wrote the manuscript. JZ and HZ made significant contributions to the research and participated in all aspects of manuscript production. XT participated in data acquisition and data interpretation. A quality management

company was responsible for supervising the study and managing each of its parts. All authors contributed to the article and approved the submitted version.

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Alpha Oscillations in Parietal and Parietooccipital Explaining How Boredom Matters Prospective Memory

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Intelligent interaction alters previous human–machine task allocation patterns. Human workers will suffer from boredom and inattention, posing a significant challenge for the human–machine interaction loop. This study aims to investigate the relationship between boredom and prospective memory, which is a memory form including the detecting, identifying, and executing functions. Thus, the attention and memory mechanisms are critical to complete prospective memory tasks when bored. This study recruited twenty-eight participants and used electroencephalography to measure the alpha power in brain regions. The results indicated that parietal oscillations had a mediation effect on prospective memory, which could be associated with the frequent unstable attention. In addition, this study found that parietooccipital oscillations linked boredom and prospective memory, and the default mode network (DMN) and visual processing during boredom could better explain this finding. The findings of this study suggested that attention management and influences of processing visual information were starting points to cope with boredom because they could help prepare for prospective memory and make optimal decisions accordingly.

Keywords: electroencephalography, boredom, prospective memory, parietooccipital, parietal

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INTRODUCTION

The growing intelligence and autonomy of systems extend human capabilities but challenge human ability to oversee and interact with systems effectively when needed. Interacting with intelligent and autonomous systems increases passive user interaction, and human workers are just like supervisory controllers. Thus, human workers are easily getting bored because they are experiencing long idle time and low task load in those passive user interaction tasks, such as monitoring and vigilance.

Boredom could decline task performances due to the failure of attention management in passive user interaction. In most cases, humans are expected to keep attention and vigilance to deal with occasional but urgent tasks through their event-based or time-based cues. However, those who are bored and inattentive are likely to miss cues and fail to complete tasks. In workplaces such as aviation and medicine, workers are well-training to execute future works with cues associated

with their prospective remembering of intentions (Key Dismukes, 2012). Theoretically, prospective memory is an ability not only to ensure human implementation in future situations, but also to return to the interrupted task receiving cues and entering memory retrieval procedures (Dodhia and Key Dismukes, 2008). According to the dynamic multiprocess framework, detecting cues related to previous training is vital to initiate prospective memory retrieval (Scullin et al., 2013; Shelton and Scullin, 2017). Whereas both boredom and attention failures could hinder the initiation of prospective memory retrieval and increase vulnerability to forgetting. It is worth noticing that passive user interaction is universal in dull but intelligent workplaces where humans are vulnerable to boredom and forgetting intentions. Thus, preventing humans from prospective memory impairment in these boring situations is crucial.

Boredom is a transient and complex emotional state that occurs when someone is unable to reach an exact positive or negative emotion (Bench and Lench, 2019). Attention failures are often used to describe boredom because, in most boring conditions, people find it hard to concentrate on internal or external facts (Eastwood et al., 2012). In other words, boredom is related to unfavorable experiences. Specifically, a boring situation features a lack of engagement and interest, weak meaningfulness, and monotonous or low stimulation (Milyavskaya et al., 2019; Westgate, 2020).

The enhancement of machine intelligence greatly reduces task load, task engagement, and meaningfulness. Human workers are difficult to focus on their tasks. They seek compensated measures to relieve the adverse effects of inattention and boredom, namely, mind-wandering, daydreaming, distraction, and seeking. Notably, these measures are highly related to attention management. For example, mind-wandering and daydreaming shrink part of the attention resources, distraction diverts attention away from the ongoing task, and the seeking state might directly change one's feelings and thoughts (John et al., 2005; Smallwood and Schooler, 2006; Matthews et al., 2010; Cummings et al., 2015; Daniels et al., 2015). Thus, the measures to cope with boredom pose a significant challenge for human workers while interacting and allocating tasks with intelligent systems.

Different coping strategies of boredom could impair prospective memory in various ways. First, distraction is associated with frequent attention shifting. People could not manage their attention effectively to focus on cue detection. In addition, detecting irregular and less focal cues is challenging because it requires a higher demand of attentional resources (Rose et al., 2010; Cummings et al., 2013). Poor attention management could hinder prospective memory. Second, mind-wandering is negatively related to working memory span, while the higher the working memory span, the better the prospective memory (Kane et al., 2007; Smith et al., 2011). That is, working memory span might be narrowed while mind-wandering, and then prospective memory performance is declined. Seli et al. (2018) focused on the reaction time of prospective memory and reported that a more extended time was required while mind-wandering. However, prospective memory is a continual mechanism; the reaction time for detecting and identifying cues is too short to successfully retrieve memory when people are facing attentional failures and shrinking working memory span during boredom (Fish et al., 2010; Hainselin et al., 2011; Yang et al., 2015). Therefore, based on previous literature, this study argues the adverse impact of boredom on prospective memory.

Neuroscience researchers have found that although the relationship between alpha power and different arousal levels could represent diverse brain functional states, boredom is an emotion related to alpha activity happening in both low- and high-arousal situations (Fahlman et al., 2013). Drowsiness, a low arousal emotion, weakens the alpha coherence of brain regions, which indicates an increase in internal attention and a decrease in vigilance level (Cantero et al., 1999). In contrast, high-arousal emotion strengthens the alpha coherence of brain regions and might imply external attention and distraction. Several electroencephalography (EEG) studies further indicated the activity of different brain regions could indicate different boredom coping strategies, for example, sensation-seeking was positively correlated with the left frontal activity (Santesso et al., 2008). In addition, Basharpoor et al. (2019) revealed that the left frontal activity was highly associated with execution and cognitive control. Moreover, the alpha power in the left and right frontal lobes has been found to show one's attentional status, which would increase when one experienced a low task load (Klimesch, 1999). The intensity in the right middle temporal gyrus is highly associated with situational and environmental contexts and, thus, helps people concentrate on the ongoing task and avoid missing out (Lai et al., 2016). Furthermore, previous studies have found that the dynamic oscillations resulting from dorsal and ventral attention networks indicated the attentional shifting and reorienting (Corbetta et al., 2008; Vossel et al., 2014; Proskovec et al., 2018). The simultaneous function of dorsal and ventral attention networks leads to the junction of activity in different brain regions, for example, the bilateral parietotemporal (PT) junction (Vossel et al., 2009).

Neurocorrelated evidence of attention on prospective memory indicates that people draw attention away from the ongoing task while detecting the cues of prospective memory (Wang et al., 2013). According to the results from functional MRI (fMRI), the temporal and occipital cortexes are involved in the cue detection process (Reynolds et al., 2009; Peira et al., 2016). In addition, the whole perspective memory task is associated with the dorsolateral and inferior prefrontal cortex, inferior parietal cortex, precuneus, and anterior cingulate cortex (Okuda et al., 2007; Bisiacchi et al., 2011; Burgess et al., 2011; Wang et al., 2013). Although researchers have reported activation differences in the left and right frontal lobes concerning the event-based and time-based prospective memory based on MRI, their major findings focused on the great relevance of frontal lobe and prospective memory (Okuda et al., 2007).

Studies on boredom have mainly concentrated on causes and coping strategies, and few have investigated how boredom influenced human jobs and behaviors, such as prospective memory. Forgetting tasks in work settings, namely, healthcare and air traffic control, can result in severe consequences (Key Dismukes, 2012; Grundgeiger et al., 2014). This study focuses

on the environment, which is of low task load and highly intelligent, and investigates human behavior with neuroscience evidence. Based on the assumption that boredom could decline the prospective memory performances, this study expects to figure out which boredom coping strategies are more likely to impair prospective memory during the task by observing alpha power in different brain regions. Although prospective memory impairment resulting from boredom could be associated with multiple boredom coping strategies, this study proposes research question 1 to identify the most critical coping strategy. Thus, this study could clarify which coping strategy in the studied environment impairs prospective memory and should be mitigated in the future. Moreover, this study is interested in predicting prospective memory while people are bored. The prediction model could further reflect the specific brain activity for effectively predicting the prospective memory performance. With the model, this study pinpoints the brain region enhancing the predictability of prospective memory while boredom. This way, the activity of the important brain region could help reveal the effectiveness of boredom intervention in the future. This study then proposes research question 2 to specify the alpha power in significant brain regions in the studied environment.

Research question 1: What boredom coping strategy could negatively influence the prospective memory?

Research question 2: Based on alpha power, what are the significant brain regions for predicting prospective memory while boredom?

This study applies EEG to measure the differences in alpha power while conducting prospective memory tasks since boredom is often associated with brain activity in the alpha band. Hence, this study analyzes alpha power based on the neural oscillations in the frontal, parietal, temporal, and occipital regions.

Human–machine task allocation is different from prior experiences because of the increasingly passive user interaction. Besides, previous patterns and issues of human–machine interaction no longer fit future models. Consequently, alleviating and avoiding boredom, which might result in undesirable outcomes, such as poor decision-making due inattention, is critical. The results of this study may help to determine the relationship between boredom and prospective memory. Moreover, this study could be the foundation to develop boredom intervention methods and provide suggestions from a neuroscience perspective for human-centered intelligent system design.

MATERIALS AND METHODS

Participants

This study recruited 31 university students. Three participants were excluded from the analysis, two of them had noisy and unusable EEG data, and the other had invalid memory responses. Overall, there were 28 valid samples included in this study. The number of males and females was equal, and the age ranged from 19 to 27 (mean = 22.89, *SD* = 2.15). All of them were healthy, had normal or corrected-to-normal vision, and had good mental health.

Procedure

Upon obtaining informed consent, the experimenter prepared a 64-electrode EEG montage. Then, the experimenter presented the experiment instructions, namely, participants' responsibilities, the structures and functions of the experimental dashboard, and the prospective memory task procedure. Participants were asked to play as homecare nurses monitoring and operating multidimensional homecare items through a smart homecare control dashboard to support patients. After that, participants were guided to operate the system for the exercise. A prospective memory task was given after ensuring that the participant understood how to interact with the control dashboard.

The prospective memory task in this study was designed with three sequential phases based on Glienke and Piefke (2016), namely, planning (memorizing future intentions based on either time or events), retention (interval between memory encoding and retrieval), and performance (execution with memory). This study considered prospective memory while interacting with the smart homecare control dashboard. Participants had to memorize steps to monitor and process alarms occurring in the homecare control dashboard.

First, in the planning phase, participants had to plan and memorize steps for processing alarms. Two stages were included in this phase. In stage one, the experimenter gave a table listing 10 alarm types and 23 steps, as shown in **Table 1**. Participants should match four out of twenty-three steps to each alarm type and put them in order based on their understandings. Stage one was designed to ensure that participants matched and ordered after thinking. Thus, participants were told that their answers should be logical and reasonable, although the answers did not link to their task performances. In stage two, the experimenter provided the recommended steps for memorizing. Besides, the experimenter would not bring back the answer sheet in stage one, enabling participants to compare. Both answer sheets would be taken back by the experimenter once the completion of this stage. Results of this pilot study indicated that 10 min were enough for participants to encode and memorize in this study environment. Hence, 10 min were required to complete this phase and 5 min were for each stage, respectively.

Second, the retention phase started after a 5-min break. A 10-min version attentional network test, CRSD-ANT (Weaver et al., 2013), was adopted. This attention task was conducted with the computer. Participants had to focus on fixation cross in the middle of the screen and tap with the arrow stimuli. This study employed this attention task to distract participants because prospective memory was likely to be impaired in real-life scenarios. Another 5-min break was given after this phase.

Third, in the performance phase, participants had to interact with the smart homecare control dashboard. Participants would operate with the control dashboard when the two kinds of alarms were presented. The first one was an alarm that the machine itself could not handle. Participants should operate steps based on alarm types utilizing their prior memory in the planning phase.

TABLE 1 | A list of 10 alarm types and 23 steps.

Alarm types	Home security	Electricity
		Water
		Smoke
		Door sensor
		Infrared sensor
	Personal health	Heartbeat
		Blood pressure
		Blood sugar
		Bedridden
		Emotion
Steps	Check the condition of intelligent motor	
	Check the condition of the smart homecare sensor	
	Check the data again after 30 min	
	Check the data from infrared sensor	
	Check the location of the alarm	
	Check the location of the wearable device	
	Check if the mode of blood pressure monitoring is on or not	
	Check if the mode of blood sugar monitoring is on or not	
	Check if the mode of emotion monitoring is on or not	
	Check if the mode of heartbeat monitoring is on or not	
	Contact the nearby fire and rescue agency	
	Contact the nearby hospital	
	Create the form showing details of the alarm	
	Determine the medical priority of the patient	
	Inform the nurse who is in charge of the patient	
	None	
	Restart the smart home caring device	
	Save current data	
	Send a request for immediate house care services	
	Start the mode of continuous emotion monitoring	
	Turn on the indoor firefighting robot	
	Turn on the real-time video for monitoring	
	Turn on the vibration mode	

The prospective memory performance was calculated based on the accuracy of steps. Participants were reminded to process this alarm type accurately and rapidly. The second one was an alarm that the machine automatically had processed the alarm. A message box would pop up showing the information to inform participants. By clicking the "OK" button, participants could continue their task. The first alarm would occur every 5–6 min and the number of this kind of alarm in this phase was seven. Compared to the first alarm type, the occurrence of the second alarm type was more frequent, with an interval of around 30 s. To simulate the monitoring task in real workplaces in this phase, the experimenter told participants that both the kinds of alarms occurred randomly and no feedback was given before alarms. Specifically, every alarm was independent and participants had to concentrate on the smart homecare control dashboard and operate when needed. Approximately, 40 min were required for the completion of this phase. **Figure 1** illustrates the whole prospective memory task procedure in this study.

After completing the performance phase, participants would fill out questionnaires, which measured the task load and boredom during the interaction in the performance phase. Around 2 h were needed to complete the whole experiment.

Smart Homecare Control Dashboard

The experimental platform was a smart homecare control dashboard developed with Python 3. As house care nurses, participants had to interact with this control dashboard for monitoring and operating when there were situations. **Figure 2** shows the interface of the control dashboard consisting of a button to start the control dashboard, home security monitoring, personal health monitoring, monitoring summary, personal health data, operations, map, and monitoring statistics.

First, there was a white button at the top right, which participants had to click to start the control dashboard. Second, home security monitoring and personal health monitoring reported information about alarms. In home security monitoring and personal health monitoring, the alarm information would be presented with five parameters, namely, the alarming number, patient characteristic, reasons for the alarm, current alarm state, and update time of the alarm state. Besides, the word color changed as the current alarm states: the green was for those solved alarms, the blue was for those alarms were processing, and the red was for those alarms kept warning. The alarm summary displayed information of solved alarms with five parameters as well, while there were slightly different from the prior two displays. In addition to the alarming number, patient characteristics, and time

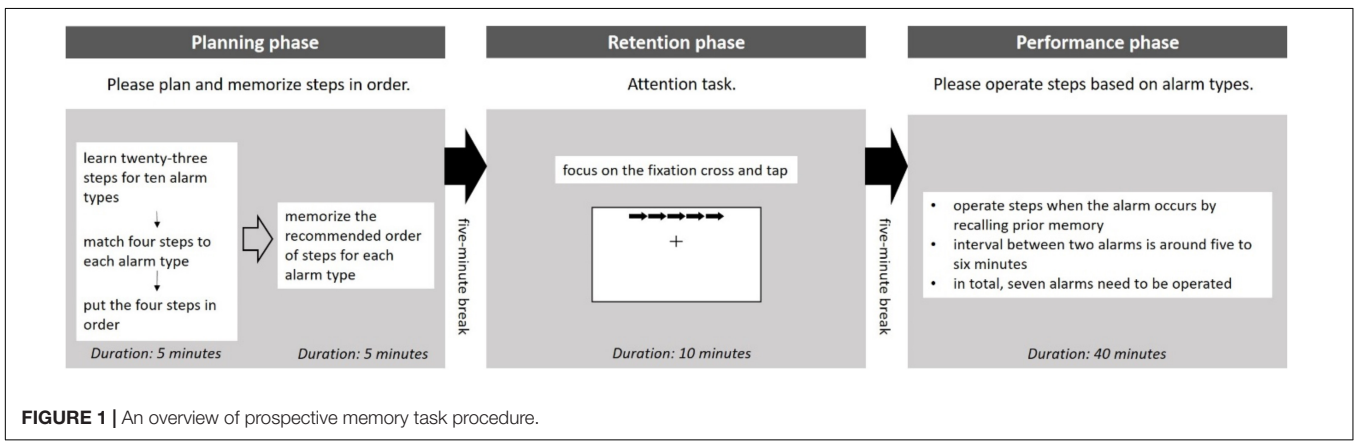

FIGURE 1 | An overview of prospective memory task procedure.

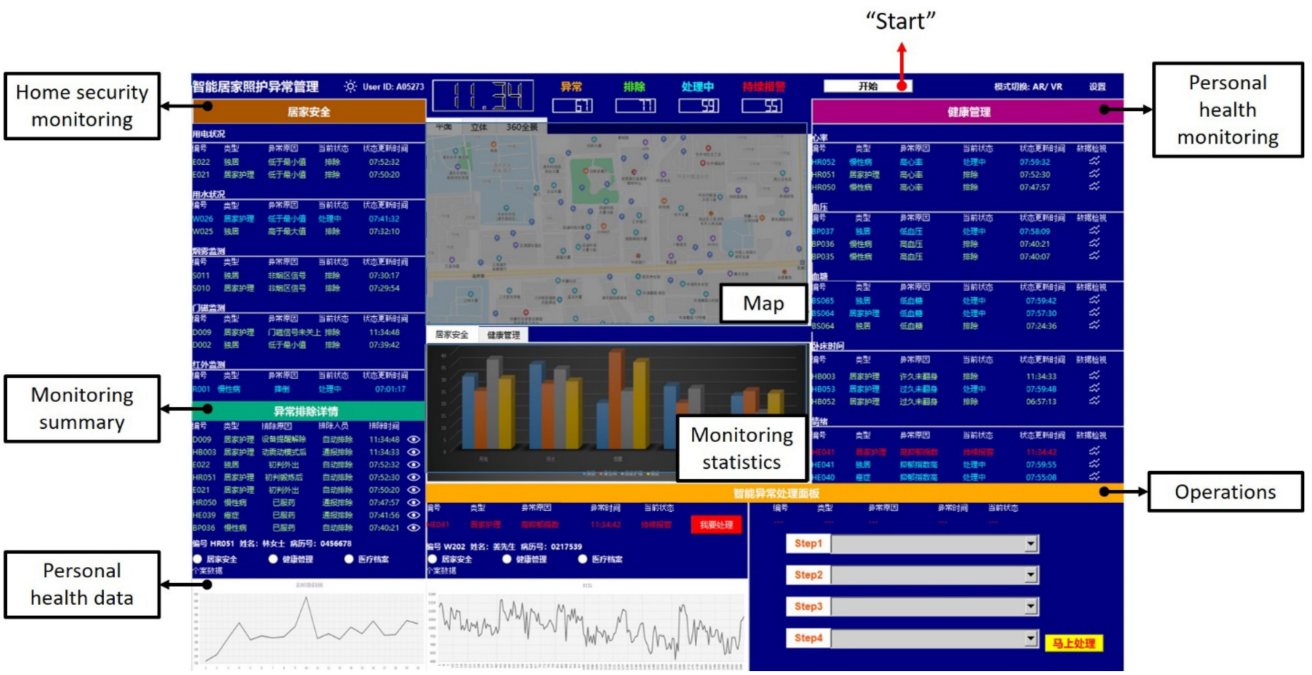

FIGURE 2 | The interface of the smart homecare control dashboard.

of the alarm state update, reasons for solving the alarm and the way for solving the alarm (by human or machine) were reported. All the alarms were generated randomly and automatically by the control dashboard.

Third, the operations were located at the bottom left corner of the interface, designed to operate steps for alarms. The alarm that the machine could not handle would be presented in the left area of this panel. By clicking the red button, the information shown on the left would be transmitted to the top right area. Then, participants could process the alarm using the four scrollable menus in the right area. As shown in **Figure 3**, participants had to scroll to the corresponding step following the order of Step 1, Step 2, Step 3, and Step 4. The yellow button at the bottom right corner should be clicked to confirm the steps for processing. Then, a message box would pop up to inform participants that the control dashboard had been received successfully. By clicking the "OK" button, the control dashboard would continue. Unlike the alarm requiring human participants, the alarm that was directly handled by the machine would inform participants only with a message box. Again, a click on the "OK" button was required. All the alarms for processing were generated randomly and automatically by the control dashboard. In addition, the control dashboard would refresh once a new alarm occurred.

Next, the map was located at the top middle of the interface, presenting the location of the alarm immediately. In addition, historical health data of the patient were presented at the bottom left of the interface, which enabled a quick understanding of the condition of the patient. In addition, the number of alarms was reported with bar charts below the maps based on either home security monitoring or personal health monitoring.

Electroencephalography Data Acquisition

Electroencephalographic data were recorded during the prospective memory task by Neuroscan 64-channels EEG system and SynAmps 2 amplifier system (bandpass = 0.05–100 Hz). The equipment was designed by Compumedics Limited, Australia. An online reference was placed on the left mastoid, and the average of the left and right mastoids was re-referenced offline. Data from the EEG were digitized at 1,000 Hz, and electrode impedance was below 10 kiloohms (kΩ). Electrodes placed at both the eyes (close to the temple) and the left eye (below and above) recorded horizontal and vertical electrooculographic (EOG) activity, respectively.

Electroencephalography Preprocessing

Signal processing and analysis of EEG data were performed in Matlab R2021a (The MathWorks Incorporation, Natick, Massachusetts, United States) using the EEGLab toolbox (Delorme and Makeig, 2004). The data were filtered at 0.5–30 Hz after re-referencing. Channels with amplitudes exceeding ± 100 microvolts (μV) were marked as bad and excluded because their signals were noisy. In general, the threshold of bad channels was 15% of the total channels. This study ensured that the number of bad channels among all valid samples met the criteria. On average, 0.07 channels per participant ($SD = 0.19$) were removed. In addition, poor signals were removed visually before processing independent component analysis (ICA). According to the results of ICA, this study identified and removed components denoting

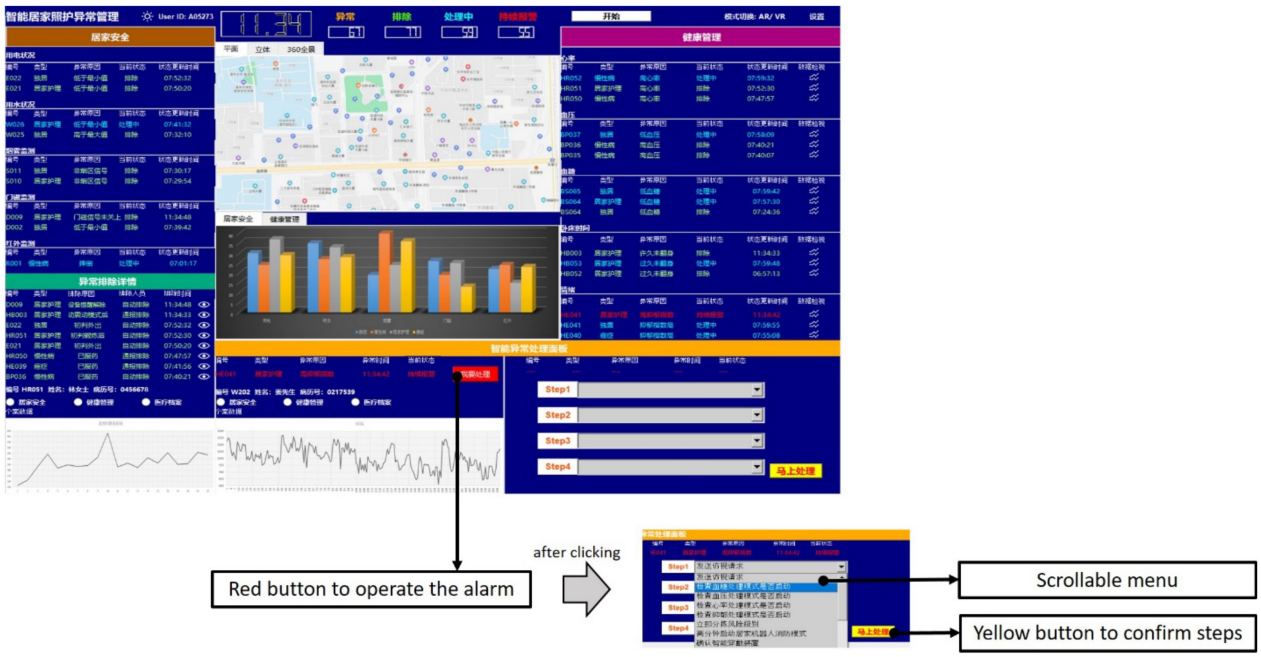

FIGURE 3 | The alarm requiring participants to process in operations.

artifacts using ICLabel (Pion-Tonachini et al., 2019). This study rejected components with higher rank by considering their IC labels, particularly for the labels of *Eye* with a probability of at least 0.5. On average, 13.22% ($SD = 0.04$) of components were excluded.

Measures and Data Analysis

Subjective, objective, and physiological measures were collected in this study. First, this study used NASA-TLX (Hart and Staveland, 1988) and the Multidimensional State Boredom Scale (MSBS) (Fahlman et al., 2013) to examine task load and boredom subjectively. Both subjective measures were to ensure that the studied interaction with the smart homecare control dashboard matched the real-life scenarios, which of low task load and aroused boredom successfully.

Second, the objective measure was the prospective memory performance. This study calculated the accuracy of prospective memory based on steps that they submitted to process alarms during the performance phase. On average, the mean accuracy was 66.78% (SD = 0.19). In statistical analyses, the accuracy of prospective memory was a dependent variable.

Third, a Matlab function sub_stft, provided by Hu and Zhang (2019), was used for the time-frequency analysis. This study evaluated the brain activity of each region through the power within the frequency band of alpha (8–13 Hz). Seven brain regions were divided in this study. **Table 2** presents the brain regions and their corresponding electrodes. Then, this study calculated the alpha power between the two time intervals in seven brain regions. One was a 10-min interval in the middle and the other was a 5-min interval before the end of the recording. Previous studies about boredom induction in vigilance and intelligent driving tasks suggested that 15–21 min were required to become bored (Martel et al., 2014; Samrose et al., 2020). This study then selected 15–25 min (a 10-min interval in the middle) after starting to ensure that participants were bored. In addition, the last 5 min were selected to make a comparison for exploring brain activities. This study compared alpha power differences by subtracting the alpha power in the middle interval from the alpha power in the latter interval. The positive value implied the inactive brain in the studied period. In contrast, the negative value indicated the activation of the brain region in this period. The alpha power differences between the two time intervals in seven brain regions were applied as independent variables in statistical analyses.

All the analyses were conducted with R Statistical Software (version 4.0.2). This study performed causal inference mediation analyses with the R package "*mediation*" (version 4.5.0). The default function *lm()* provided with the R environment was used for performing all the regression analyses.

TABLE 2 | The analysis of the brain regions and the corresponding electrodes in this study.

Brain region	Electrode
Anteriorfrontal (AF)	FP1, AF3, FPZ, FP2, AF4
Frontal (F)	F7, F5, F3, F1, FZ, F2, F4, F6, F8
Frontal central (FC)	FC5, FC3, FC1, FCZ, FC2, FC4, FC6
Centrotemporal (CT)	T7, C5, C3, C1, CZ, C2, C4, C6, T8
Centroparietal (CP)	CP5, CP3, CP1, CPZ, CP2, CP4, CP6
Parietotemporal (PT)	TP7, P7, P5, P3, P1, PZ, P2, P4, P6, P8, TP8
Parietooccipital (PO)	PO7, PO5, PO3, O1, POZ, OZ, PO4, PO6, PO8, O2

RESULTS

Subjective Results

Different boredom manipulations lead to diverse reactions and behaviors. According to the MSBS results, the experiment induced boredom through four paths: time perception (mean = 4.36, $SD = 1.52$), disengagement (mean = 3.95, $SD = 1.00$), inattention (mean = 3.86, $SD = 1.23$), and low arousal (mean = 3.69, $SD = 1.05$). In addition, participants received the system information passively. They were expected to implement memory tasks urgently during the experiment, in a way similar to air traffic control and memory. NASA-TLX (mean = 6.47, $SD = 1.09$) revealed that this study was of low task load (Grier, 2015). Overall, the four boredom dimensions and low task load guaranteed that this experimental scenario and task were comparable to the novel human–machine interaction.

In addition, this study conducted correlation analyses of MSBS, NASA-TLX, and prospective memory separately to reveal the relationship among them. First, the results of MSBS and prospective memory reported that the disengagement ($r_s = 0.39$, $p = 0.04$) and the total boredom score ($r_p = 0.33$, $p = 0.08$) were significantly correlated to prospective memory. Second, the results of NASA-TLX and prospective memory presented that the frustration level ($r_s = -0.39$, $p = 0.04$) was significantly correlated to prospective memory. The results of correlation analyses showed that both boredom and low task load correlated to prospective memory. Meanwhile, the results indicated that participants might attempt to focus on the task and get better performances.

Research Question 1

To answer research question 1, this study conducted mediation analyses according to three criteria for determining the mediation effect proposed by Barron and Kenny (1986). At first, the direct effect was tested between the independent variable and the dependent variable. Next, the second analysis was to test the effect of the independent variable on the mediator. Then, this study tested the effect of the mediator and the independent variable on the dependent variable.

In the current analyses, the alpha power difference of anteriorfrontal (AF) was served as an independent variable, and prospective memory performance was used as a dependent variable. The alpha power differences of centroparietal (CP), centrotemporal (CT), parietotemporal (PT), and parietooccipital (PO) were analyzed as mediators.

Among the four mediators, the mediation effect was found in the alpha power difference of CP. Based on the CP, three regression models testing the mediation effect were presented as Model 1, Model 2, and Model 3.

$$\text{Prospective memory} = \beta_0 + c \times AF + e_1 \quad \text{Model 1}$$

$$\text{CP} = \beta_1 + a \times AF + e_2 \quad \text{Model 2}$$

$$\text{Prospective memory} = \beta_2 + c' \times AF + b \times CP + e_3 \quad \text{Model 3}$$

According to model 1, results reported a significant direct effect of AF on prospective memory ($B = 1.22$, $p = 0.046$).

TABLE 3 | Regression of prospective memory on AF and prospective memory.

Model	Results			
	Estimate	**SE**	***T***	***p*-value**
Model 1:				
Model information				
Prospective memory on AF	1.22	0.58	2.13	0.046**
Model 2:				
Model information				
CP on AF	0.55	0.29	1.88	0.075*
Model 3:				
Model information				
Prospective memory on AF*CP	−76.57	27.37	−2.80	0.016**
Non-parametric bootstrap confidence interval	**Estimate**	**95% C.I.**		***p*-value**
Average causal mediation effect	−53.1	[−107.0, −11.7]		0.003**
Average direct effect	−32.9	[−75.9, −1.3]		0.038**
Total effect	−86.0	[−180.0, −14.2]		0.012**
Proportion mediated	0.6	[0.6, 0.9]		0.009**

*N = 28; *p < 0.1; **p < 0.05.*

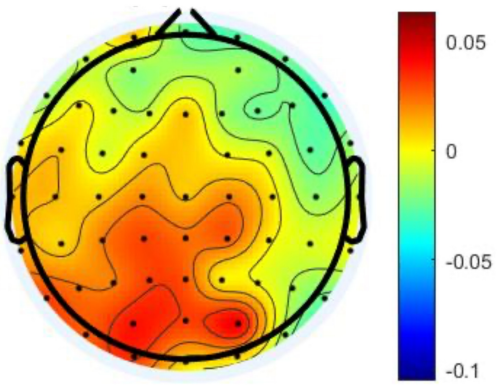

FIGURE 4 | The topography demonstrates the differences of the alpha power between two studied intervals.

Next, the results of model 2 showed a significant effect of AF on CP ($B = 0.55$, $p = 0.075$). Then, the results of model 3 also reported a significant effect of AF and CP on prospective memory ($B = -76.57$, $p = 0.016$). Afterward, this study determined whether the mediation effect is significant or not with R package "*mediation*" (Tingley et al., 2014). Non-parametric bootstrapping with 5,000 resamples was then conducted. The results revealed significant causal mediation effect ($B = -53.1$, $p = 0.003$), direct effect (B = −32.9, $p = 0.038$), and total effect ($B = -86.0$, $p = 0.012$). **Table 3** summarizes the results of mediation analyses.

To sum up, this study found that the mediation effect of the alpha power differences in the CP was significant in the relationship between the AF and the prospective memory performance. In other words, the changes pf alpha power in CP could negatively influence the prospective memory. Moreover, **Figure 4** provides further evidence that the prospective memory

impairment resulting from the increased alpha power in CP was associated with the left hemisphere.

Research Question 2

To answer research question 2, this study conducted analyses to figure out if there is any other brain activity that could impact the causal relationship between boredom and prospective memory. This study further included other variables (CT, PT, and PO) in three separate regression models to explore whether they could help interpret the relationship between alpha differences in the AF, F, and FC.

At first, this study constructed a regression model with the alpha power differences in the AF, F, and FC as independent variables and prospective memory performance as the dependent variable. Then, the CT, PT, and PO were introduced individually. According to the results, the PO could marginal significantly increase the prediction ability on prospective memory ($R^2_{AF,F,FC} = 0.37$, $R^2_{AF,F,FC,PO} = 0.45$, $p = 0.06$), while the CT and PT did not meet a statistically significant level. Furthermore, the results also revealed that the alpha power in AF, FC and F, and PO were nested. The results from the comparison of both models showed that the alpha power in the PO lobe could effectively enhance the predictability of boredom to prospective memory.

DISCUSSION

This study ensured that the experimental design focused on the features of future human–machine interaction scenarios, which were boredom and low task load, *via* a subjective questionnaire about the boredom and perceived task load during the interaction in the performance phase. Considering that alpha oscillations were found to be significant in CP and PO during the prospective memory task, the current findings will offer deeper indications in the following discussion.

Alpha Oscillations in Centroparietal

Although the alpha power in the posterior brain regions is associated with feelings of relaxation and calm, it does not indicate that humanity is in the resting state (Lagopoulos et al., 2009). The parietal lobe is the common brain structure for novel thoughts (Schacter and Addis, 2007). Usually, creative and novel ideas require integration for many types of unrelated information and memory processes recalling past experiences. Benedek et al. (2018) conducted a study to investigate the brain mechanism of the generation of creative thoughts. Their fMRI results reported activation in the left inferior parietal lobe and supramarginal gyrus, which indicated that the mechanism for new idea construction was similar to the encoding and decoding of memory. In other words, it is not easy to generate creative ideas with merely either external information or memory. People acquire unrelated information based on their knowledge system. In addition, they retrieve semantic and episodic memory for divergent thinking and creative idea generation (Benedek et al., 2012). However, emotions, such as boredom, could lead to poor memory performance because daydreaming, mind-wandering, and other divergent thinking with high internal attention could worsen external stimuli perception for memory retrieval (Barron et al., 2011). Goldberg and Todman (2018) focused on boredom and studied mood-congruence memory. Their results pointed out that memory impairment might be associated with the encoding stage resulting from the attentional failure.

The dorsal and ventral attention networks are mainly responsible for top-down and bottom-up control, respectively. From the neuroscience perspective, the dorsal attention network relies on parietal activity and the ventral attention network links to the temporal lobe. Previous studies have shown that behaviors with top-down control are related to alpha oscillations in the parietal lobe, and they could hinder knowledge-based memory processes because of the limitation of attentional buffer capacity (Klimesch, 2012; Benedek et al., 2014a). Using top-down control to cope with memory-based tasks critically depends on alpha oscillations because large and distributed brain networks are related to the transfer of information between memory systems (Min and Park, 2010). To prevent mind-wandering and distraction, frequent shifting between both attention networks can be observed accordingly. Vossel et al. (2009) further revealed that the activation of the dorsal and ventral attention networks was a representation of the reorienting processes for regaining attention.

This study was conducted by performing a bottom-up and memory-based experiment. The significant effect of the parietal lobe might indicate that participants in the present intelligent interaction could lead to the loss of situation awareness similar to the top-down processing. Benedek et al. (2014b) investigated the alpha power in the parietal regions based on hemispheres. Their results suggested that higher internal attention was related to higher alpha power in the right-parietal lobe. Meyer et al. (2018) indicated that hemispheric differences played an important role when it comes to internal and external attention. In this study, **Figure 4** presents that the majority of the increase of alpha power were in the left-posterior brain regions. This study suggested that the boredom coping strategy while interacting with intelligent systems should be related to the unstable attention mechanism.

The findings in the study of Yakobi et al. (2021) might help to interpret the results of this study. They argued that people continued in sensory processing even though they were asked to do tasks with low task load in an uninteresting environment. Indeed, continuous sensory processing could imply the inattentive status of individuals, making people not sensitive enough to detect the cues of prospective memory retrieval. Moreover, according to the prospective memory decision control (PMDC) model (Stirckland et al., 2018), Boag et al. (2019) reported that prospective memory could facilitate ongoing decision-making when there was no time pressure. In contrast, time pressure would occupy limited-capacity cognitive resources and reduce attentional control. Overall, the practical implication of this study for preventing prospective memory impairment is suggested for passive user interaction, i.e., future task allocation in human–machine collaborative intelligent systems should concentrate on operators' attention management and inhibit top-down control and divergent thinking. The meaning and attentional components (MACs) model can further support

the proposed practical implication since the boredom state occurring in most human–machine collaboration cases is regarded as attentional boredom resulting from understimulation (Westgate and Wilson, 2018).

Alpha Oscillations in Parietooccipital

Introducing parietooccipital activity can significantly predict prospective memory that could be influenced by boredom. Although boredom is associated with alpha oscillations, especially in the frontal lobe, this study further found that the parietooccipital lobe might be critical for investigating prospective memory, which would decline with boredom. As discussed in section "Alpha Oscillations in Centroparietal," the activation of the parietal lobe is linked to creativity and divergent thinking. According to this study, the functional connectivity between the parietal and occipital lobes should be worth noting regarding the relationship between boredom and prospective memory. This study referred to the empirical research and gathered two reasons for the results. First, the default mode network (DMN) should be activated in the current boredom induction scenario, which is a brain activity to cope with boredom induced by low task load. According to the study of Fink et al. (2018), the time-related changes in divergent thinking during the creativity task were related to the left supramarginal gyrus and the right occipital lobe. In addition, Shi et al. (2018) then reported causality between the DMN and creativity. This study argued that brain activity in the PO might reflect internal brain conditions even though the EEG evidence lacked spatial resolution. The DMN is evoked when one is experiencing disengagement and inattention (Danckert and Merrifield, 2018). Meanwhile, from a psychophysiological perspective, the DMN indicates the resting brain and unoccupied brain regions (Manson et al., 2007). Second, visual processing was engaged in the experiment, as participants had to keep their eyes open to complete the task, increasing the importance of the occipital lobe. The occipital lobe is the primary visual processing center, and alpha power activity in the occipital lobe could be associated with the facilitation of visual information selection, including conscious execution (Jensen et al., 2002; Samaha et al., 2015).

After the discussion about the oscillation in PO, the question about how the PO can help predict prospective memory during boredom will be explained accordingly. Park et al. (2011) investigated the functions of working memory and visual-related brain activity. Their findings suggested that blind people presented effective connectivity from the DMN to the left frontoparietal network and from the occipital cortex to the right frontoparietal network during the 2-back task. The experiments in their study did not cover the visual tasks. Instead, they applied verbal and sound cues with tone and spatial information for the investigation. The research team further suggested that the occipital cortex was engaged in the execution of working memory. Moreover, Smith et al. (2011) revealed that working memory was closely associated with prospective memory. Specifically, people who have a larger working memory span could probably have higher prospective memory performance. Therefore, this study reports that brain activity in PO could demonstrate memory mechanisms, which should be adapted to the memory processes with most sensory channels.

However, dealing with visual information, such as cues, is crucial for prospective memory retrieval and decision-making in real-life settings. The alpha oscillation in PO is utilized for the anticipatory neural biasing mechanism preparing for visuospatial attention and motor function and maximizing their reward of decision-making (Heuer et al., 2017). This study then suggests that using alpha oscillations in PO to understand prospective memory during boredom should be applied to both psychophysiological and practical areas.

Limitations and Future Research

There are some limitations to this study. First, the induction of interacting boredom extended the time length of the EEG experiment, which might have caused fatigue and other negative effects. However, this study did not analyze other emotions toward perspective memory separately. Second, this study is limited by the small sample size due to the long experimental duration.

Although the results of this study are helpful to identify the link between boredom and prospective memory, they are preliminary and await further replication for concise interpretation in future research. First, future studies need to look at the effects on top-down and bottom-up information processing differences since this study did not directly assess their influences and the exact mechanisms remain unknown. Second, this study revealed the DMN to provide reasonable explanations of the relationship between boredom and prospective memory, and further investigation is needed to support this argument. Third, this study has concluded the relationships from the signals from the scalp, but it is worth noting that the inferior brain regions, such as the inferior frontal gyrus, could also be contributing to the influences of boredom on prospective memory. Thus, this study proposes that further evidence, based on a higher spatial resolution, would be beneficial to understanding the link between boredom and prospective memory.

CONCLUSION

This study explored the effects of boredom on prospective memory. The alpha power in seven brain regions while interacting with the intelligent system was measured with EEG. Alpha oscillations were used to examine the relationship between boredom and prospective memory.

The results of this study reported that the prospective memory impairment was associated with distraction while bored in interacting with the intelligent and complex system. The results showed that alpha oscillations in both the parietal and parietooccipital regions supported the proposed findings. The mediation effect on the parietal region pointed out that the changes pf alpha power in CP could negatively influence the prospective memory. In addition, the finding from the parietooccipital activity was associated with the DMN, which revealed that individuals would consciously avoid irrelevant external information when they were bored in the study context.

Therefore, the findings from this study suggest that attention management and influences of processing visual information could improve the preparation of prospective memory and enhance decision quality during the task periods.

The increasing passive user interaction with intelligent systems shapes novel human–machine task allocation styles, but human workers encounter challenges to handle situations needing human control effectively. This study used EEG to enumerate the way that boredom influences prospective memory. Consequently, this study provided evidence from brain activity to understand behavioral changes in human–machine intelligent interactions. Furthermore, the findings of this study could be applied to the foundation of future human-centered system design and intervention measures.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Department of Industrial Engineering, Tsinghua University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

P-HC and P-LR: conception and design of the work, data analysis, and interpretation. P-HC: manuscript. P-LR: validation and supervise this study. All authors read and approved the final manuscript.

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Did It Change Your Mind? Neural Substrates of Purchase Intention Change and Product Information

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Price and customer ratings are perhaps the two most important pieces of information consumers rely on when shopping online. This study aimed to elucidate the neural mechanism by which the introduction of these two types of information influences the purchase intention of potential consumers for hedonic products. Participants performed a lip-care product shopping task during functional magnetic resonance imaging, in which they re-disclosed purchase intentions referring to the information of price or rating provided about the products that they had previously disclosed their purchase intentions without any information. Data from 38 young female participants were analyzed to identify the underlying neural regions associated with the intention change and product information. The bilateral frontopolar cortex, bilateral dorsal anterior cingulate cortex (dACC), and left insula activated higher for the unchanged than changed intention condition. The right dACC and bilateral insula also activated more toward the price than the rating condition, whereas the medial prefrontal cortex and bilateral temporoparietal junction responded in the opposite direction. These results seem to reflect the shift to exploratory decision-making strategies and increased salience in maintaining purchase intentions despite referring to provided information and to highlight the involvement of social cognition-related regions in reference to customer ratings rather than price.

Keywords: price, customer rating, purchase intention, frontopolar cortex, salience processing

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INTRODUCTION

Advances in technology and the outbreak of coronavirus 2019 (COVID-19) have aided the meteoric explosion of the e-commerce marketplace. A survey by McKinsey & Company suggests an average of 30% growth in online purchases due to the onset of the pandemic (Charm et al., 2020). Similar to the decision-making process of offline shopping, even in online ones, if consumers have a need, they search for information, evaluate alternatives, make a purchase decision, and assess post-purchase satisfaction. Compared to traditional offline shopping, online shopping boasts greater convenience and efficiency as it allows consumers to browse and shop products with more options beyond store hours from the comfort of their home (Wang et al., 2005).

Despite these advantages, uncertainty and lack of trust remain intrinsic problems of online shopping because consumers cannot physically assess products. In order to mitigate this issue and encourage sales, retailers provide a wide range of information about their products on online platforms, and consumers rely heavily on that information to make purchasing decisions.

In fact, it is understood that besides the perceived security concerns and interactive experience with the website, the amount of information available in a product has a significant impact on consumer behavior (Ballantine, 2005). Details such as brand, descriptions, images, price, reviews, and ratings are important cues that consumers seek in their decision-making process.

The use of neuroimaging techniques, particularly functional magnetic resonance imaging (fMRI), has been under the spotlight as a powerful tool in understanding the consumption behavior in recent decades (Lim, 2018a). The consensus is that rigorous empirical investigations and available resources for new researchers coming into this multidisciplinary field of consumer neuroscience are still lacking and rather heterogeneous (Lee et al., 2018). In an effort to expand the transdisciplinary field of consumer neuroscience or neuromarketing, recent publications offer a comprehensive overview of the different applications of neuroscientific methods, research designs, and possible ethical issues (Lim, 2018b). In addition, information on how data should be managed and processed using actual data specific to business research has widened the scope and boundaries of neuromarketing studies (Lim, 2018b; Robaina-Calderin and Martin-Santana, 2021).

Different modes of visualization in online shopping are an excellent way to mimic a brick-and-mortar experience and reduce the perceived risk. For example, online retailers have started to offer virtual try-on technology, which allows users to directly interact with products by zooming and rotating them (Kim and Forsythe, 2008; Jai et al., 2014). Interestingly, several neuroimaging studies have investigated the neural substrates of product presentation, where these sensory-enabling presentations engage the superior parietal lobule associated with mental imagery and the ventral striatum related to reward processing (Jai et al., 2014; Kim et al., 2021). These findings have confirmed the significance of product presentation and elucidated the neural engagements while the product is being evaluated.

Price information is also one of the most important factors that influence consumer behavior in an online setting and has been extensively researched (Kim et al., 2012; Beneke and Carter, 2015). The perception of price is an extremely complicated cue because it is not only a monetary sacrifice in exchange for a product or service but also a delivery of product quality (Lichtenstein et al., 1993). Perceived price points can have both positive and negative effects on purchase intentions, such that a higher price may indicate higher quality, but may discourage consumers if perceived as excessive (Dodds et al., 1991).

A previous neuroimaging study reported the role of the medial prefrontal cortex (mPFC) and insula in the prediction of consumer behavior in response to price (Knutson et al., 2007). In this study, mPFC activity increased when consumers saw a lower-than-expected price and predicted purchase behavior, whereas insula activity was increased when the price was perceived too high. The order in which price information is exposed to consumers is also believed to be crucial in shaping product preferences. Another neuroimaging study reported differences in the activation of the mPFC, suggesting the primacy effect in the consumer decision-making process (Karmarkar et al., 2015). Interestingly, in this study, mPFC activity increased for purchased over non-purchased products in the product primacy condition, but not in the price primacy condition, and striatal activity increased for purchased products regardless of the primacy conditions, suggesting that seeing the price before the product promoted consumers to consider its monetary worth, whereas seeing the product before price encouraged them to focus on its desirability. Taken together, the way a product is presented influences not only purchasing behavior but also neural responses, particularly the reward process.

Online stores include customer ratings, which are related to the positive effect of word-of-mouth on purchasing behavior (Chintagunta et al., 2010; Ye et al., 2011; Anderson and Magruder, 2012; Kim et al., 2012), and are considered to be a major factor influencing purchasing decisions (Bughin et al., 2010; Floyd et al., 2014). Extensive research has demonstrated that product reviews and consumer's purchase intentions have a positive relationship (Chevalier and Mayzlin, 2006; Park et al., 2007). Although written and descriptive product reviews are important for shaping purchase intentions, previous studies show that average customer ratings are highly influential as well, especially among younger shoppers (Hong and Park, 2012; von Helversen et al., 2018).

When the influence of others' opinions was studied using fMRI, it was found that conflict with group opinion activated the rostral cingulate zone and deactivated the ventral striatum, both of which are known to compute prediction errors (Klucharev et al., 2009), suggesting that such neural changes may lead to the realization for the need to conform and trigger behavioral adjustment. Several other neuroimaging studies have also shown conforming to group opinion that activates the ventral striatum and medial orbitofrontal cortex (mOFC), suggesting that accepting social norm is rewarding (Campbell-Meiklejohn et al., 2010; Zaki et al., 2011; Cascio et al., 2015). Furthermore, social influences in the decision-making process may be important in this issue, and brain regions that deserve special attention are the temporoparietal junction (TPJ) and posterior superior temporal sulcus (pSTS), which are regarded as the key to understanding the mental states of others or mentalization (Saxe and Kanwisher, 2003). When actual salespeople were recruited as participants, it was found that TPJ activity was associated with the ability to read their customer's minds (Dietvorst et al., 2009). Social influence of own decisions was instantaneously reflected in the TPJ, and its activity was actually modulated by opposing opinions of others (Zhang and Gläscher, 2020). In addition, the mPFC has been associated with the social decision-making process. For example, using products and their ratings from an online retail site, mPFC activity was found to be modulated by the reliability of social information and confidence of own judgment in a Bayesian fashion (De Martino et al., 2017).

There is an intricate interaction between the price and customer ratings of a retail product. Ratings are more influential for high-end products than low-end products because higher prices allow consumers to utilize information like product reviews to mitigate the perceived risk (Maslowska et al., 2017). Additionally, lowering the price of products with low customer

ratings has been shown to alleviate its adverse effects and increase purchasing behavior (Kuo and Nakhata, 2016).

The consumer decision process is certainly influenced by the type of product involved. Cosmetics are considered hedonic goods, a broad category of products that are purchased for enjoyment, emotion regulation, and self-enhancement, and carry social meaning, as opposed to those for problem-solving (utilitarian goods) (Dhar and Wertenbroch, 2000; Ajitha and Sivakumar, 2017). Consumers are more sensitive to others' opinions and price points in hedonic goods than in utilitarian goods when in doubt about the products (Parry and Kawakami, 2015; Ajitha and Sivakumar, 2017). Although the literature on consumer behavior largely highlights the importance of customer ratings and prices on the consumer decision-making process, there is a substantial gap between behavioral and neuroscientific evidence.

Because of the involvement of the simultaneous processing of such a large amount of information, consumer decision-making is expected to engage multiple cognitive control mechanisms. Previous studies point out the dorsolateral prefrontal cortex (dlPFC), dorsal anterior cingulate cortex (dACC), and caudate as key structures associated with these cognitive control processes (Egner and Hirsch, 2005; Botvinick, 2007; Stelzel et al., 2010). The highly connected nature of the dlPFC seems to contribute to various cognitive processes such as decision strategy, inhibition, and reasoning (Clark and Manes, 2004). The dACC has been shown to activate toward conflicting options and facilitate decision-making by assessing the decision-making strategy generated by the dlPFC (Wallis, 2007). The caudate is another important region as several studies have shown its involvement in adaptive decision-making (Tricomi and Lempert, 2015; Doi et al., 2020). Social cognition is another component that plays a role in the consumer decision-making process, as shopping is a highly social activity, especially when it involves others' product opinions. The literature generally reports the mPFC, TPJ, and pSTS as cardinal brain areas involved in social cognition (Gallagher and Frith, 2003; Kramer et al., 2010; Olson et al., 2013). This involvement of multiple functions suggests that neural regions respond differently throughout the course of consumer decision-making.

The purpose of this study was to elucidate the neural mechanism by which the introduction of product information influences the purchase intention of potential consumers for hedonic goods and to identify the neural regions associated with the level of intention change. The investigation also aimed to probe how these functions are rendered during evaluation and choice phases of the decision-making process. We expected that cognitive processes related to decision-making, including cost-benefit calculation and action control, and social cognition would respond distinctively depending on the purchase intention change and product information. Accordingly, we hypothesized that the prefrontal regions, dACC, and caudate, which are important in making decision strategies and other cognitive processes, would be involved in information-related changes in purchase intention during the evaluation phase, whereas the temporal areas and TPJ, structures known for their role in social cognition, would respond in favor of customer ratings during the choice phase. In addition, we hypothesized that increases in purchase intention would be correlated with the magnitudes of ventral striatum activity and mOFC activity, as they are critical nodes in the reward circuit.

MATERIALS AND METHODS

Participants

A total of 42 healthy young female volunteers were recruited *via* online advertisement. Exclusion criteria included left-handedness, pregnancy, and neurological or psychiatric diseases. All participants were provided informed written consent before the study; the study was approved by the Institutional Review Board of Yonsei University Severance Hospital and carried out in accordance with the Declaration of Helsinki. Data from four participants were excluded from the analysis due to excessive missing trials (>15%) or skewed distribution of intention change scores, and thus, data from the remaining 38 participants (age, 23.6 ± 2.0; education years, 16.2 ± 1.6) were used for the analysis.

Experimental Procedure

Participants performed a lip-care product shopping task (**Figure 1**) during fMRI. The task included a total of 84 lip-care images collected from various online cosmetic websites. All images were cropped to show only the content and body without the lid and were presented on a white background. All brand marks were erased to eliminate the branding effect. In a presurvey conducted prior to the fMRI session, participants responded to the question "How much do you want to buy?" on a 4-point Likert scale (0: "not at all", 1: "somewhat", 2: "moderately", 3: "very much") to indicate the level of purchase intention for each product. No information about price or rating was disclosed to them at this point.

In the lip-care product shopping task, 84 items were randomly assigned to either price or rating condition so that price and rating could influence the purchasing decision. The price information for each product was randomly generated, ranging from 5,000 Korean Won (KRW; approximately US$4.50) to 35,000 KRW (approximately US$31.50). The average price was about 17,300 KRW (approximately US$15.70). Customer ratings were represented in five-star images. The rating information was randomly assigned to each of 42 products, ranging from 0.5 to 5 stars, with an average of 2.9 stars. The information was placed beneath the product and presented in blue.

The task was composed of two runs, with each run having 42 trials and lasting approximately 7 min 10 s. One lip-care product was presented per trial, where price or rating information was presented for 2 s (information period). After jittering an average of 2 s, participants were asked to answer the same question as given in the presurvey in a time of 3 s on a 4-point Likert scale (choice period). Intervals between trials were jittered for an average of 3 s.

Behavioral Data Analysis

For each product, the change in purchase intention was calculated by subtracting the purchase intention score at the presurvey from the purchase intention score during the

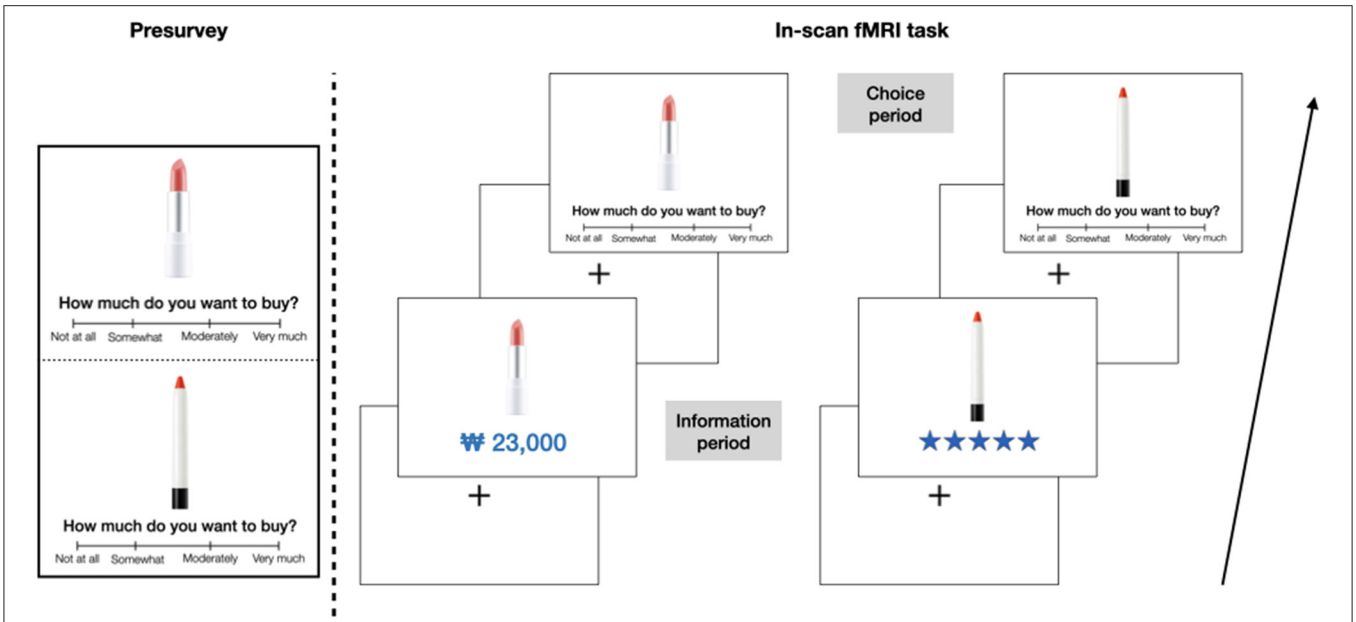

FIGURE 1 | Experimental design. Prior to the fMRI task, an online presurvey was conducted, where participants were asked to indicate their level of purchase intention on a 4-point Likert scale for each lip-care product. In the fMRI task, the same products were presented either with price or star rating information for 2 s, and then, participants disclosed the level of purchase intention on the same scale once more.

fMRI session. A score difference of zero was considered no change ("unchanged") and a non-zero score difference was deemed as being changed in the level of intention ("changed"). First, to check the validity of dividing the trials as such, the proportions of trials were compared using a one-sample binomial test at 0.5 test proportion. Once determined to be appropriate, change scores were compared between the two product information factors (price and rating) using the chi-square test. Behavioral data were analyzed using SPSS 25.0 (SPSS, Inc., Chicago, IL).

Imaging Data Acquisition

All functional scanning was performed on 3.0 Tesla MRI scanner (Ingena 3.0T CX, Philips Healthcare, Best, NL) with a 32-channel head coil. For each participant, echo-planar imaging scans were acquired with the following parameters: field of view = 224, repetition time = 2,000 ms, echo time = 30 ms, flip angle = 90°, number of acquisitions = 215, number of slices = 31, slice thickness = 3 mm with 1 mm interstitial gap, and matrix size = 80 × 80. A high-resolution T1-weighted anatomical scan was also obtained from each participant using a 3D gradient echo (field of view = 224, number of slices = 220, slice thickness = 1 mm, matrix size = 224 × 224) after the functional scan.

Imaging Data Preprocessing and Statistical Analysis

The first five scans were discarded for magnetic field stabilization. The rest of the images were preprocessed and analyzed using SPM12 (https://www.fil.ion.ucl.ac.uk/spm/). Functional data were realigned for head motion correction and corrected for slice-timing. Head movement artifacts were assessed in individual subjects to confirm that the maximum head motion in each axis was <3 mm. Individual anatomical image was coregistered to mean functional images coregistered on the individual anatomical image, spatially normalized to Montreal Neurological Institute (MNI) template space, and then smoothed with a Gaussian kernel of 6-mm full-width at half-maximum.

Once preprocessed, general linear model (GLM) was performed in the first-level analysis. Two types of analyses were performed, namely, categorical and parametric, for the intention change given respective product information. To identify the underlying neural regions associated with the intention change and product information, four main regressors (i.e., changed-price, unchanged-price, changed-rating, and unchanged-rating) were created at the information period for each run. Each trial was modeled at the onset time of the information period with the duration of 2 s. Another GLM was conducted with the same four main regressors of interest modeled at the respective onset time of the choice period with the duration of the reaction time (RT) for each run (Grinband et al., 2008). Additional six nuisance regressors were included as regressors-of-no-interest, and a high-pass filter was applied at 128 Hz to correct for low-frequency drift and physiological noise.

At the second level, the resulting four contrast images modeled for each participant were entered into the flexible factorial model for the main effects and interaction effects between the two factors in each of the information and choice periods. *Post-hoc* analysis was performed to identify the direction of differences by extracting parameter estimates of each significant cluster with a radius of 5 mm sphere using MarsBaR 0.44.

TABLE 1 | Main and interaction effects of intention change and product information at the information period.

Region	HEM	Cluster size	F	MNI coordinates			*Post hoc*
				X	Y	Z	
Main effect of intention change							
FPC	L	201	16.57	−12	54	22	Unchanged > Changed
FPC	R	148	21.77	22	48	16	Unchanged > Changed
dACC	B	136	19.57	0	28	24	Unchanged > Changed
dACC	R	118	18.57	16	30	24	Unchanged > Changed
PCC	L	196	19.63	−14	−32	44	Unchanged > Changed
SMG	L	308	25.61	−60	−38	28	Unchanged > Changed
SMG	R	200	22.44	60	−40	34	Unchanged > Changed
Insula	L	112	21.35	−22	12	−14	Unchanged > Changed
Main effect of product information							
mOFC	L	320	35.30	−22	34	−6	Price > Ratings
dACC	R	338	21.06	16	26	30	Price > Ratings
Lingual gyrus	B	1,988	41.34	8	−58	2	Price > Ratings
Insula	L	489	24.60	−36	−2	16	Price > Ratings
Insula	R	119	20.19	34	−32	24	Price > Ratings
mPFC	B	113	19.30	6	34	48	Ratings > Price
MTG	L	285	31.11	−52	0	−20	Ratings > Price
MTG	L	155	29.71	−60	−26	−10	Ratings > Price
MTG	R	181	38.25	62	−18	−10	Ratings > Price
TPJ	L	580	31.83	−50	−60	28	Ratings > Price
TPJ	R	385	33.64	56	−52	28	Ratings > Price
IPS	R	109	16.06	36	−46	44	Ratings > Price
Interaction effect							
None							

HEM, hemisphere; MNI, Montreal Neurologic Institute; B, bilateral; R, right; L, left; FPC, frontopolar cortex; dACC, dorsal anterior cingulate cortex; PCC, posterior cingulate cortex; SMG, supramarginal gyrus; mOFC, medial orbitofrontal cortex; mPFC, medial prefrontal cortex; MTG, middle temporal gyrus; TPJ, temporoparietal junction; IPS, intraparietal sulcus.

The second type of analysis, parametric analysis, was performed to investigate the neural regions modulated by the level of intention change given the price or rating information. The two product information main regressors were entered, and then, the change scores of each valid trial were included as parametric regressors to estimate neural responses for each period. Onset, duration, convolution, and six nuisance regressors-of-no-interest were set the same as those in GLM. Positive and negative relationships were tested separately between neural signals and change scores for each information condition. The resulting contrasts were submitted to one-sample *t*-tests. All statistical inferences were set at a threshold of family-wise error (FWE) corrected $P_{FWE} < 0.05$ at the cluster level with a cluster-defining threshold of uncorrected $p < 0.001$.

RESULTS

Behavioral Data

We first assessed the proportions of changed and unchanged trials using a one-sample binomial test. The overall proportions were 48.9% (SD = 0.098) for changed condition and 51.1% (SD = 0.098) for unchanged condition and did not significantly differ between the two conditions ($P > 0.05$). Factoring in price and rating information, the chi-square test revealed no difference between purchase intention change and product information types ($\mathcal{X}^2 = 1.03$, $P > 0.05$).

Imaging Data

Effects of Intention Change During the Evaluation of Product Information

Table 1 presents the neural regions showing the main effects of intention change and product information and their interaction effects at the information period. The main effect of intention change was identified in the bilateral frontopolar cortex (FPC), bilateral dACC, left posterior cingulate cortex, bilateral supramarginal gyrus, and left insula. As shown in **Figure 2A-1**, *post-hoc* analysis indicated that those regions were more activated in the unchanged condition than in the changed condition, whereas no region was more activated in the changed condition than in the unchanged condition. The main effect of product information was observed in multiple brain regions. *Post-hoc* analysis indicated that among these regions, the left mOFC, right dACC, bilateral lingual gyrus, and bilateral insula responded more to the price condition than to the rating condition, whereas the bilateral mPFC, bilateral middle temporal gyrus, bilateral TPJ, and right intraparietal sulcus responded more to the rating

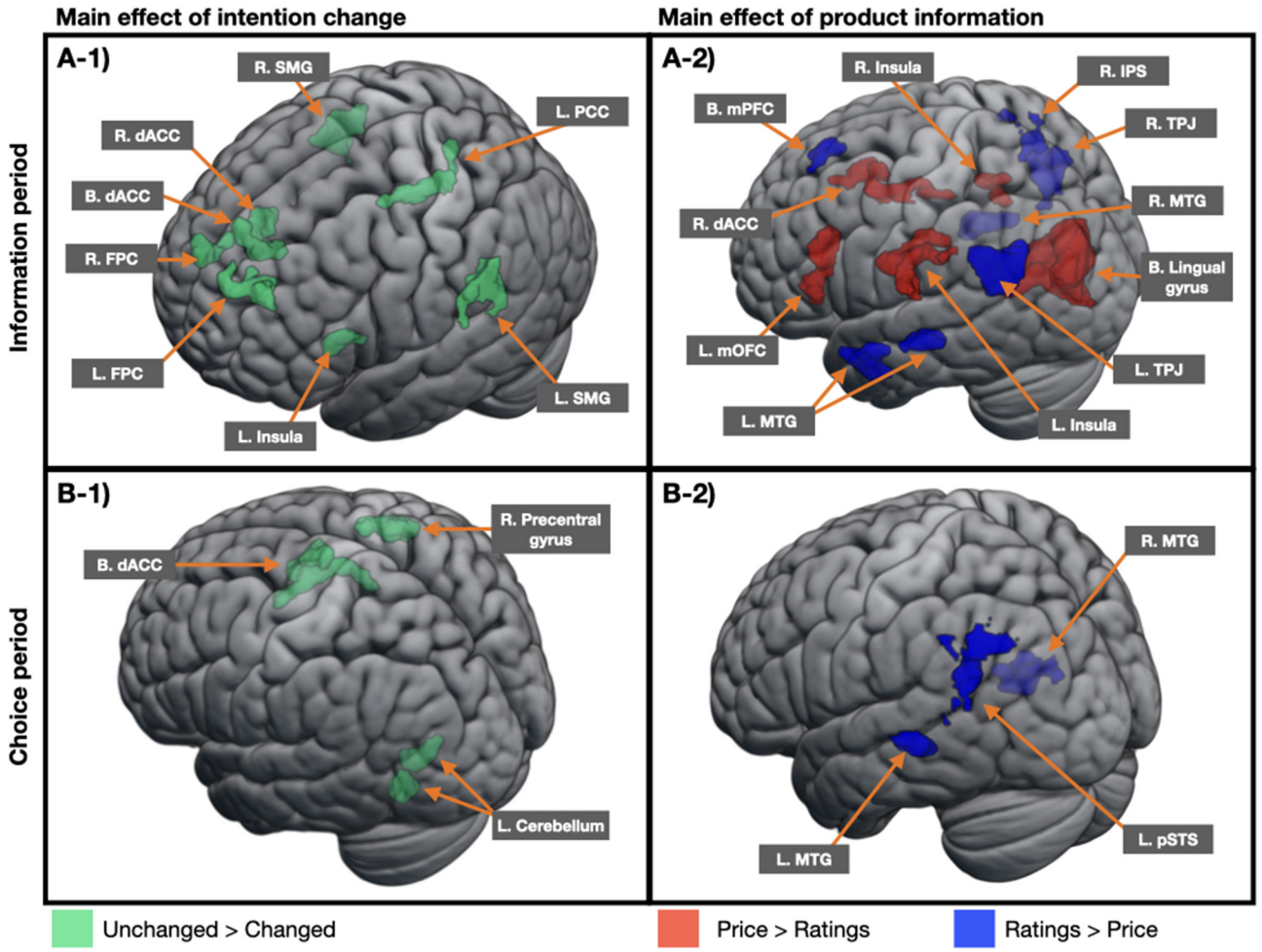

FIGURE 2 | An illustration of neural regions showing the main effects of intention change and product information in the categorical analysis. All regions showing the main effect of intention change were more activated in the unchanged condition than in the changed condition at both the information period **(A-1)** and choice period **(B-1)**. **(B)** The regions showing the main effect of product information were mixed with those that responded more to the price condition and those that responded more to the rating condition at the information period **(A-2)**, but were more activated in the rating condition than in the price condition at the choice period **(B-2)**. B, bilateral; L, left; R, right; FPC, frontopolar cortex; dACC, dorsal anterior cingulate cortex; PCC, posterior cingulate cortex; SMG, supramarginal gyrus; mOFC, medial orbitofrontal cortex; mPFC, medial prefrontal cortex; MTG, middle temporal gyrus; TPJ, temporoparietal junction; IPS, intraparietal sulcus; pSTS, posterior superior temporal sulcus.

condition than to the price condition (**Figure 2B-1**). However, no significant interaction effects were found.

Effects of Product Information During the Choice Process

Table 2 presents the neural regions showing the main effects of intention change and product information and their interaction effects at the choice period. The main effect of intention change was identified in the bilateral dACC, right precentral gyrus, and left cerebellum. As shown in **Figure 2A-2**, *post-hoc* analysis indicated that those regions were more activated in the unchanged condition than in the changed condition, whereas no region was more activated in the changed condition than in the unchanged condition. The main effect of product information was observed in the left pSTS and bilateral middle temporal gyrus. As shown in **Figure 2B-2**, *post-hoc* analysis indicated that those regions were more activated in the rating condition than in the price condition, whereas no region was more activated in the price condition than in the rating condition. However, no significant interaction effects were found.

Parametric Modulation of Intention Change

Table 3 presents results from parametric modulation analysis of intention change. At the information period, the intention change score negatively modulated the activities of the bilateral FPC, bilateral supplementary motor area, and right caudate for price information (**Figure 3A-1**) and also negatively modulated the activities of the right FPC, left insula, and left cerebellum for rating information (**Figure 3A-2**). However, no regional activity was positively modulated by the intention change score

TABLE 2 | Main and interaction effects of intention change and product information at the choice period.

Region	HEM	Cluster size	F	MNI coordinates			*Post hoc*
				X	Y	Z	
Main effect of intention change							
dACC	B	441	25.36	8	6	42	Unchanged > Changed
Precentral gyrus	R	233	18.93	28	−24	60	Unchanged > Changed
Cerebellum	L	148	22.74	−12	−60	−14	Unchanged > Changed
Cerebellum	L	119	20.42	−26	−62	−20	Unchanged > Changed
Main effect of product information							
pSTS	L	315	23.38	−46	−54	26	Ratings > Price
MTG	L	122	28.55	−62	−36	−2	Ratings > Price
MTG	R	280	24.76	62	−26	−2	Ratings > Price
Interaction effect							
None							

HEM, hemisphere; MNI, Montreal Neurologic Institute; B, bilateral; R, right; L, left; dACC, dorsal anterior cingulate cortex; pSTS, posterior superior temporal sulcus; MTG, middle temporal gyrus.

at this period. At the choice period, the intention change score negatively modulated the activities of the right precentral and postcentral gyri for price information (**Figure 3B-1**), whereas it positively modulated the activities of the right supramarginal gyrus and right insula for rating information (**Figure 3B-2**).

DISCUSSION

This study provided evidence that price and customer ratings may influence purchase intentions for hedonic products, and this influence may be represented differently depending on the stage of the decision-making process. Unlike the original hypothesis, the change scores did not differ between the price and rating conditions, and no region showed significant interaction effects between intention change and product information. As expected, however, cognitive control structures responded differently to products with changed and unchanged purchase intentions during the information period, and social cognition structures responded differently to rating and price information during the choice period. Notably, these responses were stronger for the unchanged than changed condition and for rating than price information. Overall, analyses identified the prominence of strategy, social cognition, and salience processing in the consumer decision-making process.

The most characteristic region found in the main effect of intention change at the information period was the FPC. This region has been regarded as a vital component in the higher order cognition, such as reasoning, goal monitoring, strategy, and goal-directed behavior in decision-making (Koechlin et al., 1999; Ramnani and Owen, 2004; Daw et al., 2006; Kim et al., 2011; Mansouri et al., 2017). Engagement in exploration strategies for goal-directed behavior is essential to achieve an optimal decision-making outcome in complex and dynamic situations, like shopping. Exploration strategies refer to gathering different information, estimating the cost and benefit values of available options, and redistributing resources accordingly. Although we initially expected the dlPFC to be involved because of its relevance to cognitive control and decision strategy, the present data suggest a greater reliance of exploration strategies over exploitation strategies (Mansouri et al., 2017). Previous studies have consistently indicated the unique role of the FPC in the operation of exploration strategies (Daw et al., 2006; Laureiro-Martinez et al., 2014; Mansouri et al., 2017). There is also a report that the activation of the FPC is related to efficient decisions based on cognitive flexibility in an exploitation-exploration decision-making task demanding profit maximization (Laureiro-Martinez et al., 2014).

Based on these roles, FPC activation for unchanged over changed purchase intention demonstrated in our data may convey greater simultaneous assessment of goals, including current and alternative, computation of decision values, and reallocation of cognitive resources to achieve the best outcome when purchase intentions did not change. In addition, parametric modulation analysis showed that FPC activity during the information period was negatively modulated by the purchase intention change scores for both the price and rating conditions. In other words, FPC activity increased as the intention to purchase decreased regardless of price or ratings. Given that the FPC is a key player in the exploratory decision-making, such modulatory effect seen in the data may also communicate that the shift from exploitation strategies to information-driven exploration strategies underlies the process in which the introduction to price or rating curbs one's desire to purchase. Our results suggest that these cognitive processes may occur more even when evaluating products rather than making choices, which seems logical in that it requires strategizing before making a choice.

Other regions showing the main effect of intention change at the information period included the dACC and insula. Given that these two regions are critical members of the salience network that aids decision-making (Uddin et al., 2017), the preferential activation may imply that intention-unchanged beauty products are more salient than intention-changed products. A previous study using social acceptance and rejection tasks also elucidated

TABLE 3 | Results from parametric modulation of intention change.

Region	HEM	Cluster size	T	MNI coordinates			Direction
				X	Y	Z	
Price							
Information period							
FPC	L	492	−5.33	−24	46	24	Negative
FPC	B	1,060	−5.12	2	58	20	Negative
SMA	B	154	−4.45	−4	8	64	Negative
Caudate	R	207	−4.14	18	8	14	Negative
Choice period							
Precentral gyrus	R	213	−5.06	38	−24	60	Negative
Postcentral gyrus	R	142	−4.60	34	−24	44	Negative
Ratings							
Information period							
FPC	R	199	−4.13	14	54	16	Negative
Insula	L	177	−4.61	−22	22	12	Negative
Cerebellum	L	402	−4.97	−22	−66	−20	Negative
Choice period							
SMG	R	391	4.54	46	−40	42	Positive
Insula	R	202	4.69	38	16	2	Positive

HEM, hemisphere; MNI, Montreal Neurologic Institute; B, bilateral; R, right; L, left; FPC, frontopolar cortex; SMA, supplementary motor area; SMG, supramarginal gyrus.

that activations of these areas were related to salience processing rather than negative experiences (Perini et al., 2018). In particular, the dACC was also more activated in the unchanged than changed condition at the choice period, but the insula was not. Decades of research suggest that the dACC is highly interconnected with other regions in the brain and contributes to a variety of functions, such as cognitive control, calculation of costs and benefits of actions, and behavioral adjustment and salience processing (Alexander and Brown, 2011; Uddin et al., 2017; Yee et al., 2021). Furthermore, this region is thought to calculate the expected values of control that are sensitive to reward and punishment (Shenhav et al., 2013; Lake et al., 2019) and contribute to the cognitive control process by integrating the incentive values (Yee et al., 2021). Taken together, the cognitive control process of the dACC including these various functions seems to have a strong effect on the maintenance of purchase intentions despite the interference of provided information.

The two salience-related regions, namely, dACC and insula, also showed the main effect of product information, reacting more strongly in the price condition than in the rating condition. Previous evidence associates the dACC with cognitive functions and the insula with affective functions within the framework of salience processing (Critchley et al., 2004; Menon and Uddin, 2010; Shenhav et al., 2013; Gogolla, 2017). Therefore, increased activity toward price information seen in the main effect of product information may indicate a greater saliency of price, which prompts cognitive control by calculating the expected values of control and integrating the subjective motivational values. In addition, the mOFC was also found to show a preference for price information over rating information, which is understandable in that the region is often known to be related to subjective valuation and preference in many decision-making studies (O'Doherty, 2011; Westbrook et al., 2019).

On the contrary, the mPFC and TPJ were more activated in the rating condition than in the price condition at the information period. The pSTS showed the same pattern at the choice period. These three regions are regarded as being important in social cognition and theory of mind, as they are often seen to be active in the process of perspective-taking (Gallagher and Frith, 2003; Saxe and Kanwisher, 2003; Frith and Frith, 2006; Vollm et al., 2006). Previous data substantiate that these regions are highly associated with dynamic belief updating, a critical process for aligning one's own and other's beliefs to predict correct outcomes (Baker et al., 2017; De Martino et al., 2017; Rusch et al., 2020). Taken together, it is possible that participants in our experiment were trying to scrutinize the product by dynamically referring to their own assessment of a product and by inferring to the reasoning behind a given rating. Oftentimes, when we shop online, we make our own opinion about a product based on the images and then analyze why other customers have given such rating. Therefore, activations in the mPFC and TPJ toward the rating condition at the information period may be a reflection of the process by which shoppers assess their own and others' opinions by reasoning about a given rating. Furthermore, the recruitment of the pSTS at the choice period indicates that when customer ratings are presented to shoppers, these social cognitive functions may continue from product evaluation to choice process.

Meanwhile, categorical analysis of our data demonstrated several neural areas showing the main effects of intention change and product information, but no interaction effect between the two factors was observed. The lack of interaction effect may be due to the combination of both increased and decreased purchase

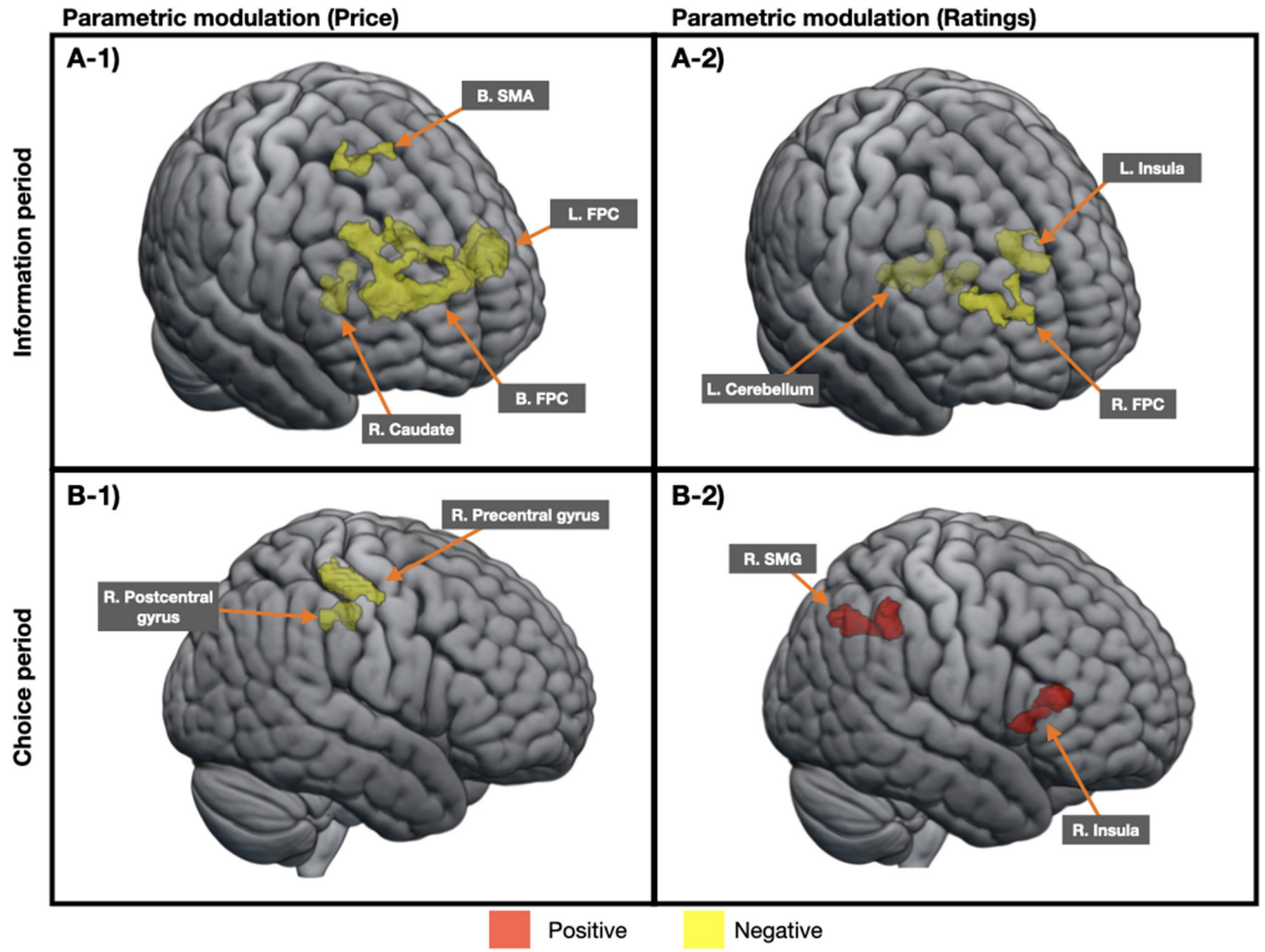

FIGURE 3 | An illustration of regions associated with the intention change scores in parametric modulation analysis. At the information period, regions showing the negative parametric effect were observed in both the price condition **(A-1)** and rating condition **(A-2)**. On the contrary, at the choice period, regional activities were negatively modulated in the price condition **(B-1)** and positively modulated in the rating condition **(B-2)**. B, bilateral; L, left; R, right; FPC, frontopolar cortex; SMA, supplementary motor area; SMG, supramarginal gyrus.

intentions to represent the changed condition. Nevertheless, the results accentuated the neural underpinnings of unchanged purchase intentions upon exposure to product information. In addition, subsequent parametric analysis effectively presented evidence of regions linearly modulated by the level of purchase intention change depending on the type of product information, such as the caudate in the price condition and the insula in the rating condition. Considering that the caudate engages in several functions, such as the adaptive decision-making, motivation, and emotion processing (Grahn et al., 2008; Stelzel et al., 2010; Doi et al., 2020), the inverse modulatory effect of the change-in-intention scores on caudate activity when price information is disclosed possibly conveys how consumers focus more on the negative side over the benefits of purchasing as their desires decrease. On the contrary, the modulation of insula activity by intention change based on customer ratings showed a negative relationship with left insula activity at the information period and a positive relationship with right insula activity at the choice period. Given that the insula incorporates various signals to determine the salience of stimuli as a prominent area in salience and emotion processing (Gogolla, 2017), this opposite relationship according to the period of decision-making may signify lateralization of insula activity, which leads to greater salience and emotion associated with rating information as the desires decrease or increase.

One of the strengths of this study is that the number of participants included in the analysis was 38, which was sufficient for an experimental neuroimaging study. The type of this study is an "experiment with increased behavioral realism," in which consumer behavior is measured in a laboratory setting and follows a within-subject design (Viglia et al., 2021). Such design is considered especially advantageous in consumer research because data tend to contain less noise and have higher statistical power, and a smaller sample size is deemed adequate (Viglia

et al., 2021). The sample size may be an important issue in neuromarketing research (Lim et al., 2019). In fact, the sample size was much smaller in fMRI neuroimaging studies than in other fields of study, mainly due to the financial burden of running studies, but showed acceptable levels of test-retest reliability (Bennett and Miller, 2010; Plichta et al., 2012). In a thorough evaluation of sample sizes of fMRI publications, the median sample size was 14.5, and high-impact neuroimaging journals in 2018 had a median sample size of 24 (Szucs and Ioannidis, 2020). Another strength lies in the way the stimulus is presented. The way one processes information is influenced by chronic disposition, which refers to one's stable orientation or motivation, and situational priming, which indicates the temporary impact of a particular scenario or situation (Lisjak et al., 2012). In order to reduce the cognitive load of stimulus processing and to induce heuristic processing to enable a more efficient design (Lim, 2015), the stimuli in this study consisted of pictorial illustrations with the exception of the response question shown to gauge one's willingness to purchase.

In addition to these strengths, several limitations should also be noted. First, as demographic factors such as age, gender, and income heavily influence consumer behavior (Kalyanam and Putler, 1997), including only young female adults as participants has the effect of excluding confounding factors but also limits the scope of interpretation. Moreover, information regarding income was not collected. Additionally, only lip-care products were used in the study, which poses a possible generalizability issue of the study. Future studies should incorporate a variety of product types such as utilitarian items and other hedonic social products that are readily used by male and female consumers of all ages.

CONCLUSION

This study delineated the e-commerce consumer process and incorporated price and customer rating information to explore the neural substrates of changing purchase intentions for hedonic products. The results indicated that brain regions related to cognitive control and social cognition processing were involved differently depending on the type of information. In particular, the findings highlighted the employment of the FPC for an information-driven explorative decision-making strategy in changing purchase intentions during the evaluation phase. Furthermore, salience processing-related regions were importantly involved in maintaining purchase intentions despite referring to provided information during both evaluation and choice phases of the decision-making process. When information to help shoppers make a purchase decision was presented, social cognition-related regions were engaged in reference to customer ratings rather than price in both product evaluation and choice processes.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board of Yonsei University Severance Hospital. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HK and JK conceived and designed the experiments and performed the experiments. HK analyzed the data and drafted the manuscript. J-JK edited and revised the manuscript. All authors contributed to the article and approved the submitted version.

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Metaphorical or Straightforward? Comparing the Effectiveness of Different Types of Social Media Advertising

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The existing studies have analyzed the advertising effects of metaphorical advertisements and straightforward adverts in traditional advertising media. However, their advertising effects on social media are still unclear. To address this issue, this study uses eye-tracking and questionnaires to examine two types of social media tourism advertising—metaphorical and straightforward in posts with both high and low popularity. This within-subject (n = 55) experiment was designed to examine the effects of social media tourism advertising types on visual attention and tourism intention and to identify the moderating role of post popularity based on the elaboration likelihood model (ELM). We found that advertising types had no significant effect on visual attention, but metaphorical advertisements increased tourism intention compared with straightforward adverts. Furthermore, we found that the level of post popularity moderated the effect of advertising types on visual attention. Specifically, metaphorical adverts in highly popular posts attracted more visual attention in the advertising text area and in the whole advert. Straightforward adverts in posts with low popularity attracted more visual attention in the advertising text area. This research advances the current literature by exploring the effects of social media tourism advertising types and has implications for managers deciding on strategies for social media tourism marketing.

Keywords: metaphorical advertisements, straightforward advertisements, post popularity, visual attention, eye-tracking technology, elaboration likelihood model

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INTRODUCTION

Metaphorical advertisements are adverts that appeal implicitly through abstract and artistic words (Ang and Lim, 2013). Metaphorical advertisements are widely used in marketing because they can increase communication between consumers and advertisers (Maclnnis et al., 1991), enhance the interest in the advertising (Ang, 2002), and improve the advertising attitude of consumers (McQuarrie and Mick, 1999). Straightforward advertisements, in contrast, appeal explicitly through literal and narrative words (Lagerwerf and Meijers, 2008). Straightforward advertisements have long been used for the launch of new products because they highlight their features and make the information easier to receive (Ziamou and Ratneshwar, 2003). Previous research on tourism advertising in traditional media, such as television, press, and radio, has found that metaphorical advertisements tend to attract more visual attention and promote buying due to the longer

processing time and the more positive attitudes of the audience (Phillips and McQuarrie, 2009). Does it mean that metaphorical advertisements are also better on social media? The answer is still uncertain. Unlike traditional tourism advertisements, social media tourism advertisements have the characteristics of "explosion and fragmentation" (Bartschat et al., 2021), and a large amount of advertising information often appears at the same time in the moment of searching. Due to the limited cognitive resources of consumers (Lavie, 1995), it seems that the easier-to-understand straightforward advertisement leaves a deeper impression on consumers than the metaphorical advertisement. Therefore, our research addresses how metaphorical advertisements and straightforward advertisements compare in the context of social media and also explores the boundary conditions influencing this effectiveness.

Based on the elaboration likelihood model (ELM), there are two methods of persuasion, namely, central and peripheral routes (Petty and Cacioppo, 1986). Central route persuasion is that which likely "resulted from a person's careful and thoughtful consideration of the true merits of the information presented in support of an advocacy." Peripheral route persuasion is that which more likely "occurs as a result of some simple cues in the persuasion context that induces change without necessitating scrutiny of the true merits of the information presented" (Petty and Cacioppo, 1986). These simple peripheral cues refer to stimuli that can affect attitudes without necessitating processing of the message arguments, such as source expertise, source credibility, and so on (Petty and Cacioppo, 1986). Post popularity is also an important factor in peripheral cues (Chang et al., 2015). Post popularity is defined by the number of online likes, shares, and comments. It is regarded as an important influence on consumers when they are processing posts on social media (Park et al., 2007). When the post popularity is low, consumers' attitudes and behaviors are mainly influenced by the content of the post, but when the post popularity is high, they are more likely to be influenced by simple cues in the post. In other words, the attitude and behavior of consumers differ depending on the popularity of the post. Therefore, our study takes post popularity as the moderating variable to explore the boundary conditions of advertising types.

Advertising information overload is a feature of social media. The number of advertisements that people are exposed to every day has risen from 2,000 to 5,000 (Ahn et al., 2018). The intangibility of the tourism experience makes the effect of tourism advertising largely dependent on visual attention. Based on this, visual attention has become a key factor for measuring the effectiveness of tourism advertising. A recent study, however, has also suggested that, since actual travel behavior is difficult to measure, tourism intention often becomes the final factor for measuring advertising effectiveness (Weng et al., 2021). Therefore, this study explores the effectiveness of social media tourism advertising types using both visual attention and tourism intention. With the help of eye-tracking technology and questionnaires, we explored the influence of metaphorical vs. straightforward social media advertising on visual attention and tourism intention and the moderating role of post popularity.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Tourism Advertising and Visual Attention

Researchers have divided advertisements into metaphorical and straightforward (Lakoff and Johnson, 1980), which are then further divided into textual and pictorial based on their advertising elements (McQuarrie and Phillips, 2005). In earlier studies, the focus has mainly been on pictorial advertisements (Oįehnoviča et al., 2016), but text in tourism adverts is still the focus of research on advertising effectiveness (Adu-Ampong, 2016).

Attention is regarded as a mechanism for additional processing of selective information (Greenwald and Leavitt, 1984), while visual attention "can be thought of as relying on a collection of paintbrushes (neurons) that are trying to paint stimuli (objects in the environment) on a canvas (the visual cortex) so that perceptual processes can interpret the canvas" (Janiszewski et al., 2013). According to the limited attention model, individuals will select their visual attention, that is, they may prioritize the processing of stimulating information according to their own preferences (Lynch and Srull, 1982). There are two selective methods. The first is top-down salient filtering selection, and the second is bottom-up control selection (Pieters and Wedel, 2004). The former belongs to the realm of unconscious automatic selection, which is mainly based on the physical characteristics of the visual stimulus itself (e.g., color, size, brightness, and so on) (Janiszewski, 1998), while the latter belongs to the conscious proactive selection, which is mainly based on the long-term formation of preferences, expectations, and motivations (Itti and Koch, 2001).

In the field of tourism advertising, existing research has mainly explored the influence of advertising elements such as texts, pictures, brand logos, colors, and sizes on visual attention. Results have included the finding that adverts that contain landscape pictures with naturally embedded words (Li et al., 2016), brands logos of the destination (Lourenção et al., 2020), and colors similar to those of the web pages (Chiu et al., 2017) can attract more visual attention. Some studies have also examined the influence of banner advertising types on visual attention and found that static advertisements can first attract the audience's visual attention, while dynamic advertisements can attract more visual attention from the audience (Hernández-Méndez and Muñoz-Leiva, 2015). Although these studies have been valuable, there are still many research questions that need to be addressed. First, most of these studies have been conducted in the traditional advertising context, investigating the visual attention of billboard, print, and website advertisements, but ignoring the emerging context of social media tourism advertisements. Second, most of the existing research has mainly focused on the influence of advertising elements on visual attention rather than the type of advertising. Therefore, to advance the research, this study

explores the effect of social media tourism advertising types (metaphor and straightforward) on visual attention.

The ELM, which provides a general framework for organizing, categorizing, and understanding the basic processes underlying the effectiveness of persuasive communications, is widely used in metaphorical advertising research. Central route and peripheral route persuasion can be seen as opposite extremes of a continuum (Hardy et al., 2018). Central route persuasion requires greater effort and leads to the largest behavioral effect, while the peripheral route does not involve much cognitive effort (Petty and Cacioppo, 1986). Metaphorical advertisements are abstract and creative. They can activate more associations in a consumer's semantic memory, making them call on transcendental knowledge and logical thinking to carefully scrutinize advertisements, which requires more cognitive efforts (Lee et al., 2019). In contrast, straightforward advertisements are easy to understand and take less cognitive effort. When a message is presented to individuals in different contexts and situations, the way recipients process the message will vary according to how much cognitive effort they devote to that message (Hardy et al., 2018). Therefore, it can be speculated that consumers will adopt the central route when processing metaphorical advertisements and the peripheral route when processing straightforward advertisements. Visual attention is the key to information processing (Just and Carpenter, 1980), so the allocation of cognitive resources can be taken as the allocation of visual attention. Since metaphorical advertisements require more processing, they will require more visual attention. Therefore, we proposed the following hypothesis:

> H1: Compared with straightforward advertisements, metaphorical advertisements increase visual attention.

Tourism Advertising and Tourism Intention

Tourism intention is a popular indicator for assessing the effectiveness of tourism advertisements (Weng et al., 2021). The stronger the tourism intention, the more likely the tourists engage in actual tourism behavior. Tourism advertisements stimulate tourism intention by presenting destination-related information in pictures, words, videos, and so on (Walters et al., 2007). Existing research mainly explores the influence of advertising elements, such as text or pictures, and advertising media (print, video, virtual reality, and so on) on tourism intention. Findings have shown that, compared with tourism advertisements without text, tourism advertisements composed of both text and pictures stimulate higher tourism intention (Tercia et al., 2020). Print advertisements stimulate higher tourism intention than VR advertisements, and video advertisements stimulate higher tourism intention than print advertisements (Guerrero-Rodríguez et al., 2020; Weng et al., 2021). Some studies have also explored the influence of subjective and objective language styles on consumer behavior in the context of hotel advertising. The results showed that subjective advertisements, characterized by more personalized features, resulted in higher click-through rates, while objective advertisements with greater brand consistency led to a higher advertising conversion rate (Huang and Liu, 2021).

Even though extensive studies have focused on the influence of tourism advertisements on tourism intention, few studies have studied social media tourism advertisements. The relative effectiveness of straightforward and metaphoric advertising is also highly relevant to a field where abstract and creative words might be assumed to better portray a destination as a good utopia (Phillips et al., 2021). According to Tao et al. (2022), straightforward advertisements are generally considered to be more conducive to encouraging consumers to make decisions since they can directly display the functions of products. The question of which style of advertisement stimulates higher tourism intention still needs further exploration.

Compared with the peripheral route that relies on simple cues for information processing, the central route that relies on thoughtful consideration can produce a more enduring persuasion (Petty and Cacioppo, 1986). Furthermore, the ELM suggests that "the final consequence of the route to persuasion is that attitudes formed *via* the central route should be more resistant to counterpropaganda than attitudes formed *via* the peripheral route." In other words, individuals who process information through the central route are more receptive to marketing messages than individuals who process information through the peripheral route (Petty and Cacioppo, 1986; Chang et al., 2020). Yang (2015) found that the higher the level of elaboration, the higher the purchase intention. Chang et al. (2020) found that, compared with the peripheral route (post aesthetics and post popularity), consumers in the central route (information completeness and information accuracy) had a more positive attitude toward advertisements and higher purchase intention. From this, it is suggested that individuals adopting the central route will have higher behavioral intentions. Therefore, we proposed the following hypothesis:

> H2: Compared with straightforward advertisements, metaphorical advertisements increase tourism intention.

The Moderating Role of Post Popularity

Post popularity refers to the number of online likes, shares, and comments (Chang et al., 2020). It is a critical factor for increasing the persuasiveness of a post. The more popular the post, the more worthy of attention and the higher the credibility of the post. Jin and Muqaddam (2018) found that the level of post popularity could moderate the influence of post types on perceived narcissism, and Mekawie and Hany (2019) found that the level of post popularity could moderate the influence of product types on purchase intention. Our study speculated that post popularity would moderate the influence of advertising types on visual attention and tourism intention. For this study, we set the high post popularity to 838,796 likes, 592,398 shares, and 150,171 comments, while the low post popularity to 228 likes, 4 shares, and 12 comments.

Post popularity moderates the effect of advertising types on visual attention. High post popularity means that a large number of users pay attention to the post, and based on the herding effect (Banerjee, 1992), other users will also pay attention

to the post (Mattke et al., 2020). Metaphorical advertisements can stimulate more elaboration in processing, so will get more visual attention than straightforward advertisements in posts with high popularity. Posts with low popularity attract fewer viewers and less attention, so the herding effect means that other users will also reduce their attention to the post (Mattke et al., 2020). Since processing capacity is limited, individuals may prefer to allocate it to simple cognitive tasks (Cabañero Gómez et al., 2021). The implication is that viewers are more willing to process straightforward advertisements than metaphorical advertisements in low popularity posts. In other words, straightforward advertisements gain more visual attention from audiences. Therefore, we proposed the following hypothesis:

> H3: Post popularity moderates the effects of advertising types on visual attention. Metaphorical adverts attract more visual attention in highly popular posts and less attention in posts with low popularity than straightforward adverts.

Post popularity can also moderate the effect of advertising types on tourism intention. Highly popular posts lead to discussion, most of which is around sharing experience and knowledge. These discussions are spontaneous, authentic, and nonprofit, which can increase an audience's interest in the products and improve the advertising effect (Daugherty et al., 2008). In highly popular posts, metaphorical advertisements that need careful and thoughtful scrutiny are often more persuasive than straightforward adverts (Chang and Yen, 2013). Low post popularity means less discussion, which increases uncertainty and perceived risk, leading to a negative effect on purchasing. Straightforward advertisements that focus on product functions and features can, however, lessen the perceived risks and promote purchase. Therefore, we proposed the following hypothesis:

> H4: Post popularity moderates the effect of advertising types on tourism intention. Metaphorical advertisements stimulate higher tourism intention in highly popular posts and lower tourism intention with low popularity than straightforward adverts.

RESEARCH METHODOLOGY

Experimental Design

The hypotheses proposed in this study were tested using a 2 × 2 within-subject design, with two advertising types (metaphorical vs. straightforward) and two levels of post popularity (high vs. low). The experimental stimuli were posts on Sina Weibo featuring tourism advertisements. Four destinations were selected for the experiment, and each destination was set up with four conditions (high/low popularity metaphorical advertisements and high/low popularity straightforward advertisements). In all, there were 16 posts. To eliminate the sequential effect, a multifactor Latin square design was adopted. The 16 posts were divided into four groups, each with four adverts, and each advert corresponding to an experimental condition. Each participant was randomly assigned to one of the groups, and after browsing a post, they answered questions about their tourism intention. The scale for tourism intention consisted of six items adapted from Zeithaml et al. (1996) using a Likert 7-point scale.

- "I'm looking forward to traveling to that destination."
- "I'd like to travel to that destination."
- "For this trip, I will choose that destination first."
- "I have been looking forward to traveling to that destination."
- "I will recommend my relatives and friends to travel to this destination."
- "I will travel to the destination with my family and friends."

The mean of tourism intention was 4.675, the SD was 1.147, and the Cronbach's α was 0.924. When the participants finished the eye movement experiment, they were asked to evaluate the stimulus. This was to complete the manipulation test of the experimental materials.

Experimental Stimuli

Sina Weibo

We chose Sina Weibo for the following reasons. First, Sina Weibo is a huge social media platform (similar to Facebook and Instagram) that integrates life and entertainment in China. At the end of September 2021, the platform had 573 million monthly active users, 80% of them born after 1995 (Weibo, 2021a). The platform's demographics also map well to those of tourism, given the tourists are getting younger (Torres-Moraga et al., 2021). Second, according to the Weibo's User Development Report in 2020, tourism topics topped the list of life topics on Sina Weibo, and there were several tagged themes with a discussion volume of over 100 million (e.g., "Travelling with Ding Zhen," "Snow in Beijing Summer Palace") (Weibo, 2021b). Sina Weibo has become an important platform for tourists to share and discuss tourism experiences.

Pretest 1: Choice of Destinations

How well-known a destination is affects visual attention and tourism intention. We chose moderately well-known destinations for the study that showed no significant difference between them in terms of familiarity. To ensure the consistency and equivalence of the content of the adverts, both cultural and natural landscape destinations were selected from the Ministry of Culture and Tourism of China's list of National AAAAA Tourist Attractions. We excluded the top 20 destinations from the list of destinations released by Ctrip (the largest travel website in China). We ultimately chose 16 destinations: Jin Zhong, Bao Ding, Chang Chun, Xin Zhou, Ordos, Ning Bo, Yan Tai, Wu Xi, Huang Shan, Yi Chang, Wei Hai, Zhang Jiajie, Shang Rao, Yue Yang, Fo Shan, and Aba Tibetan Autonomous Prefecture. We designed a questionnaire to measure the familiarity with and attractiveness of the 16 destinations. One item was used to measure the attractiveness of each destination—"I think this travel destination is attractive," and four items from the Baloglu

(2001) scale were used to measure the familiarity with each destination:

- "I have heard this destination introduced by my relatives or friends."
- "I have seen or heard about this tourism destination in relevant media."
- "I specifically searched for the tourism destination through relevant media."
- "How many times have I visited the destination?"

The results showed that, among the 16 destinations, four destinations—Jin Zhong, Bao Ding, Yan Tai and Chang Chun—ranked in the middle position, and there was no significant difference in familiarity with them ($M_{Jin\ Zhong}$ = 2.93, $M_{Bao\ Ding}$ = 3.27, $M_{Yan\ Tai}$ = 3.29, $M_{Chang\ Chun}$ = 3.35; p's > 0.05) and attractiveness ($M_{Jin\ Zhong}$ = 3.29, $M_{Yan\ Tai}$ = 3.40, $M_{ChangChun}$ = 3.69, $M_{Bao\ Ding}$ = 3.77; p's > 0.05). Based on this, we chose these four cities as the destinations for the study.

Pretest 2: Advertising Types and Post Popularity

We designed two types of advertising (metaphorical and straightforward) and two levels of post popularity (high/low) for each destination. We collected nine landscape photos for each destination, which is the maximum allowed for a post. We used Photoshop to give all the images the same tone and set all sizes to 1,920 × 1,080 pixels. We designed metaphorical and straightforward advertising text for each destination, giving us eight adverts. These were then placed with high and low popularity posts, giving 16 advertisements in total. Based on our definitions for high and low popularity, the posts used had 838,796 likes, 592,398 shares, and 150,171 comments, and 228 likes, four shares, and 12 comments, respectively. The 16 designed adverts were published through Sina Weibo, and 46 participants were invited to evaluate them to determine whether they were metaphorical or straightforward. The question from Delbaere et al. (2011) was used to define this, using a Thurstone scale—"Do you think the ad is explicit and factual, or abstract and artistic?" (1 = explicit and factual, 7 = abstract and artistic). The results showed that there were significant differences between metaphorical advertisements and straightforward advertisements in Jin Zhong ($M_{straight\ forward}$ = 2.85, $M_{metaphorical}$ = 4.89, $p < 0.001$), Bao Ding ($M_{straight\ forward}$ = 3.02, $M_{metaphorical}$ = 4.96, $p < 0.001$), Yan Tai ($M_{straight\ forward}$ = 2.96, $M_{metaphorical}$ = 5.33, $p < 0.001$), and Chang Chun ($M_{straight\ forward}$ = 3.46, $M_{metaphorical}$ = 5.25, $p < 0.001$) (refer to **Table A1** of **Appendix A**).

Participants

We selected college students as participants in the experiment. Using a single sample group is beneficial to avoid the interference of population characteristics in the experiment (Wang and Hung, 2019). More importantly, the demographic characteristics of college students are similar, and the internal differences are small, which is conducive to data analysis and comparison. The sample was also more representative and ecologically valid because 16- to 25-year-olds account for 80% of active users on Sina Weibo (Weibo, 2021a).

We recruited 60 college students with experience on Sina Weibo to participate in the experiment. After eliminating five invalid data, 55 valid samples were retained (28 women and 27 men with an average age of 22.37). We used G-power 3.1 for sample size estimation. The results showed that the sample size required for this study was n = 34. Therefore, using 55 samples was statistically in line with the experimental requirements of this study.

Procedure

A calibration test was conducted before the experiment to ensure the average deviations in two directions were < 1 (Li et al., 2020). The eye-tracker (Eyeso EC80) at a sampling rate of 30FPS was attached beneath the laptop screen (13.3-inch monitor) with a resolution of 1,920 × 1,080 pixels.

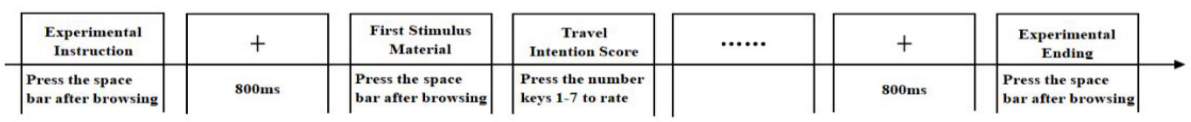

FIGURE 1 | Flowchart of eye movement experiment for a single trial.

TABLE 1 | Descriptive statistics of eye movement data.

		High-popularity post				Low-popularity post			
		The whole advert		The text area		The whole advert		The text area	
		FC	FD	FC	FD	FC	FD	FC	FD
MAs	M	60.927	27,378.618	39.982	15,907.236	53.655	23,864.236	34.618	12,984.945
	SD	33.084	17,037.004	24.446	11,534.261	24.221	12,812.575	19.261	8,422.605
SAs	M	50.655	22,849.236	35.582	14,069.109	54.964	26,201.400	37.927	14,709.382
	SD	27.034	13,965.714	19.758	10,374.576	27.255	13,488.223	21.422	9,757.983

MAs, metaphorical advertisements; SAs, straightforward advertisements; FC, the number of fixations; FD, the fixation duration.

Participants were positioned approximately 70 cm from the monitor. The default calibration settings of the eye-tracker were used to run the calibration. Since instruction can affect viewing patterns (Müller et al., 2012), we told the participants what they needed to imagine through the experiment instruction. We conducted a series of practical experiments to help the participants get familiar with the operation and process of the experiment and avoid operational errors. The formal experiment included four stages, namely, reading the experiment instructions, seeing a plus sign in the center of the screen, browsing social media tourism advertisements, and scoring the tourism intention items. The flowchart of

TABLE 2 | Results of repeated measures of two-factor ANOVA.

			Visual attention							
			The whole advert				The text area of the advert			
	Tourism intention		FC		FD		FC		FD	
	MS	F	MS	F	MS	F	MS	F	MS	F
AT	16.382	12.686**	1,104.768	3.457	66.080	0.726	16.364	0.184	17.773	0.010
PP(H/L)	2.062	2.771	120.768	0.265	0.362	0.003	125.255	0.762	71.605	1.627
AT × PP	0.180	0.183	1,844.405	6.829*	648.305	6.984*	817.164	5.227*	174.513	7.364**

AT, advertising types; PP, post popularity.
*The fixation duration (FD) was measured in seconds, *p < 0.05, **p < 0.01.*

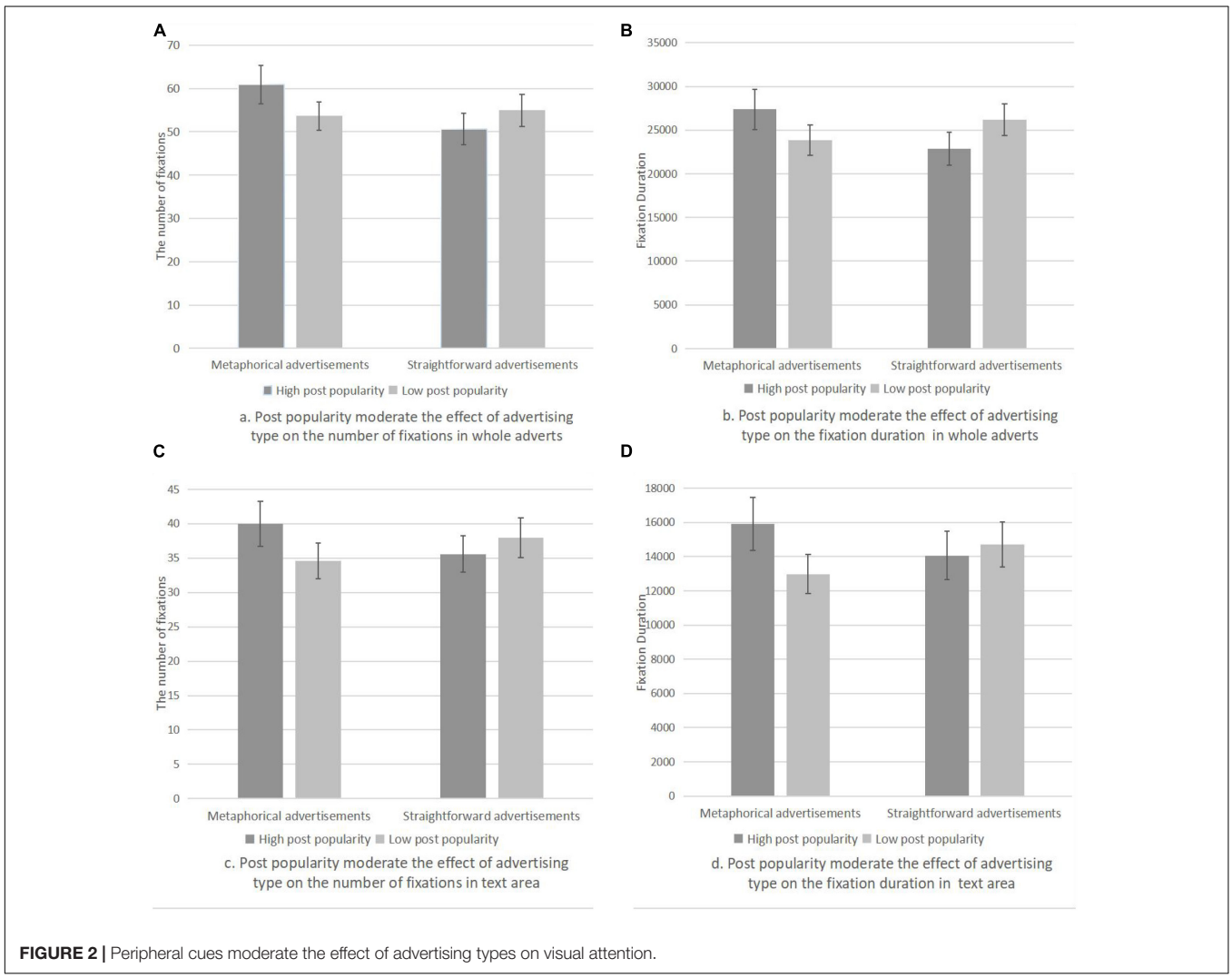

FIGURE 2 | Peripheral cues moderate the effect of advertising types on visual attention.

the eye movement experiment for a single trial is shown in **Figure 1**.

DATA ANALYSIS

Eye Movement Indicators

Area of interest (AOI) is a basic unit of visual attention (Scott et al., 2019). Its scope is defined by the research purpose (Bialkova and van Trijp, 2011). Our study sets both the text area and the whole advert as the interest areas. A fixation is defined as "the brief amount of time when the eyes stay temporarily still and gaze at a specific point of the visual field" (Rayner, 2009). The number of fixations (FC) and fixation duration (FD) are the most common indicators in eye movement experiments (Bialkova and van Trijp, 2011). The FC is a reliable indicator of visual attention, which reflects how many times the audiences' eyes paused on an area (Li et al., 2016). The FD reflects the time that an audience spends on one fixation (Li et al., 2016). In line with previous study, such as Hernández-Méndez and Muñoz-Leiva (2015), Li et al. (2016; 2020), we selected the FC and the FD to test the participants' visual attention.

Manipulation Checks

After the experiment, the subjects were asked to score their perception of the advertising types ("Do you think the advertisements are explicit and factual, or abstract and artistic?" 1 = explicit and factual, 7 = abstract and artistic) and post popularity ("Do you think the ads is low popularity, or high popularity?" 1 = low popularity, 7 = high popularity) from 1 to 7. The results show that there were significant difference between straightforward advertisements and metaphorical advertisements of the four destinations: Jin Zhong ($M_{straight\ forward}$ = 2.49, $M_{metaphorical}$ = 4.76, t (108) = -8.81, $p < 0.001$), Bao Ding ($M_{straight\ forward}$ = 2.76, $M_{metaphorical}$ = 4.58, t (108) = 6.98, $p < 0.001$), Yan Tai ($M_{straight\ forward}$ = 3.01, $M_{metaphorical}$ = 3.94, t (108) = 6.70, $p < 0.001$), and Chang Chun ($M_{straight\ forward}$ = 2.72, $M_{metaphorical}$ = 4.49, t (108) = 6.72, $p < 0.001$). Additionally, there was also a significant difference between high post popularity and low post popularity (M_{high} = 5.20, M_{low} = 3.39, t (108) = 5.51, p = 0.00). These results indicated that intended stimuli were manipulated successfully in the experiments.

Descriptive Statistical Analysis Results

The experiment measured the FC and FD of the participants for the whole posts and the text area. The mean and standard deviation of the FC in the whole adverts were 55.050 and 28.141, and the FD was 25,073.372 ms and 14,431.395 ms. The mean and standard deviation of the FC in the text area were 37.027 and 21.275, the FD was 14,417.668 ms and 10,022.356 ms. **Table 1** shows the descriptive statistics of the eye movement indicators in the whole tourism advertisements and the text area under the high and the low post popularity.

Hypothesis Testing

For social media tourism advertising types referring to Sina Weibo, a 2 (tourism advertising type: metaphor vs. straightforward) × 2 (post popularity: high vs. low) repeated ANOVAs were performed regarding the visual attention and tourism intention. The results are shown in **Table 2**.

Results of repeated ANOVAs indicated that there was no significant difference in the FC and the FD for the whole adverts and the text area between metaphorical advertisements and straightforward advertisements (ps > 0.05) for visual attention. Thus, hypothesis 1 is not supported.

Results of repeated ANOVAs indicated that tourism intentions were significantly higher when processing the metaphorical

TABLE 3 | Pairwise comparisons.

		High-popularity posts		Low-popularity posts	
		Metaphorical adverts	Straightforward adverts	Metaphorical adverts	Straightforward adverts
	Dependent variable	M (SD)	M (SD)	M (SD)	M (SD)
Visual attention	FCP	60.927 (4.461)	50.655 (3.645)	53.655 (3.266)	54.964 (3.675)
	F	10.104**		0.156	
	FDP	27,378.610 (2,297.269)	27,378.618 (2,297.269)	23,864.236 (1,727.639)	22,849.236 (1,883.136)
	F	8.831**		1.254	
	FCT	39.982 (3.296)	35.582 (2.664)	34.618 (2.597)	37.927 (2.889)
	F	3.894		2.769	
	FDT	15,907.236 (1,555.279)	14,069.109 (1,398.908)	12,984.945 (1,135.704)	14,709.382 (1,315.766)
	F	3.873		4.603*	

*$p < 0.05$, **$p < 0.01$.

FCP, the number of fixations in whole adverts; FDP, fixation duration in whole adverts; FCT, the number of fixations in text areas; FDT, fixation duration in text areas.

advertisements than straightforward advertisements ($M_{metaphorical}$ = 4.959, $M_{straightforward}$ = 4.413, $F(1,54)$ = 12.686, p = 0.001 < 0.01). Thus, hypothesis 2 is supported.

Results of repeated ANOVAs showed that there was no significant interaction of post popularity and advertising type on tourism intentions ($F(1, 54)$ = 0.183, p = 0.67). Thus, hypothesis 3 is not supported. However, post popularity moderated the relationship between advertising types and the FC ($F(1, 54)$ = 6.829, p = 0.012 < 0.05) and FD ($F(1, 54)$ = 6.984, p = 0.011 < 0.05) for the whole adverts (**Figures 2A,B**). Post popularity also moderated the relationships between advertising types and the FC in the text area ($F(1, 54)$ = 5.227, p = 0.026 < 0.05) and the FD ($F(1,54)$ = 7.364, p = 0.009 < 0.01) (**Figures 2C,D**). Thus, hypothesis4 is preliminarily verified.

To analyze the influence of advertising types on visual attention and tourism intention at every level of post popularity, simple effect analysis was further employed. As presented in **Table 3**, results showed that with high post popularity, the influence of advertising types on the FC and FD was significant for the whole adverts and marginally significant for the textual area ($F_{FCP}(1, 54)$ = 10.104, p_{FCP} = 0.002 < 0.01; $F_{FDP}(1, 54)$ = 8.831, p_{FDP} = 0.004 < 0.01; $F_{FCT}(1, 54)$ = 3.894, p_{FCT} = 0.054; F_{FDT} (1, 54) = 3.873, p_{FDT} = 0.054). With low post popularity, there was no significant difference for the FC and FD between metaphorical advertisements and straightforward advertisements in either the whole adverts or the text area. However, the effect of straightforward advertisements on the FD was significant in text areas [$F(1, 54)$ = 4.603, p = 0.036 < 0.05].

In summary, with high-popularity posts, metaphorical advertisements attracted more visual attention for the whole area and the text area than straightforward advertisements. With low popularity posts, straightforward advertisements attracted more visual attention to the text area than metaphorical advertisements. Thus, hypothesis 4 is further supported.

CONCLUSION AND DISCUSSION

Conclusion and Implication

By applying eye-tracking experiments and questionnaires, this research aimed to investigate the influence of social media advertising types on visual attention and tourism intention, considering levels of post popularity. We used tourism advertisements with posts on Sina Weibo. The results showed that the type of social media advertising had no significant effect on visual attention. This is inconsistent with previous research into traditional advertising only, which suggested that metaphorical advertisements attracted more visual attention. This may be because, in the context of social media, most users will encounter tourism advertisements when browsing (i.e., information encounters) as well as during purposeful information searches. At the moment of encounter, users tend to scan quickly to process what they see Jeong et al. (2011), so neither metaphorical advertisements nor straightforward can gain more visual attention.

We also found that, based on the theoretical framework of ELM, metaphorical advertisements stimulated higher tourism intention. The reason for this is that, compared with the peripheral route that relies on simple cues for information processing, the central route relies on thoughtful consideration and can produce more enduring persuasion (Petty and Cacioppo, 1986). We also found that the level of post popularity can moderate the influence of social media advertising types on visual attention. For high-popularity posts, metaphorical advertisements attract more visual attention than straightforward advertisements, both for the whole advert and the text area. Posts with low popularity, however, showed no significant difference in the visual attention between the advertising types for the whole advert, but more visual attention for straightforward advertisements in the text area. These findings are explained by the fact that metaphorical advertisements in high-popularity posts stimulate more elaborate processing than straightforward advertisements. In low-popularity posts, the subjects want specific and clear information to reduce perceptual uncertainty. In this case, straightforward advertisements featuring the product functions gain more visual attention.

The main theoretical contributions of this study are as follows. First, previous studies on tourism advertising rarely discuss the effects of different advertising types based on the style of expression and rarely discuss the visual attention through eye movement experiments. Exploring the context of social media advertising, this study examines the visual attention of metaphorical advertisements and straightforward advertisements in the whole advert and the text area, which fills the gap in existing research into tourism advertising. In addition, this study reveals a novel finding that is different from traditional tourism advertising research. Most previous studies suggest that metaphorical advertisements stimulate more visual attention than straightforward advertisements. However, we found that this conclusion was not valid in the social media context. Additionally, we found that the type of advertising only had a significant impact on visual attention when moderated by the level of post popularity. This is an interesting finding which supplements existing tourism advertising research.

Second, the ELM has rarely, if ever, been applied to studies of tourism advertising. Our application of the ELM demonstrates not only how the advertising types influence visual attention and tourism intention in social media marketing but also how post popularity influences these. This verifies the power of ELM to predict and explain the effect of tourism advertisements and expands the scope for applying the ELM. Petty and Cacioppo (1986) defined source expertise and source credibility as peripheral cues when they first proposed the ELM. As a result, scholars have tended to consider only these two factors as peripheral cues. It was not until Yoo et al. (2016) verified interactivity and accessibility as peripheral cues that this view was changed. Our research takes this further by adding post popularity (number of likes, shares, and comments) as peripheral cues.

Third, in previous studies, tourism advertising effectiveness has been mostly assessed through self-reporting, making the accuracy of the measurement controversial (Wang et al., 2020). In addition, although a few scholars have used eye-tracking experiments to conduct tourism advertising research, most of these studies have ignored theoretical support (Lever et al., 2019),

or just analyzed the visual pattern of participants but ignored the subjective intention prediction. This study builds a theoretical framework using the ELM and employing eye movement experiments and questionnaires to test hypotheses, extending the line of research on visual processing in the tourism field.

This study also makes some practical suggestions for tourism marketing. Results indicate that, in social media, advertising types have no significant influence on visual attention, except when moderated by post popularity. Therefore, post popularity is the obvious key to influence visual attention. Destinations could improve post popularity by creating hot topics that attract visual attention. Specifically, marketers can combine social media to jointly create hot themes. Hot themes usually appear on the hotlist, which can attract users to click and browse, thus improving post popularity. Encouraging users to interact (i.e., likes, shares, and comments) by lottery (i.e., cash, discount coupons, free air tickets, etc.) is a common way to improve post popularity. Likes and comments can increase the activity of posts, while shares can make more people interact with posts. Inviting key opinion leaders to promote destinations on social media is also a good strategy. Opinion leaders usually have a large number of loyal fans, and destination promotion can attract these fans to interact, thus increasing post popularity.

Results showed that, compared with straightforward advertisements, metaphorical advertisements increased people's tourism intention. Therefore, destinations should increase the exposure of metaphorical advertisements. Specifically, marketers should harness the resource of users, whose shares are more credible and convincing than the information officially released by the destination (Huerta-Álvarez et al., 2020). Marketers could post metaphorical tourism advertising design activities on social media and invite all users to participate. Every user on social media can freely generate, process, and publish information. Inviting a large number of users to participate in the advertising design activity could increase the spread effect of advertisements and credibility. Marketers should also cooperate with influencers (i.e., online celebrities) to conduct topic marketing. In 2020, there were many tourism-tagged themes with over 100 million discussions on Sina Weibo (Weibo, 2021b). These themes usually start with an influencer's post. When the post garners more likes, shares, and comments through interaction among fans, other influencers follow and post on the topic too. In this way, the communication effect of advertisements snowballs.

Limitations and Future Research

There are some limitations that need to be acknowledged. First, this study controls the types of pictures and only explores the effect of advertising types from the perspective of the expressive style of the text. Future research could explore the influence of visual metaphors on advertising effectiveness from the perspective of picture styles. Second, taking our sample from college students limits generalizability, and future research could expand the sample range. Finally, this research focuses on static advertising. With the popularity of video marketing, the effect of video tourism advertising on visual attention and tourism intention is also worthy of future research.

DATA AVAILABILITY STATEMENT

The data generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was reviewed and approved by the Ethics Committee of the Neurotourism Laboratory at Huaqiao University. All participants provided written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XD and PF made substantial contributions to the work, participated in all aspects of the manuscript, conducted the experiment, analyzed the data, and wrote the manuscript. JW participated in the data acquisition and data interpretation stage. ML oversaw the study and managed every part of the research.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

APPENDIX

TABLE A1 | Experimental stimulus materials.

Destinations	Type	High popularity post	Low popularity post
Bao Ding	MA		
	SA		
Jin Zhong	MA		
	SA		

(Continued)

TABLE A1 | (Continued)

Destinations	Type	High popularity post	Low popularity post
Yan Tai	MA		
	SA		
Chang Chun	MA		
	SA		

MA, metaphorical advertisements; SA, straightforward advertisements. Photos displayed were obtained from Baidu (https://image.baidu.com/).

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Consumer Anxiety and Assertive Advertisement Preference: The Mediating Effect of Cognitive Fluency

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Companies often seek to persuade consumers to buy products or services through assertive advertising, but such advertising is often resisted by consumers. In order to identify ways to increase consumers' preference for assertive advertising, this study starts by considering consumers' anxiety and finds, through two between-group experiments, that the emotional state of consumers when viewing advertisements affects their attitudes toward assertive advertisements: anxious consumers have a more positive attitudes toward assertive advertisement, and cognitive fluency plays a mediating role in the relationship between consumer anxiety and consumer attitudes toward assertive advertisement. This study incorporates consumer anxiety into the study of assertive advertising, thus both enriching the theoretical research on assertive advertising and consumer anxiety and providing novel ideas for companies to enhance the effectiveness of their assertive advertising strategies.

Keywords: assertive advertising, consumer anxiety, effectiveness, attitude toward advertisement, preference, cognitive fluency

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INTRODUCTION

Advertising is an important means by which companies seek to persuade consumers to buy products or services (Rana and Arora, 2021). In order to increase the persuasion effect, companies often use assertive advertising (Baek et al., 2015; Kim et al., 2017), with commanding rather than suggestive language that forces consumers to obey instructions (Miller et al., 2007). Notably, 72% of advertisements in the top 10 US print magazines contain assertive language such as "visit us," "buy now," and "call now" (Zemack-Rugar et al., 2017). Even well-known advertisements such as Nike's "Just Do It," Sprite's "Obey Your Desire," and Burger King's "As You Go" are assertive ads (Wang and Zhang, 2020). However, the existing literature on the effectiveness of assertive advertising is controversial. On the one hand, studies have found that consumers resist assertive advertising (Grandpre et al., 2003; Fitzsimons and Lehmann, 2004; Miller et al., 2007; Kronrod et al., 2012a), because such advertising creates a perception of coercion in consumers (Grandpre et al., 2003), creating pressure to conform, which in turn provokes resistance from audiences (Dillard and Shen, 2005; Pavey and Sparks, 2009), limiting the effectiveness of assertive advertising (Fitzsimons and Lehmann, 2004; Dillard and Shen, 2005; Quick and Considine, 2008). On the other hand, there are also studies showing that assertive advertising has obvious effects. In advertisements promoting, for example, hedonic products and environmental protection, the use of assertive advertising improves the persuasion effect (Kronrod et al., 2012a,b), and the persuasive effect will be affected by the consumer's level of self-confidence, perceived effort, cultural differences, non-compliance guilt,

and other factors (Terlutter et al., 2010; Baek et al., 2015; Kim et al., 2017; Zemack-Rugar et al., 2017). It is evident that the success of assertive advertising depends on factors such as the content of the advertisement and the individual audience.

This paper takes emotion as another consumer individual factor, and explores whether assertive advertising has obvious persuasive effects on anxious consumers. Anxious consumers were identified as appropriate study subjects because of the large number of consumers who often experience transient anxiety in certain consumption situations, e.g., an inexperienced homebuyer who is concerned about losing the opportunity to buy a desirable home may feel anxious when making an offer, how they will invest and save; or how they will choose a medical plan (Gino et al., 2012). Anxiety often affects consumers' judgment and decision-making (Raghunathan and Pham, 1999); therefore, how to effectively target anxious consumers for advertising and marketing is particularly important. Furthermore, anxiety, as an emotion, is characterized by high uncertainty and low control (Smith and Ellsworth, 1985; Raghunathan and Pham, 1999), so individuals in anxious moods have a marked aversion to uncertainty (Maner et al., 2007). The message of assertive advertising is clear, easy to understand (Miller et al., 2007), and has obvious control (Reavey et al., 2018); therefore, we believe that the above characteristics of assertive advertising complement those of anxious consumers. Consistently, this match makes their preference for assertive advertising significantly higher than that of non-anxious consumers. This paper verifies this conjecture through experiments. In addition, we reveal the internal mechanism that causes consumers under anxiety to prefer assertive advertising, that is, the mediating effect of cognitive fluency. Cognitive fluency is an important factor in determining the effectiveness of advertising (Storme et al., 2015). We believe that the assertive language in advertisements helps anxious consumers under anxiety to perceive certainty. This matching makes anxious consumers more sensitive to assertive language. The cognitive processing of advertisements is more fluent, thus forming a positive advertisement attitude. Experiment 2 verifies our speculation.

Overall, this paper makes three theoretical contributions. First, this study incorporates consumer anxiety as an individual influencing factor into the research system, expanding the theoretical research on assertive advertising; second, the results enrich the theory of consumer anxiety and provides a clear understanding of which advertisements consumers prefer when under anxiety. Finally, this paper reveals the psychological mechanism of consumers' preference for assertive advertising under anxiety, that is, the mediating effect of cognitive fluency.

THEORETICAL REVIEW

Advertisement Type

Advertisements can be classified into two types according to language intensity: assertive and non-assertive (Kronrod et al., 2012a,b; Zemack-Rugar et al., 2017; Wang and Zhang, 2020). Assertive advertisements use assertive language to persuade consumers, that is, by using verbs to directly issue orders to consumers, and adopting powerful adverbs such as "should" and "must" to clearly and directly tell consumers what to do, thus seeking to compel consumers to obey (Grandpre et al., 2003; Kronrod et al., 2012a; Baek et al., 2015). Assertive advertising is simple in form, clear in meaning, and suitable for persuading consumers (Kim et al., 2017). However, this type of advertising also creates pressure to obey, activates consumer resistance (Clee and Wicklund, 1980; Dillard and Shen, 2005; Lavoie et al., 2017; Wang and Yang, 2020), and even motivates the non-compliance guilt of disobedience, undermining the consumer-brand relationship (Zemack-Rugar et al., 2017).

For an assertive advertisement to have a positive effect, certain conditions must be met in actual application. From an advertising perspective, assertive advertising is more effective if the advertisement is anthropomorphic (Reavey et al., 2018); assertive advertising improves persuasion if the product advertised is a hedonic product (Kronrod et al., 2012b); if the content of the advertisement involves environmental protection themes: the use of assertive advertisements for urgent environmental protection appeals can arouse positive consumer perceptions (Kronrod et al., 2012a), and consumer perceived effort is key to the persuasiveness of assertive advertisements on environmental protection themes (Baek et al., 2015). From the perspective of cultural background, in countries with low self-confidence (such as Argentina), assertive advertising stimulates consumer self-confidence and produces better communication effects (Terlutter et al., 2010), whereas American consumers, for example, are likely to be more confident and more resistant to assertive advertisements than Korean consumers (Kim et al., 2017). In addition, the consumer perception of fit between assertive advertising and products drives consumer purchase intent (Wang and Zhang, 2020). To sum up, current research mainly focuses on advertising, cultural background, and individual consumer factors, while little is known about the role of consumer anxiety in assertive advertising.

Consumer Anxiety

Anxiety is a subjective emotion that makes individuals consciously perceive fear and tension (Spielberger, 1966). This emotion signals the presence of a potential threat, triggering pessimistic assessments of future events and negative psychological responses (Butler and Mathews, 1983; Raghunathan and Pham, 1999; Shepperd et al., 2005). Previous studies have classified types of anxiety into trait anxiety and situation anxiety (also known as state anxiety) (Endler et al., 1991; Endler, 1997; Stöber, 1997), A-trait refers to a more stable predisposition or proneness to state anxiety, while A-state is conceptualized as a momentary or emotional state reaction accompanied by physiological arousal (Kantor et al., 2001), the difference between the two being the individual's own tendency to behave in a particular situation or an actual reaction in a particular situation (Endler and Shedletsky, 1973).

In consumer-behavior research, the form of consumer anxiety that many studies focus on is situational anxiety, which is a short-lived emotional state triggered by threatening situations, specifically manifested in the form of emotions such as fear, depression, stress, worry, and tension (Spielberger, 1966; Brooks and Schweitzer, 2011). The origin of consumer anxiety may be

directly caused by an event or triggered by previous stimuli unrelated to the current decision (Raghunathan and Pham, 1999; Lerner and Keltner, 2001). In this paper, we focus on state anxiety, a transient emotion that anyone can experience. Over the last few decades, people have become more anxious, worrying about safety, social acceptance, and job security more than in the past, which has labeled the twentieth century "the age of anxiety." (Twenge, 2000). In daily decision-making situations, many factors can make consumers anxious, such as technology anxiety (Meuter et al., 2003), stereotype threat anxiety (Lee et al., 2011), travel anxiety (Reisinger and Mavondo, 2005), death anxiety (Rahimah et al., 2018), math anxiety (Suri et al., 2013), and status anxiety (Chiou and Pan, 2008) employee anxiety (Xue et al., 2021). These even include some specific consumption situations, for example, an inexperienced homebuyer who is concerned about losing the opportunity to buy a desirable home may feel anxious when making an offer or how to invest savings; furthermore, people may feel anxious about how to choose a course of medical treatment (Gino et al., 2012). Anxiety is characterized by high uncertainty and low control (Smith and Ellsworth, 1985; Raghunathan and Pham, 1999). Therefore, rather than trait anxiety, we are more concerned about the influence of consumers on decision-making under state anxiety, and anxious consumers tend to make decisions that promote a sense of security and self-control (Raghunathan et al., 2006) such as compulsive buying (Darrat et al., 2016). Studies have shown that consumer emotional factors play a role in advertising persuasion (Lau-Gesk and Meyers-Levy, 2009), motivate and persuade consumers, and often guide people's attitudes and behaviors (Andrade and Cohen, 2007). Existing research does not shed light on the form of advertising that anxious consumers prefer. The focus of this paper, thus, is how—when facing the powerful persuasion effects of assertive advertisements—consumers under anxiety make decisions, and what attitudes they have toward such advertisements.

Cognitive Fluency

Cognitive fluency, which is broadly defined as the ease by which a stimulus can be perceived, processed, or retrieved (Hoorens and Bruckmüller, 2015), involves subjective fluency, which varies according to the stimuli, external environment, and individual perception and conceptual fluency (Alter and Oppenheimer, 2009). Cognitive fluency is embodied in the fluency of concepts, language, space, perception, and decision-making (Oppenheimer, 2008). Among these, perceptual fluency is caused by lower-order cognition and is related to the presentation of stimuli, while conceptual fluency involves higher-order cognitive processes related to recognition of the relationship between the form and the content of the stimulus, the significance of the context, or the stimulus classification (Cabeza and Ohta, 1993). Greater fluency generally provokes favorable responses, giving consumers the perception of ease of processing, low effort, and high efficiency (Reber et al., 2004), which increases their subjective preference for stimuli (Winkielman et al., 2003), positive evaluation (Shen et al., 2008), and trust (Schwarz et al., 2021). Cognitive fluency is applied in the field of advertising. Important cognitive processes related to consumer-related subjective experience help improve image fluency and facilitate the understanding of narrative advertising (Chang, 2013). Cognitive fluency improves consumers' fluency in processing advertising information. The face of a disfluent celebrity in an advertisement affects brand memory (Liu and Liu, 2020). The more smoothly the advertisements are processed, the easier it is to stimulate consumption. attention, processing motivation, and processing depth, among others, to improve advertising attitudes and increase purchase intention (Storme et al., 2015).

RESEARCH HYPOTHESIS

Consumer Anxiety, Assertive Advertising and Advertising Attitudes

Consumers generally perceive assertive advertising to be sales-oriented, using strong language to "hard sell." This approach not only makes consumers perceive rudeness (Roberts and Kreuz, 1994; Dillard et al., 1997) but also a form of public persuasion (Zemack-Rugar et al., 2017). Consumers have accumulated knowledge in their long-term interactions with various marketing stimuli, making them adept at identifying marketing persuasion techniques that they perceive as reflecting the advertiser's manipulative intent (Campbell, 1995). The persuasive knowledge model suggests that consumers have negative perceptions of advertising when they realize that they are being manipulated (Campbell and Kirmani, 2000), and that consumers' consciously formed advertising perceptions ultimately shape advertising attitudes (Shimp, 1981). Attitude toward advertising refers to the tendency of consumers to respond favorably or unfavorably to specific advertising stimuli (MacKenzie and Lutz, 1989), and, based on this, we infer that consumers will question the intentions of advertisers due to assertive advertising. This leads to psychological resistance, which leads to a negative attitude toward assertive advertising.

Advertising language often expresses multi-layered and ambiguous meanings, and consumers must use inductive reasoning to process this information (Reavey et al., 2018). However, anxious consumers are confronted with a large number of advertisements every day, and cannot process this information effectively (Marquez, 1977) because of their cognitive exhaustion which leads to a decline in their ability to interpret and comprehend information (Sengupta and Johar, 2001). As a result, they prefer safe and high-control options (Taylor, 1974; Raghunathan et al., 2006), and avoid risk and uncertainty even when the decision-making task in advertising is not associated with anxiety-inducing stimuli (Brooks and Schweitzer, 2011). In the interaction of consumers with advertisements in the face of such emotion, they are more inclined to collect information from advertisements and use it as cues to make decisions (Gino et al., 2012). Compared with non-assertive advertising, the persuasive message of assertive advertising is considered clear and easy to understand (Miller et al., 2007), which reduces the low sense of control and uncertainty caused by the advertising message. Consumers are guided by direct and clear actions, thus creating a stronger preference for assertive advertising among anxious

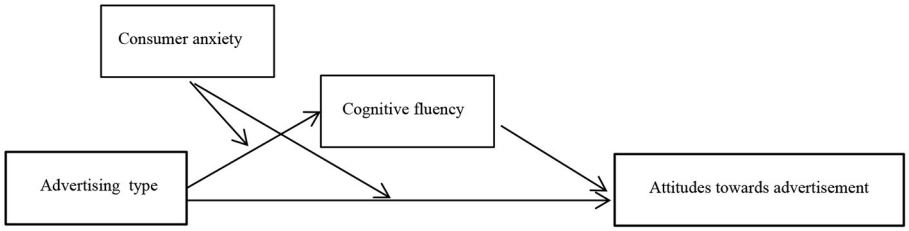

FIGURE 1 | The conceptual model of this study.

consumers than non-anxious ones. Based on this, we propose the following hypothesis:

H1: Anxious consumers have more positive attitudes toward assertive advertisement than non-anxious consumers.

The Mediating Role of Cognitive Fluency

Consumers can clarify their purchase intentions through advertising information and preferences. Assertive advertisements often use imperative adverbs such as "should" and "must" (Baek et al., 2015), making consumers feel compelled to follow certain instructions (Okazaki et al., 2010) that are difficult to reject (Kronrod et al., 2012a,b). Therefore, the consumer's behavioral tendency and the explicit instruction of the assertive advertisement form a double message, which affects the cognitive fluency. Moreover, this approach makes them feel that their freedom and autonomy are threatened (Dillard and Shen, 2005), and consumers will refuse to comply with a strong motivation to protect personal freedom (Clee and Wicklund, 1980; Dillard and Shen, 2005; Pavey and Sparks, 2009), and even induce resistive behaviors (Clee and Wicklund, 1980; Dillard and Shen, 2005; Lavoie et al., 2017; Wang and Yang, 2020). In contrast, when facing important decisions, anxious consumers feel uncertain about their ability to make the right decisions, lack confidence in their own judgment (Gino et al., 2012), and tend to think that they are in a non-dominant position and lacking control (Maddux et al., 1988). When consumers form judgments and make decisions, they are more inclined to respond to information that is easy to process (Shah and Oppenheimer, 2007), and when the content of the information is concise, it is easier to stimulate consumers' cognitive fluency (Novemsky et al., 2007). Assertive advertising gives consumers clear instruction in action decision-making, and such advertising information is more convincing (O'Keefe, 1997), which makes the direction of action clear, thereby increasing the cognitive fluency of advertising. The more smoothly the advertising information is recognized, the easier it is to capture consumers' attention, processing motivation, and processing depth, thereby enhancing consumers' attitudes toward advertising (Storme et al., 2015). Based on this, we propose the following hypothesis:

H2: Cognitive fluency plays a mediating role in the effects of consumer anxiety and advertising type on consumer advertising attitudes.

H2a: Anxious consumers have higher cognitive fluency with assertive advertisement and thus have more positive attitudes toward such advertisement.

H2b: Non-anxious consumers have higher cognitive fluency with non-assertive advertisement and thus have more positive attitudes toward such advertisement.

The conceptual model of this study is shown in **Figure 1**.

EXPERIMENT 1

Pre-experiment

The purpose of the pre-experiment is to select suitable material for assertive advertising and anxiety emotion manipulation in the formal experiment. In terms of advertising, according to the experimental method of Kronrod et al. (2012b), this paper selects the virtual brand BMY earphones that offer both practical and hedonic value as advertised products.The advertising language of one of the assertive advertisements was "BMY earphones, you must buy"and that of the other, i.e. the non-assertive advertisement, was "BMY earphones are worth trying." Sixty subjects were invited to rate the assertiveness of the two advertising phrases using the manipulative question "I feel that someone is ordering me to take action in this advertisement" on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The assertiveness of the assertive advertisement (M assertive = 4.83, SD assertive = 0.75) was statistically significantly higher than that of the non-assertive advertisement (M non-assertive = 1.00, SD non-assertive = 0.00, $t(29) = 28.12$, $p < 0.01$); t-tests were performed under heteroscedasticity conditions; as a result, df are different to those expected for a homovariance t-test. Therefore, the two advertisements were identified as stimulant materials for the advertising experiments of this study.

In accordance with Brooks and Schweitzer (2011) and Gino et al. (2012), to manipulate the anxiety of consumers, a clip from the movie "Vertical Limit[1]" "(between 0 min 29 s and 6 min 25 s) is used induce to anxiety, while in the non-anxiety group, we used a clip from the BBC documentary" The Great Barrier Reef[2]" (between 0 min 0 s and 5 min 0 s) to induce neutral emotions. Similarly, 60 subjects were invited to score the anxiety-evoking

[1]The video was obtained from a paid website in China, whose url is https://www.youku.com/show_page/id_zcc00e198962411de83b1.html.

[2]The video was obtained from a paid website in China, whose url is https://v.youku.com/v_show/id_XMTY2Mjc1Njc2MA==.html?spm=a2h0c.8166622.PhoneSokuProgram_1.dtitle&s=51a675b038e211e6bdbb.

degree of the two videos. The manipulative questions used were based on the personal emotional scale compiled by Raghunathan and Pham (1999), and the item "I felt anxious" was selected as the subject. The anxiety manipulative test questions were measured using a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). The final movie "Vertical Limit" segment induced statistically significantly higher anxiety (M anxiety = 6.30, SD anxiety = 0.70) than the BBC documentary "Great Barrier Reef" segment (M non-anxiety = 1.23, SD non-anxiety = 0.43, $t(34) = 48.10$, $p < 0.01$); t-tests were performed under heteroscedasticity conditions; as a result, df are different to those expected for a homovariance t-test, and the two movies were selected as the emotional-manipulation experimental material of this study.

Formal Experiment

The purpose of Experiment 1 is to verify the difference in attitude between anxious consumers and non-anxious consumers toward assertive advertising, namely, to test hypothesis 1.

Procedure and Measurement

This study adopted a 2 (advertising type: assertive advertising vs. non-assertive advertising) × 2 (consumer anxiety: anxiety vs. non-anxiety) between-group experimental design. A total of 200 college students were recruited from a university in Northeast China to participate in this experiment. The final valid sample was 188 (average age was 19.6 years old, and 82 were female, accounting for 43.6%). All subjects were randomly assigned to one of four conditions corresponding to a between-subjects design. First, the anxiety group was asked to watch the clip from the movie "Vertical Limit" (0 min 29 s to 6 min 25 s) to induce anxiety, while the non-anxious group watched the BBC documentary "The Great Barrier Reef" (0 min 0 s to 5 min 0 s) to induce a neutral emotion, and then answer the question "I feel anxious" on the anxiety-manipulation test. Next, subjects in both the assertive and the non-assertive advertisement group were asked to view the corresponding advertising materials and to complete the manipulative test question for the assertive ads: "From this ad, I feel that someone is ordering me to take action," and fill in the measurement items for advertising attitude. To measure advertising attitude, in accordance with the advertising attitude scale compiled by MacKenzie and Lutz (1989) and Lee et al. (2005), combined with the research context, three items were determined: "I feel this advertisement is good," "This advertisement attracts me," and "I like this advertisement." (Cronbach's $\alpha = 0.96$). All measurements are on a 7-point Likert scale (1 = strongly disagree, 7 = strongly agree). Finally, subjects filled in basic information questions to complete the experiment. The subjects were rewarded with a small gift after completing all the items.

Results and Discussion

Manipulation Checks

The independent sample t-test on consumer anxious types and advertising types showed that the anxiety score of the anxiety group (M anxiety = 5.37, SD anxiety = 1.43) was statistically significantly higher than that of the non-anxiety group (M non-anxiety = 2.60, SD non-anxiety = 1.43, $t(186) = 13.19$, $p < 0.01$); the scores of assertive advertisement groups (M assertive = 5.55, SD assertive = 1.56) were statistically significantly higher than those of non-assertive advertisement groups (M non-assertive = 1.65, SD non-assertive = 0.85, $t(150) = 21.52$, $p < 0.01$ e advertisement groups (M non-assertive = 1.65, SD non-assertive = 0.85, $t(150) = 21.52$, $p < 0.01$); t-tests were performed under heteroscedasticity conditions; as a result, df are different to those expected for a homovariance t-test, indicating that the manipulation was successful.

Main Effect Analysis

The main effect analysis shows that the main effect of assertive advertising on advertising attitude is significant [$F(1, 184) = 12.84$, $p < 0.01$], and consumer anxiety has a significant impact on advertising as evident from analyzing the variance of consumer anxiety, advertising type, and advertising attitude. The main effect was significant [$F(1, 184) = 14.05$, $p < 0.01$], and the interaction effect between assertive advertising and consumer anxiety was significant [$F(1, 184) = 49.92$, $p < 0.01$]. So, hypothesis 1 was supported. A simple effect analysis was carried out by writing statements in SPSS to verify how the interaction of advertising types and consumer sentiment affects advertising attitudes. The results show that consumers under anxiety have a more positive attitude toward advertising [M assertive = 4.92; SD assertive = 0.22; M non-assertive = 2.79; SD non-assertive = 0.21; $F(1, 184) = 49.90$, $p < 0.01$]; non-anxious consumers have more positive attitudes toward non-assertive advertising [M non-assertive = 3.45; SD non-assertive = 0.19; M assertive = 2.76; SD assertive = 0.18; $F(1, 184) = 7.01$, $p < 0.01$,power analysis =0.926; effect size=0.264], as shown in **Figure 2**; therefore, hypothesis 1 was confirmed.

EXPERIMENT 2

The purpose of Experiment 2 was to verify the mediating effect of cognitive fluency on consumer anxiety, advertising type, and advertising attitude, namely, to test hypothesis 2,2a, and 2b.

Procedure and Measurement

A total of 200 college students were recruited to participate in this experiment from a university in Northeast China, and 187 subjects finally completed the experiment (the average age was 19.17 years, and 92 were women, accounting for 49%). The procedures for Experiment 2 and Experiment 1 were basically the same. All subjects were randomly assigned to one of four conditions corresponding to a between-subjects design. The subjects were required to complete the test questions about the manipulativeness of assertive advertisements and then complete the cognitive fluency measurement scale. The measurement of cognitive fluency was based on Chae and Hoegg (2013) and Hoorens and Bruckmüller (2015), and comprised the following three items, "This advertisement is very simple," "This advertisement is easy to understand," and "I understand this advertisement very clearly." Finally, participants answered questions on advertisement attitude and provided basic

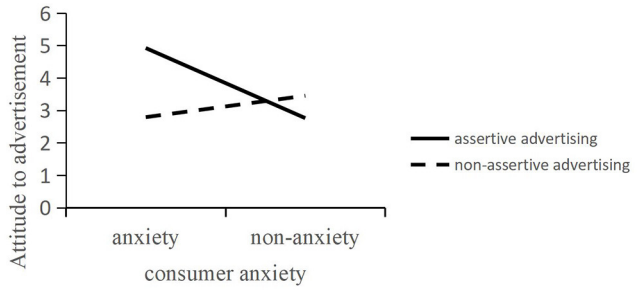

FIGURE 2 | The interaction between advertising types and consumer anxiety in Experiment 1.

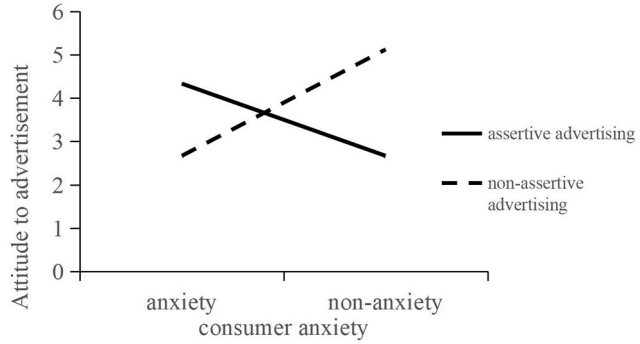

FIGURE 3 | The interaction between advertising types and consumer anxiety in Experiment 2.

information such as their age and gender. The subjects were rewarded with a small gift after completing all the items.

Results and Discussion

Manipulation Checks

The results of independent samples *t*-test on consumer types and advertising types showed that the emotional score of the anxiety group (M anxiety = 5.91, SD anxiety = 1.09) was statistically significantly higher than that of the non-anxious group [M non-anxious = 1.51, SD non-anxious = 0.10, $t(185) = 28.81$, $p < 0.01$]; the assertive score of the advertisements in the assertive advertisements group (M assertive = 5.35, SD assertive = 1.90) was statistically significantly higher than that of the non-assertive advertisements group [M non-assertive = 2.48, SD non-assertive = 1.60, $t(185) = 10.91$, $p < 0.01$], indicating that the experimental manipulation was successful.

Main Effect Analysis

Analysis of variance on consumer anxiety, advertising type, and advertising attitude showed that the main effects of assertive advertising [$F(1, 183) = 4.01$, $p = 0.047$] and consumer anxiety [$F(1, 183) = 4.03$, $p = 0.046$] on advertising attitude were both statistically significant; furthermore, the 2 (anxiety vs. non-anxiety) × 2 (assertive advertising vs. non-assertive advertising) analysis of variance (ANOVA) revealed a significant main effect of advertising attitude [$F(1, 183) = 5.83$, $p < 0.01$], re-confirming Hypothesis 1. In order to further understand how advertising types and consumer anxiety affect advertising attitudes, this study used SPSS to conduct a simple effect analysis. The results showed that consumers in an anxious emotion had a more positive attitude toward assertive advertisement (vs. non-assertive advertisement) [M assertive = 4.33; SD assertive = 0.19; M non-assertive = 2.66; SD non-assertive =0.18;$F(1, 183) = 37.78$, $p < 0.01$]; non-anxious consumer advertising attitudes toward non-assertive advertisement (vs. assertive advertisement) more positive [M non-assertive = 5.12; SD non-assertive =0.20;M assertive = 2.66; SD assertive =0.19;$F(1, 183) = 79.56$, $p < 0.01$, power analysis =0.925; effect size=0.265], as shown in **Figure 3**.

Mediating Effect Analysis

In accordance with the mediation effect analysis procedure proposed by Zhao et al. (2010) and Shi et al. (2011), we use a step-by-step process for testing mediation. Furthermore, referring to the bootstrap method proposed by Preacher et al. (2007) and Hayes (2013), the PROCESS program in SPSS was used to test the mediation effect. This paper uses the process model 8 in SPSS to test the mediating effect of cognitive fluency (Cronbach's α = 0.84) effect, and the sample size was set to 5,000. The results showed that, with the advertising attitude as the dependent variable, the mediating effect of cognitive fluency was statistically significant (LLCI = 1.43, ULCI = 2.55, excluding 0) under the 95% confidence interval, and the effect coefficient was 1.95. Specifically, the mediating effect of cognitive fluency in the influence of assertive advertising and consumer anxiety on advertising attitudes is statistically significant (LLCI = −1.38, ULCI = −0.64, excluding 0). The mediating effect of cognitive fluency in the influence of non-assertive advertising and non-anxious emotion on advertising attitudes was statistically significant (LLCI = 0.66, ULCI = 1.32, excluding 0), thus verifying hypothesis 2, 2a and 2b.

DISCUSSION AND CONCLUSION

In this paper, two experiments were conducted to verify the influence of the interaction of consumer anxiety (anxiety vs. non-anxiety) and advertising type (assertive advertising vs. non-assertive advertising) on advertising attitudes and the mediating effect of cognitive fluency. Specifically, the results of Experiment 1 show that when consumers are anxious, using assertive advertising can improve consumer advertising attitudes more than non-assertive advertising; and when consumers are in a non-anxious state, using non-assertive advertising is more effective than non-assertive advertising. Assertive advertising can improve consumer attitude toward advertising.

The results of Experiment 2 further showed that cognitive fluency played a mediating role in the interaction effect of consumer anxiety (anxiety vs. non-anxiety) and advertising type (assertive advertising vs. non-assertive advertising) on

advertising attitudes. Anxious consumers have higher cognitive fluency for assertive advertisements, and thus have a more positive attitude toward assertive advertisements; non-anxious consumers have higher cognitive fluency toward non-assertive advertisements, so they are more responsive to non-assertive advertisements. The attitude of the advertising is more positive.

Implications

The theoretical contributions of this study are mainly reflected in three aspects. First, the conclusions of this paper enrich the research on assertive advertising. In regard to the benefits and disadvantages of assertive advertising, previous researchers have been divided in their opinions; many have discussed the effectiveness of assertive advertising in various specific situations, but few studies have examined it from the perspective of consumer anxiety. This paper takes a novel perspective, namely the anxiety of consumers, and discusses the attitudes of consumers under anxiety to assertive advertising, thereby expanding the research boundary of the effectiveness of assertive advertising. Second, this paper enriches the research on consumer anxiety theory. Previous research has mainly focused on the drivers of consumer anxiety and its impact on decision-making, but little work has been done on the impact of advertising attitudes. This paper takes anxious consumers as the research object, and discusses their response to assertive advertising, which provides a theoretical basis for appropriate advertising types for this group and also deepens the theoretical system of consumer anxiety. Finally, this paper reveals the psychological mechanism of consumer preference for assertive advertising under anxiety, that is, the mediating effect of cognitive fluency, thus offering an in-depth exploration of the psychological mechanism underlying the influence of assertive advertising on consumer advertising attitudes.

This paper provides suggestions for corporate marketing strategies. The findings provide ideas for marketers to design advertisements in different language styles. Consumers who are anxious prefer assertive advertisements; therefore, when designing advertisements, attention should be paid to gaining the favor of these consumers through assertive language and cues. In the actual marketing environment, we acknowledge that it is currently difficult to directly identify an anxious customer; despite this, it can be applied in situations that are likely to elicit anxiety (such as buying a house or making insurance investment), and our conclusions are valuable when purchasing such products or services. Advertisements should use more slogans to emphasize clear and short action instructions, which can more effectively reduce hesitation of anxious consumers in purchasing decisions and alleviate the uncertainty caused by the lack of instructions in advertising information. Furthermore, the results provide insights for the enterprise market segmentation strategy. The market research department of an enterprise can measure the anxiety of consumers through questionnaires, and then formulate different types of advertisements for different market segments according to the results. In international marketing, different market categories can be divided explicitly according to the anxiety level of consumers in the target market in a cross-cultural context. In certain market situations such as purchasing complex products (such as automobiles, high-tech products) (Lee et al., 2011) or less familiar products (such as insurance investments, real estate) (Gino et al., 2012), it is more likely to induce consumer anxiety. In these segmented market where consumers are prone to anxiety, assertive advertising should be the main method, and attention should also be paid to activating high uncertainty or low sense of control (flash sale) among consumers during the publicity process so as to achieve better persuasive effects.

Limitations

This paper is the first to explore consumer preference for arbitrary advertising from the perspective of consumer anxiety, so there are still some limitations and problems to be addressed. First, this paper only studies attitudes toward assertive advertisement under the boundary condition of consumer anxiety; there may be other boundary conditions, such as product type. The subjects in the experiment in this paper are college students; accordingly, the experimental products selected are headphones, which are both hedonic and practical. However, in fact, when hedonic or practical products are more described as hedonic functions, assertive advertising will lead to greater compliance of consumers (Kronrod et al., 2012b), Therefore, for anxious consumers, whether there is still a difference in the persuasive effect of utility and hedonic products in assertive advertising remains to be further explored. Second, our experimental sample has limitations. In order to ensure more rigorous control of state anxiety, laboratory samples were used in both Experiment 1 and Experiment 2, and random sampling was not carried out in different age groups. Therefore, follow-up research can use a wider sample for further verification. We also suggest that future studies aim to perform verification and generalization of the present results. Finally, in addition to the print advertisements discussed in this article, assertive language is increasingly used in online live broadcasts, and the language of network anchors has begun to show an assertive trend, thus forming a generalization of the stimulation of assertive language whether anxious consumers also have preferences in this regard remains to be studied.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

JW finished all steps of the study and performed the statistical analysis and revised the manuscript and contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

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The Impact of Online Reviews on Consumers' Purchasing Decisions: Evidence From an Eye-Tracking Study

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This study investigated the impact of online product reviews on consumers purchasing decisions by using eye-tracking. The research methodology involved (i) development of a conceptual framework of online product review and purchasing intention through the moderation role of gender and visual attention in comments, and (ii) empirical investigation into the region of interest (ROI) analysis of consumers fixation during the purchase decision process and behavioral analysis. The results showed that consumers' attention to negative comments was significantly greater than that to positive comments, especially for female consumers. Furthermore, the study identified a significant correlation between the visual browsing behavior of consumers and their purchase intention. It also found that consumers were not able to identify false comments. The current study provides a deep understanding of the underlying mechanism of how online reviews influence shopping behavior, reveals the effect of gender on this effect for the first time and explains it from the perspective of attentional bias, which is essential for the theory of online consumer behavior. Specifically, the different effects of consumers' attention to negative comments seem to be moderated through gender with female consumers' attention to negative comments being significantly greater than to positive ones. These findings suggest that practitioners need to pay particular attention to negative comments and resolve them promptly through the customization of product/service information, taking into consideration consumer characteristics, including gender.

Keywords: online reviews, eye-tracking, consumers purchasing decisions, emotion valence, gender

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INTRODUCTION

E-commerce has grown substantially over the past years and has become increasingly important in our daily life, especially under the influence of COVID-19 recently (Hasanat et al., 2020). In terms of online shopping, consumers are increasingly inclined to obtain product information from reviews. Compared with the official product information provided by the sellers, reviews are provided by other consumers who have already purchased the product *via* online shopping websites (Baek et al., 2012). Meanwhile, there is also an increasing trend for consumers to share their shopping experiences on the network platform (Floh et al., 2013). In response to

these trends, a large number of studies (Floh et al., 2013; Lackermair et al., 2013; Kang et al., 2020; Chen and Ku, 2021) have investigated the effects of online reviews on purchasing intention. These studies have yielded strong evidence of the valence intensity of online reviews on purchasing intention. Lackermair et al. (2013), for example, showed that reviews and ratings are an important source of information for consumers. Similarly, through investigating the effects of review source and product type, Bae and Lee (2011) concluded that a review from an online community is the most credible for consumers seeking information about an established product. Since reviews are comments from consumers' perspectives and often describe their experience using the product, it is easier for other consumers to accept them, thus assisting their decision-making process (Mudambi and Schuff, 2010).

A survey conducted by Zhong-Gang et al. (2015) reveals that nearly 60% of consumers browse online product reviews at least once a week and 93% of whom believe that these online reviews help them to improve the accuracy of purchase decisions, reduce the risk of loss and affect their shopping options. When it comes to e-consumers in commercial activities on B2B and B2C platforms, 82% of the consumers read product reviews before making shopping choices, and 60% of them refer to comments every week. Research shows that 93% of consumers say online reviews will affect shopping choices, indicating that most consumers have the habit of reading online reviews regularly and rely on the comments for their purchasing decisions (Vimaladevi and Dhanabhakaym, 2012).

Consumer purchasing decision after reading online comments is a psychological process combining vision and information processing. As evident from the literature, much of the research has focused on the outcome and impact of online reviews affecting purchasing decisions but has shed less light on the underlying processes that influence customer perception (Sen and Lerman, 2007; Zhang et al., 2010; Racherla and Friske, 2013). While some studies have attempted to investigate the underlying processes, including how people are influenced by information around the product/service using online reviews, there is limited research on the psychological process and information processing involved in purchasing decisions. The eye-tracking method has become popular in exploring and interpreting consumer decisions making behavior and cognitive processing (Wang and Minor, 2008). However, there is very limited attention to how the emotional valence and the content of comments, especially those negative comments, influence consumers' final decisions by adopting the eye-tracking method, including a gender comparison in consumption, and to whether consumers are suspicious of false comments.

Thus, the main purpose of this research is to investigate the impact of online reviews on consumers' purchasing decisions, from the perspective of information processing by employing the eye-tracking method. A comprehensive literature review on key themes including online reviews, the impact of online reviews on purchasing decisions, and underlying processes including the level and credibility of product review information, and processing speed/effectiveness to drive customer perceptions on online reviews, was used to identify current research gaps and establish the rationale for this research. This study simulated a network shopping scenario and conducted an eye movement experiment to capture how product reviews affect consumers purchasing behavior by collecting eye movement indicators and their behavioral datum, in order to determine whether the value of the fixation dwell time and fixation count for negative comment areas is greater than that for positive comment area and to what extent the consumers are suspicious about false comments. Visual attention by both fixation dwell time and count is considered as part of moderating effect on the relationship between the valence of comment and purchase intention, and as the basis for accommodating underlying processes.

The paper is organized as follows. The next section presents literature reviews of relevant themes, including the role of online reviews and the application of eye movement experiments in online consumer decision research. Then, the hypotheses based on the relevant theories are presented. The research methodology including data collection methods is presented subsequently. This is followed by the presentation of data analysis, results, and discussion of key findings. Finally, the impact of academic practical research and the direction of future research are discussed, respectively.

LITERATURE REVIEW

Online Product Review

Several studies have reported on the influence of online reviews, in particular on purchasing decisions in recent times (Zhang et al., 2014; Zhong-Gang et al., 2015; Ruiz-Mafe et al., 2018; Von Helversen et al., 2018; Guo et al., 2020; Kang et al., 2020; Wu et al., 2021). These studies have reported on various aspects of online reviews on consumers' behavior, including consideration of textual factors (Ghose and Ipeirotiss, 2010), the effect of the level of detail in a product review, and the level of reviewer agreement with it on the credibility of a review, and consumers' purchase intentions for search and experience products (Jiménez and Mendoza, 2013). For example, by means of text mining, Ghose and Ipeirotiss (2010) concluded that the use of product reviews is influenced by textual features, such as subjectivity, informality, readability, and linguistic accuracy. Likewise, Boardman and Mccormick (2021) found that consumer attention and behavior differ across web pages throughout the shopping journey depending on its content, function, and consumer's goal. Furthermore, Guo et al. (2020) showed that pleasant online customer reviews lead to a higher purchase likelihood compared to unpleasant ones. They also found that perceived credibility and perceived diagnosticity have a significant influence on purchase decisions, but only in the context of unpleasant online customer reviews. These studies suggest that online product reviews will influence consumer behavior but the overall effect will be influenced by many factors.

In addition, studies have considered broader online product information (OPI), comprising both online reviews and vendor-supplied product information (VSPI), and have reported on different attempts to understand the various ways in which

OPI influences consumers. For example, Kang et al. (2020) showed that VSPI adoption affected online review adoption. Lately, Chen and Ku (2021) found a positive relationship between diversified online review websites as accelerators for online impulsive buying. Furthermore, some studies have reported on other aspects of online product reviews, including the impact of online reviews on product satisfaction (Changchit and Klaus, 2020), relative effects of review credibility, and review relevance on overall online product review impact (Mumuni et al., 2020), functions of reviewer's gender, reputation and emotion on the credibility of negative online product reviews (Craciun and Moore, 2019) and influence of vendor cues like the brand reputation on purchasing intention (Kaur et al., 2017). Recently, an investigation into the impact of online review variance of new products on consumer adoption intentions showed that product newness and review variance interact to impinge on consumers' adoption intentions (Wu et al., 2021). In particular, indulgent consumers tend to prefer incrementally new products (INPs) with high variance reviews while restrained consumers are more likely to adopt new products (RNPs) with low variance.

Emotion Valence of Online Product Review and Purchase Intention

Although numerous studies have investigated factors that may influence the effects of online review on consumer behavior, few studies have focused on consumers' perceptions, emotions, and cognition, such as perceived review helpfulness, ease of understanding, and perceived cognitive effort. This is because these studies are mainly based on traditional self-report-based methods, such as questionnaires, interviews, and so on, which are not well equipped to measure implicit emotion and cognitive factors objectively and accurately (Plassmann et al., 2015). However, emotional factors are also recognized as important in purchase intention. For example, a study on the usefulness of online film reviews showed that positive emotional tendencies, longer sentences, the degree of a mix of the greater different emotional tendencies, and distinct expressions in critics had a significant positive effect on online comments (Yuanyuan et al., 2009).

Yu et al. (2010) also demonstrated that the different emotional tendencies expressed in film reviews have a significant impact on the actual box office. This means that consumer reviews contain both positive and negative emotions. Generally, positive comments tend to prompt consumers to generate emotional trust, increase confidence and trust in the product and have a strong persuasive effect. On the contrary, negative comments can reduce the generation of emotional trust and hinder consumers' buying intentions (Archak et al., 2010). This can be explained by the rational behavior hypothesis, which holds that consumers will avoid risk in shopping as much as possible. Hence, when there is poor comment information presented, consumers tend to choose not to buy the product (Mayzlin and Chevalier, 2003). Furthermore, consumers generally believe that negative information is more valuable than positive information when making a judgment (Ahluwalia et al., 2000). For example, a single-star rating (criticism) tends to have a greater influence on consumers' buying tendencies than that of a five-star rating (compliment), a phenomenon known as the negative deviation.

Since consumers can access and process information quickly through various means and consumers' emotions influence product evaluation and purchasing intention, this research set out to investigate to what extent and how the emotional valence of online product review would influence their purchase intention. Therefore, the following hypothesis was proposed:

> *H1*: For hedonic products, consumer purchase intention after viewing positive emotion reviews is higher than that of negative emotion ones; On the other hand, for utilitarian products, it is believed that negative comments are more useful than positive ones and have a greater impact on consumers purchase intention by and large.

It is important to investigate Hypothesis one (H1) although it seems obvious. Many online merchants pay more attention to products with negative comments and make relevant improvements to them rather than those with positive comments. Goods with positive comments can promote online consumers' purchase intention more than those with negative comments and will bring more profits to businesses.

Sen and Lerman (2007) found that compared with the utilitarian case, readers of negative hedonic product reviews are more likely to attribute the negative opinions expressed, to the reviewer's internal (or non-product-related) reasons, and therefore, are less likely to find the negative reviews useful. However, in the utilitarian case, readers are more likely to attribute the reviewer's negative opinions to external (or product-related) motivations, and therefore, find negative reviews more useful than positive reviews on average. Product type moderates the effect of review valence, Therefore, Hypothesis one is based on hedonic product types, such as fiction books.

Guo et al. (2020) found pleasant online customer reviews to lead to a higher purchase likelihood than unpleasant ones. This confirms hypothesis one from another side. The product selected in our experiment is a mobile phone, which is not only a utilitarian product but also a hedonic one. It can be used to make a phone call or watch videos, depending on the user's demands.

Eye-Tracking, Online Product Review, and Purchase Intention

The eye-tracking method is commonly used in cognitive psychology research. Many researchers are calling for the use of neurobiological, neurocognitive, and physiological approaches to advance information system research (Pavlou and Dimoka, 2010; Liu et al., 2011; Song et al., 2017). Several studies have been conducted to explore consumers' online behavior by using eye-tracking. For example, using the eye-tracking method, Luan et al. (2016) found that when searching for products, customers' attention to attribute-based evaluation is significantly longer than that of experience-based evaluation, while there is no significant difference for the experiential products.

Moreover, their results indicated eye-tracking indexes, for example, fixation dwell time, could intuitively reflect consumers' search behavior when they attend to the reviews. Also, Hong et al. (2017) confirmed that female consumers pay more attention to picture comments when they buy experience goods; when they buy searched products, they are more focused on the pure text comments. When the price and comment clues are consistent, consumers' purchase rates significantly improve.

Eye-tracking method to explore and interpret consumers' decision-making behavior and cognitive processing is primarily based on the eye-mind hypothesis proposed by Just and Carpenter (1992). Just and Carpenter (1992) stated that when an individual is looking, he or she is currently perceiving, thinking about, or attending to something, and his or her cognitive processing can be identified by tracking eye movement. Several studies on consumers' decision-making behavior have adopted the eye-tracking approach to quantify consumers' visual attention, from various perspectives including determining how specific visual features of the shopping website influenced their attitudes and reflected their cognitive processes (Renshaw et al., 2004), exploring gender differences in visual attention and shopping attitudes (Hwang and Lee, 2018), investigating how employing human brands affects consumers decision quality (Chae and Lee, 2013), consumer attention and different behavior depending on website content, functions and consumers goals (Boardman and McCormick, 2019). Measuring the attention to the website and time spent on each purchasing task in different product categories shows that shoppers attend to more areas of the website for purposes of website exploration than for performing purchase tasks. The most complex and time-consuming task for shoppers is the assessment of purchase options (Cortinas et al., 2019). Several studies have investigated fashion retail websites using the eye-tracking method and addressed various research questions, including how consumers interact with product presentation features and how consumers use smartphones for fashion shopping (Tupikovskaja-Omovie and Tyler, 2021). Yet, these studies considered users without consideration of user categories, particularly gender. Since this research is to explore consumers' decision-making behavior and the effects of gender on visual attention, the eye-tracking approach was employed as part of the overall approach of this research project. Based on existing studies, it could be that consumers may pay more attention to negative evaluations, will experience cognitive conflict when there are contradictory false comments presented, and will be unable to judge good or bad (Cui et al., 2012). Therefore, the following hypothesis was proposed:

> *H2*: Consumers' purchasing intention associated with online reviews is moderated/influenced by the level of visual attention.

To test the above hypothesis, the following two hypotheses were derived, taking into consideration positive and negative review comments from H1, and visual attention associated with fixation dwell time and fixation count.

> *H2a*: When consumers intend to purchase a product, fixation dwell time and fixation count for negative comment areas are greater than those for positive comment areas.

Furthermore, when consumers browse fake comments, they are suspicious and actively seek out relevant information to identify the authenticity of the comments, which will result in more visual attention. Therefore, H2b was proposed:

> *H2b*: Fixation dwell time and fixation count for fake comments are greater than those for authentic comments.

When considering the effect of gender on individual information processing, some differences were noted. For example, Meyers-Levy and Sternthal (1993) put forward the selectivity hypothesis, a theory of choice hypothesis, which implies that women gather all information possible, process it in an integrative manner, and make a comprehensive comparison before making a decision, while men tend to select only partial information to process and compare according to their existing knowledge—a heuristic and selective strategy. Furthermore, for an online product review, it was also reported that gender can easily lead consumers to different perceptions of the usefulness of online word-of-mouth. For example, Zhang et al. (2014) confirmed that a mixed comment has a mediating effect on the relationship between effective trust and purchasing decisions, which is stronger in women. This means that men and women may have different ways of processing information in the context of making purchasing decisions using online reviews. To test the above proposition, the following hypothesis was proposed:

> *H3*: Gender factors have a significant impact on the indicators of fixation dwell time and fixation count on the area of interest (AOI). Male purchasing practices differ from those of female consumers. Male consumers' attention to positive comments is greater than that of female ones, they are more likely than female consumers to make purchase decisions easily.

Furthermore, according to the eye-mind hypothesis, eye movements can reflect people's cognitive processes during their decision process (Just and Carpenter, 1980). Moreover, neurocognitive studies have indicated that consumers' cognitive processing can reflect the strategy of their purchase decision-making (Rosa, 2015; Yang, 2015). Hence, the focus on the degree of attention to different polarities and the specific content of comments can lead consumers to make different purchasing decisions. Based on the key aspects outlined and discussed above, the following hypothesis was proposed:

> *H4*: Attention to consumers' comments is positively correlated with consumers' purchasing intentions: Consumers differ in the content of comments to which they gaze according to gender factors.

Thus, the framework of the current study is shown in **Figure 1**.

MATERIALS AND METHODS

The research adopted an experimental approach using simulated lab environmental settings for collecting experimental data from a selected set of participants who have experience with online shopping. The setting of the task was based on guidelines for shopping provided on Taobao.com, which is the most famous and frequently used C2C platform in China. Each experiment was set with the guidelines provided and carried out for a set time. Both behavioral and eye movement data were collected during the experiment.

Participants

A total of 40 healthy participants (20 males and 20 females) with online shopping experiences were selected to participate in the experiment. The participants were screened to ensure normal or correct-to-normal vision, no color blindness or poor color perception, or other eye diseases. All participants provided their written consent before the experiment started. The study was approved by the Internal Review Board of the Academy of Neuroeconomics and Neuromanagement at Ningbo University and by the Declaration of Helsinki (World Medical Association, 2014).

Materials

With standardization and small selection differences among individuals, search products can be objectively evaluated and easily compared, to effectively control the influence of individual preferences on the experimental results (Huang et al., 2009). Therefore, this research focused on consumer electronics products, essential products in our life, as the experiment stimulus material. To be specific, as shown in **Figure 2**, a simulated shopping scenario was presented to participants, with a product presentation designed in a way that products are shown on Taobao.com. **Figure 2** includes two segments: One shows mobile phone information (**Figure 2A**) and the other shows comments (**Figure 2B**). Commodity description information in **Figure 2A** was collected from product introductions on Taobao.com, mainly presenting some parameter information about the product, such as memory size, pixels, and screen size. There was little difference in these parameters, so quality was basically at the same level across smartphones. Prices and brand information were hidden to ensure that reviews were the sole factor influencing consumer decision-making. Product review areas in **Figure 2B** are the AOI, presented as a double-column layout. Each panel included 10 (positive or negative) reviews taken from real online shopping evaluations, amounting to a total of 20 reviews for each product. To eliminate the impact of different locations of comments on experimental results, the positions of the positive and negative comment areas were exchanged, namely, 50% of the subjects had positive comments presented on the left and negative comments on the right, with the remaining 50% of the participants receiving the opposite set up.

A total of 12,403 product reviews were crawled through and extracted from the two most popular online shopping platforms in China (e.g., Taobao.com and JD.com) by using GooSeeker (2015), a web crawler tool. The retrieved reviews were then further processed. At first, brand-related, price-related, transaction-related, and prestige-related contents were removed from comments. Then, the reviews were classified in terms of appearance, memory, running speed, logistics, and so on into two categories: positive reviews and negative reviews. Furthermore, the content of the reviews was refined to retain the original intention but to meet the requirements of the experiment. In short, reviews were modified to ensure brevity, comprehensibility, and equal length, so as to avoid causing cognitive difficulties or ambiguities in semantic understanding. In the end, 80 comments were selected for the experiment:

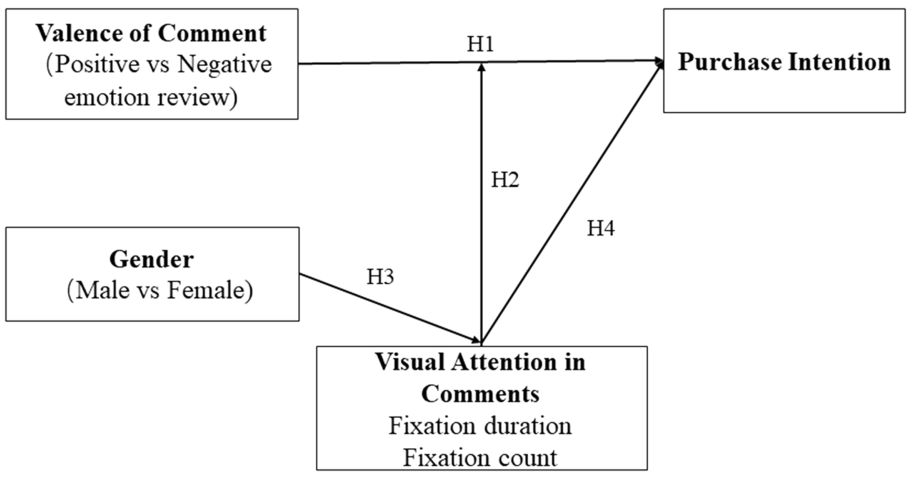

FIGURE 1 | Conceptual framework of the study.

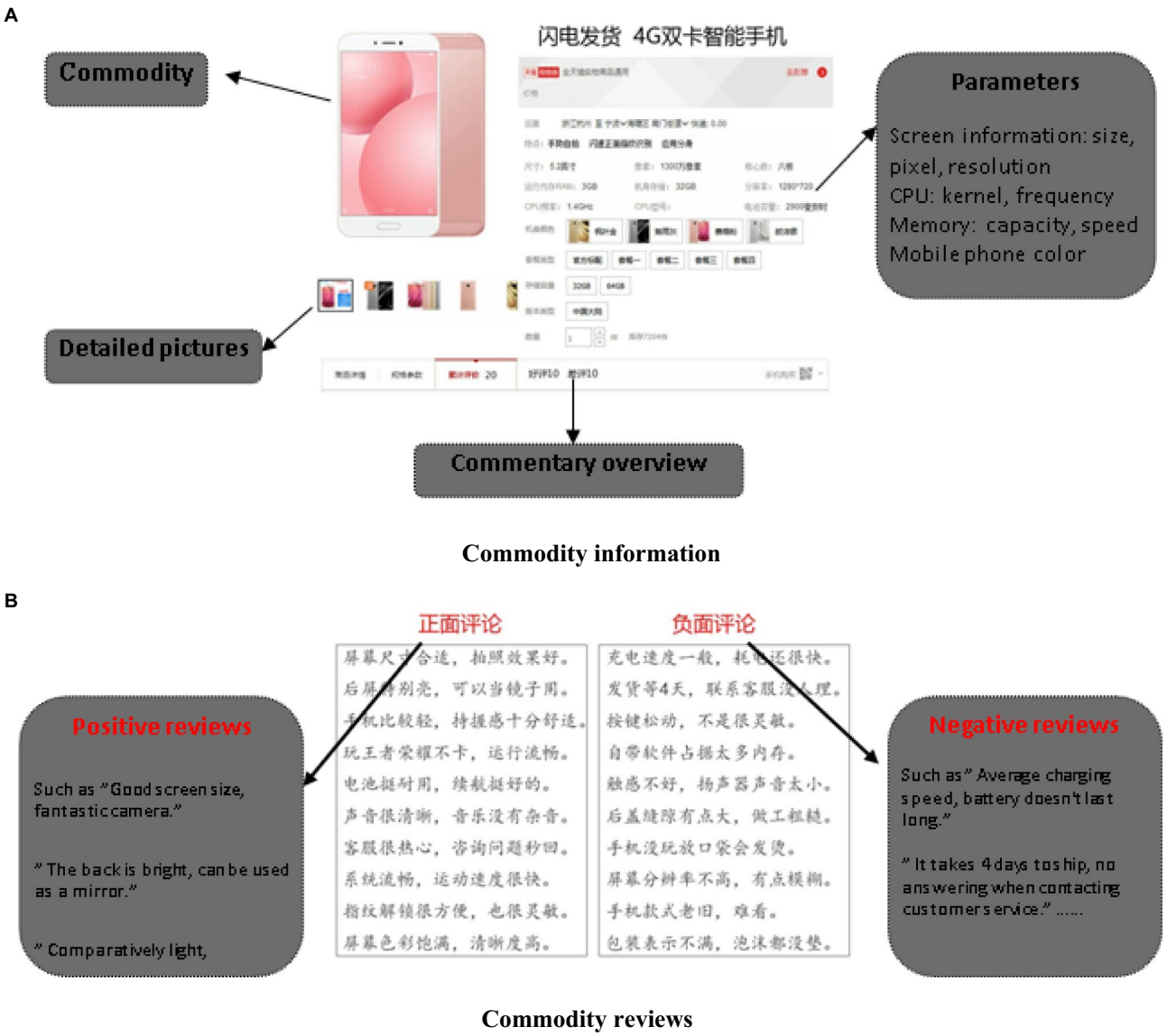

FIGURE 2 | Commodity information and reviews. **(A)** Commodity information, **(B)** Commodity reviews. Screenshots of Alibaba shopfront reproduced with permission of Alibaba and Shenzhen Genuine Mobile Phone Store.

40 positive and 40 negative reviews (one of the negative comments was a fictitious comment, formulated for the needs of the experiment). To increase the number of experiments and the accuracy of the statistical results, four sets of mobile phone products were set up. There were eight pairs of pictures in total.

Procedures

Before the experiment started, subjects were asked to read the experimental guide including an overview of the experiment, an introduction of the basic requirements and precautions in the test, and details of two practice trials that were conducted. When participants were cognizant of the experimental scenario, the formal experiment was ready to begin. Participants were required to adjust their bodies to a comfortable sitting position. The 9 points correction program was used for calibration before the experiment. Only those with a deviation angle of less than 1-degree angle could enter the formal eye movement experiment. In our eye-tracking experiment, whether the participant wears glasses or not was identified as a key issue. If the optical power of the participant's glasses exceeds 200 degrees, due to the reflective effect of the lens, the eye movement instrument will cause great errors in the recording of eye movements. In order to ensure the accuracy of the data recorded by the eye tracker, the experimenter needs to test the power of each participant's glasses and ensure that the degree of the participant's glasses does not exceed 200 degrees before the experiment. After drift correction of eye movements, the formal experiment began. The following prompt was presented on the screen: "you will browse four similar mobile phone products; please make your

FIGURE 3 | Experimental flow diagram. Screenshots of Alibaba shopfront reproduced with permission of Alibaba and Shenzhen Genuine Mobile Phone Store.

TABLE 1 | Results of mean and standard deviations.

	Fixation dwell time (ms)				Fixation count			
	Positive review		Negative review		Positive review		Negative review	
	M	SD	*M*	SD	*M*	SD	*M*	SD
Male	10140.74	6048.38	11057.59	5236.95	45.76	25.91	49.1	20.83
Female	7262.06	4543.37	12334.06	7743.16	36.26	22.22	60.07	35.35
Total	8701.4	5524.34	11695.82	6620.13	41.01	24.53	54.59	29.44

purchase decision for each mobile phone." Participants then had 8,000 ms to browse the product information. Next, they were allowed to look at the comments image as long as required, after which they were asked to press any key on the keyboard and answer the question "are you willing to buy this cell phone?."

In this experiment, experimental materials were displayed on a 17-inch monitor with a resolution of 1,024 × 768 pixels. Participants' eye movements were tracked and recorded by the Eyelink 1,000 desktop eye tracker which is a precise and accurate video-based eye tracker instrument, integrating with SR Research Experiment Builder, Data Viewer, and third-party software tools, with a sampling rate of 1,000 Hz. (Hwang and Lee, 2018). Data processing was conducted by the matching Data Viewer analysis tool.

The experiment flow of each trial is shown in **Figure 3**. Every subject was required to complete four trials, with mobile phone style information and comment content different and randomly presented in each trial. After the experiment, a brief interview was conducted to learn about participants' browsing behavior when they purchased the phone and collected basic information *via* a matching questionnaire. The whole experiment took about 15 min.

Data Analysis

Key measures of data collected from the eye-tracking experiment included fixation dwell time and fixation count. AOI is a focus area constructed according to experimental purposes and needs, where pertinent eye movement indicators are extracted. It can guarantee the precision of eye movement data, and successfully eliminate interference from other visual factors in the image. Product review areas are our AOIs, with positive comments (IA1) and negative comments (IA2) divided into two equal-sized rectangular areas.

Fixation can indicate the information acquisition process. Tracking eye fixation is the most efficient way to capture individual information from the external environment (Hwang and Lee, 2018). In this study, fixation dwell time and fixation count were used to indicate users' cognitive activity and visual attention (Jacob and Karn, 2003). It can reflect the degree of digging into information and engaging in a specific situation. Generally, a more frequent fixation frequency indicates that the individual is more interested in the target resulting in the distribution of fixation points. Valuable and interesting comments attract users to pay more attention throughout the browsing process and focus on the AOIs for much longer. Since these two dependent variables (fixation dwell time and fixation count) comprised our measurement of the browsing process, comprehensive analysis can effectively measure consumers' reactions to different review contents.

RESULTS

The findings are presented in each section including descriptive statistical analysis, analysis from the perspective of gender and review type using ANOVA, correlation analysis of purchasing decisions, and qualitative analysis of observations.

Descriptive Statistical Analysis

Fixation dwell time and fixation count were extracted in this study for each record. In this case, 160 valid data records were recorded from 40 participants. Each participant generated four records which corresponded to four combinations of two conditions (positive and negative) and two eye-tracking indices (fixation dwell time and fixation count). Each record represented a review comment. **Table 1** shows pertinent means and standard deviations.

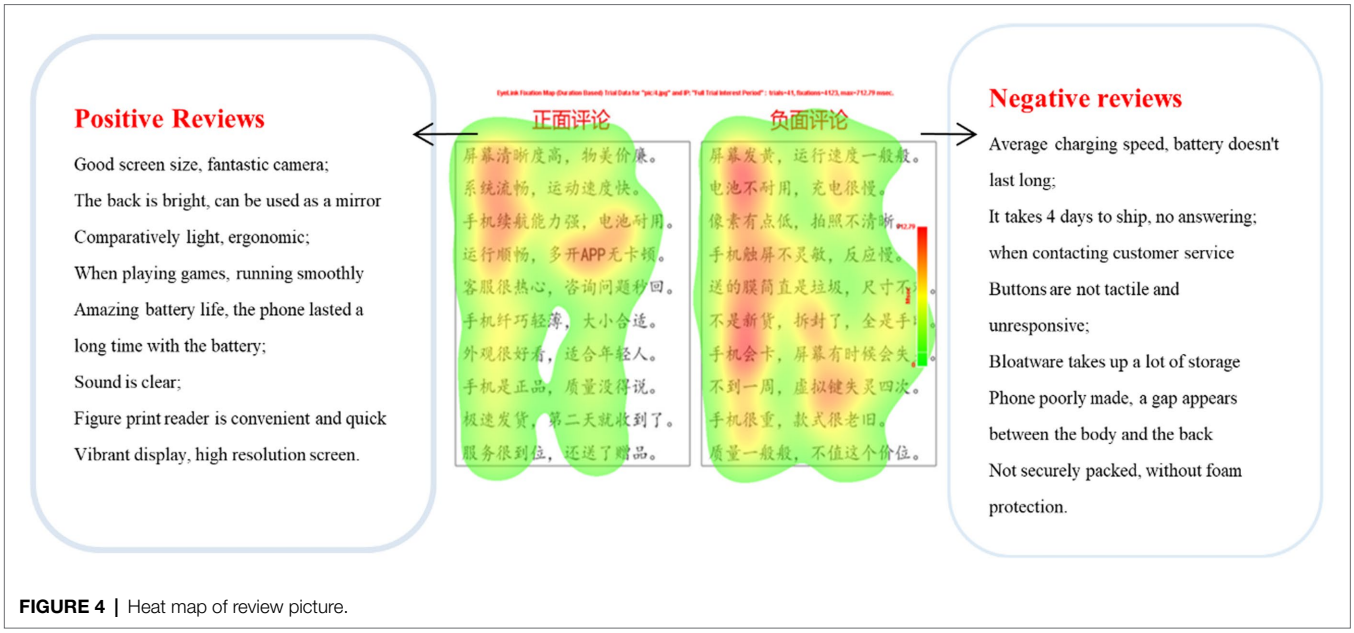

FIGURE 4 | Heat map of review picture.

TABLE 2 | Results of ANOVA analysis.

	Fixation dwell time of AOI		Fixation count of AOI	
	F	Sig. (p_1)	*F*	Sig. (p_2)
Gender	1.42	0.234	0.061	0.805
Review type	19.842*	0.000	20.702*	0.000
Gender & Review type	9.552*	0.002	11.774*	0.001

**Means significant when $\alpha = 0.05$.*

It can be noted from the descriptive statistics for both fixation dwell time and fixation count that the mean of positive reviews was less than that of negative ones, suggesting that subjects spent more time on and had more interest in negative reviews. This tendency was more obvious in female subjects, indicating a role of gender.

Fixation results can be reported using a heat mapping plot to provide a more intuitive understanding. In a heat mapping plot, fixation data are displayed as different colors, which can manifest the degree of user fixation (Wang et al., 2014). Red represents the highest level of fixation, followed by yellow and then green, and areas without color represent no fixation count. **Figure 4** implies that participants spent more time and cognitive effort on negative reviews than positive ones, as evidenced by the wider red areas in the negative reviews. However, in order to determine whether this difference is statistically significant or not, further inferential statistical analyses were required.

Repeated Measures From Gender and Review Type Perspectives—Analysis of Variance

The two independent variables for this experiment were the emotional tendency of the review and gender. A preliminary ANOVA analysis was performed, respectively, on fixation dwell time and fixation count values, with gender (man vs. woman) and review type (positive vs. negative) being the between-subjects independent variables in both cases.

A significant dominant effect of review type was found for both fixation dwell time ($p_1 < 0.001$) and fixation count ($p_2 < 0.001$; see **Table 2**). However, no significant dominant effect of gender was identified for either fixation dwell time ($p_1 = 0.234$) or fixation count ($p_2 = 0.805$). These results indicated that there were significant differences in eye movement indicators between positive and negative commentary areas, which confirms Hypothesis 2a. The interaction effect between gender and comment type was significant for both fixation dwell time ($p_1 = 0.002$) and fixation count ($p_2 = 0.001$). Therefore, a simple-effect analysis was carried out. The effects of different comment types with fixed gender factors and different gender with fixed comment type factors on those two dependent variables (fixation dwell time and fixation count) were investigated and the results are shown in **Table 3**.

When the subject was female, comment type had a significant dominant effect for both fixation dwell time ($p_1 < 0.001$) and fixation count ($p_2 < 0.001$). This indicates that female users' attention time and cognitive level on negative comments were greater than those on positive comments. However, the dominant effect of comment type was not significant ($p_1 = 0.336 > 0.05$, $p_2 = 0.43 > 0.05$) for men, suggesting no difference in concern about the two types of comments for men.

Similarly, when scanning positive reviews, gender had a significant dominant effect ($p_1 = 0.003 < 0.05$, $p_2 = 0.025 < 0.05$) on both fixation dwell time and fixation count, indicating that men exerted longer focus and deeper cognitive efforts to dig out positive reviews than women. In addition, the results for fixation count showed that gender had significant dominant effects ($p_1 = 0.18 > 0.05$, $p_2 = 0.01 < 0.05$) when browsing negative

TABLE 3 | Results of simple-effect analysis.

Fixed factor	*I*	*J*	Fixation dwell time of AOI			Fixation count of AOI		
			Mean difference (I-J)	Standard error	Sig. (p_1)	Mean difference (I-J)	Standard error	Sig. (p_2)
Male	Positive reviews	Negative reviews	−916.85	950.68	0.336	−3.34	4.22	0.430
Female			−5072.00*	950.68	0.000	−23.81*	4.22	0.000
Positive reviews	Male	Female	2878.66*	950.68	0.003	9.50*	4.22	0.025
Negative reviews			−1276.48	950.68	0.180	−10.98*	4.22	0.010

**Means significant when $\alpha = 0.05$.*

TABLE 4 | Frequency statistics of purchasing decisions.

		Whether to buy		Total
		No	Yes	
Review type (more attention)	Positive review	21	25	46
	Negative review	80	34	114
Total		101	59	160

reviews, suggesting that to some extent men pay significantly less cognitive attention to negative reviews than women, which is consistent with the conclusion that men's attention to positive comments is greater than women's. Although the dominant effect of gender was not significant ($p_1 = 0.234 > 0.05$, $p_2 = 0.805 > 0.05$) in repeated measures ANOVA, there was an interaction effect with review type. For a specific type of comment, gender had significant influences, because the eye movement index between men and women was different. Thus, gender plays a moderating role in the impact of comments on consumers purchasing behavior.

Correlation Analysis of Purchase Decision

Integrating eye movement and behavioral data, whether participants' focus on positive or negative reviews is linked to their final purchasing decisions were explored. Combined with the participants' purchase decision results, the areas with large fixation dwell time and concerns of consumers in the picture were screened out. The frequency statistics are shown in **Table 4**.

The correlation analysis between the type of comment and the decision data shows that users' attention level on positive and negative comments was significantly correlated with the purchase decision ($p = 0.006 < 0.05$). Thus, Hypothesis H4 is supported. As shown in **Table 4** above, 114 records paid more attention to negative reviews, and 70% of the participants chose not to buy mobile phones. Also, in the 101 records of not buying, 80% of the subjects paid more attention to negative comments and chose not to buy mobile phones, while more than 50% of the subjects who were more interested in positive reviews chose to buy mobile phones. These experimental results are consistent with Hypothesis H1. They suggest that consumers purchasing decisions were based on the preliminary information they gathered and were concerned about, from which we can deduce customers' final decision results from their visual behavior. Thus, the eye movement experiment analysis in this paper has practical significance.

Furthermore, a significant correlation ($p = 0.007 < 0.05$) was found between the comments area attracting more interest and purchase decisions for women, while no significant correlation was found for men ($p = 0.195 > 0.05$). This finding is consistent with the previous conclusion that men's attention to positive and negative comments is not significantly different. Similarly, this also explains the moderating effect of gender. This result can be explained further by the subsequent interview of each participant after the experiment was completed. It was noted from the interviews that most of the male subjects claimed that they were more concerned about the hardware parameters of the phone provided in the product information picture. Depending on whether it met expectations, their purchasing decisions were formed, and mobile phone reviews were taken as secondary references that could not completely change their minds.

Figure 5 shows an example of the relationship between visual behavior randomly selected from female participants and the correlative decision-making behavior. The English translation of words that appeared in **Figure 5** is shown in **Figure 4**.

The subjects' fixation dwell time and fixation count for negative reviews were significantly greater than those for positive ones. Focusing on the screen and running smoothly, the female participant decided not to purchase this product. This leads to the conclusion that this subject thought a lot about the phone screen quality and running speed while selecting a mobile phone. When other consumers expressed negative criticism about these features, the female participant tended to give up buying them.

Furthermore, combined with the result of each subject's gaze distribution map and AOI heat map, it was found that different subjects paid attention to different features of mobile phones. Subjects all had clear concerns about some features of the product. The top five mobile phone features that subjects were concerned about are listed in **Table 5**. Contrary to expectations, factors, such as appearance and logistics, were no longer a priority. Consequently, the reasons why participants chose to buy or not to buy mobile phones can be inferred from the gazing distribution map recorded in the product review picture. Therefore we can provide suggestions on how

to improve the design of mobile phone products for businesses according to the features that users are more concerned about.

Fictitious Comments Recognition Analysis

The authenticity of reviews is an important factor affecting the helpfulness of online reviews. To enhance the reputation and ratings of online stores, in the Chinese e-commerce market, more and more sellers are employing a network "water army"—a group of people who praise the shop and add many fake comments without buying any goods from the store. Combined with online comments, eye movement fixation, and information extraction theory, Song et al. (2017) found that fake praise significantly affects consumers' judgment of the authenticity of reviews, thereby affecting consumers' purchase intention. These fictitious comments glutted in the purchasers' real ones are easy to mislead customers. Hence, this experiment was designed to randomly insert a fictitious comment into the remaining 79 real comments without notifying the participants in advance, to test whether potential buyers could identify the false comments and find out their impact on consumers' purchase decisions.

TABLE 5 | Top 5 features of mobile phones.

Top	1	2	3	4	5
Features	Running smoothly	Battery life	Fever condition	Pixel	After-sale service

The analysis of the eye movement data from 40 product review pictures containing this false commentary found that only several subjects' visual trajectories were back and forth in this comment, and most participants exhibited no differences relative to other comments, indicating that the vast majority of users did not identify the lack of authenticity of this comment. Moreover, when asked whether they had taken note of this hidden false comment in interviews, almost 96% of the participants answered they had not. Thus, Hypothesis H2b is not supported.

This result explains why network "water armies" are so popular in China, as the consumer cannot distinguish false comments. Thus, it is necessary to standardize the e-commerce market, establish an online comment authenticity automatic identification information system, and crack down on illegal acts of employing network troops to disseminate fraudulent information.

DISCUSSION AND CONCLUSION

In the e-commerce market, online comments facilitate online shopping for consumers; in turn, consumers are increasingly dependent on review information to judge the quality of products and make a buying decision. Consequently, studies on the influence of online reviews on consumers' behavior have important theoretical significance and practical implications. Using traditional empirical methodologies, such as self-report surveys, it is difficult to elucidate the effects of some variables, such as review choosing preference because they are associated with automatic or subconscious

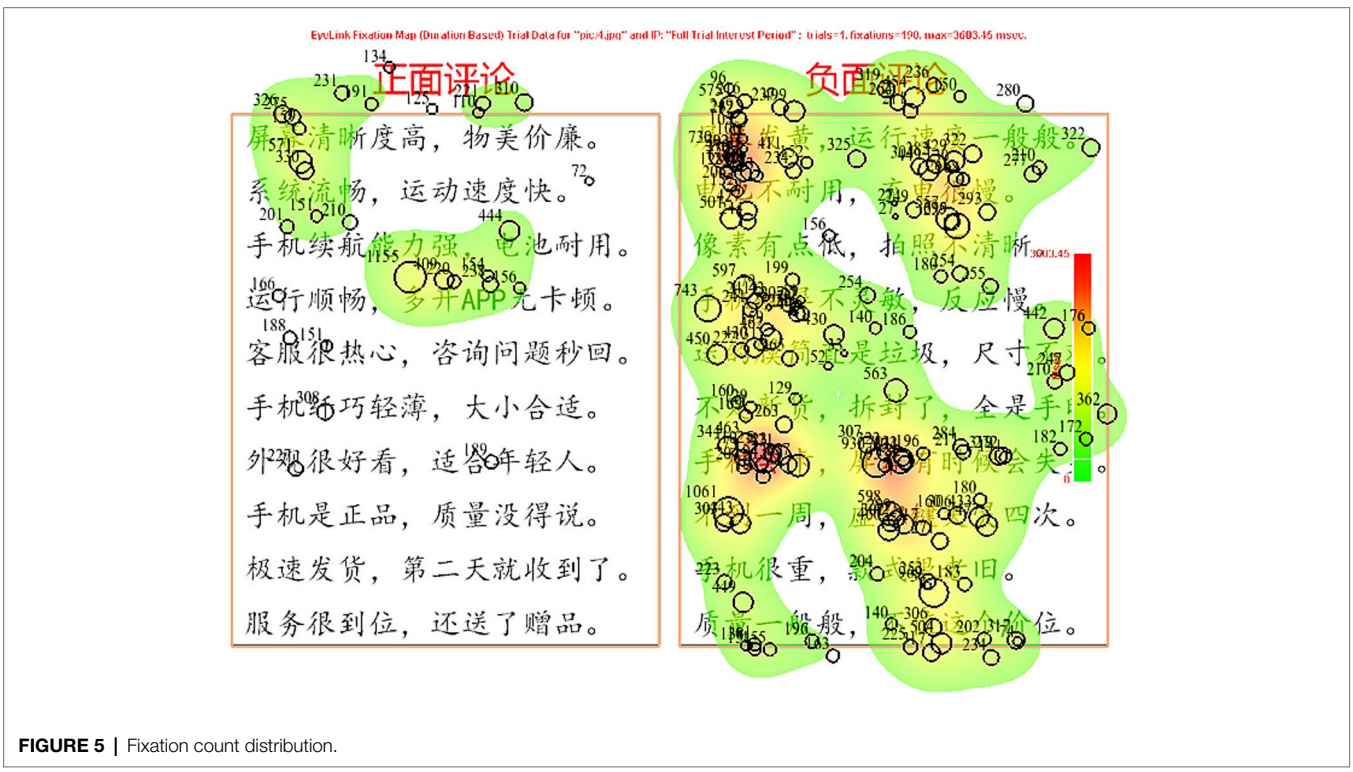

FIGURE 5 | Fixation count distribution.

cognitive processing. In this paper, the eye-tracking experiment as a methodology was employed to test congruity hypotheses of product reviews and explore consumers' online review search behavior by incorporating the moderating effect of gender.

Hypotheses testing results indicate that the emotional valence of online reviews has a significant influence on fixation dwell time and fixation count of AOI, suggesting that consumers exert more cognitive attention and effort on negative reviews than on positive ones. This finding is consistent with Ahluwalia et al.'s (2000) observation that negative information is more valuable than positive information when making a judgment. Specifically, consumers use comments from other users to avoid possible risks from information asymmetry (Hong et al., 2017) due to the untouchability of online shopping. These findings provide the information processing evidence that customers are inclined to acquire more information for deeper thinking and to make a comparison when negative comments appear which could more likely result in choosing not to buy the product to reduce their risk. In addition, in real online shopping, consumers are accustomed to giving positive reviews as long as any dissatisfaction in the shopping process is within their tolerance limits. Furthermore, some e-sellers may be forging fake praise (Wu et al., 2020). The above two phenomena exaggerate the word-of-mouth effect of negative comments, resulting in their greater effect in contrast to positive reviews; hence, consumers pay more attention to negative reviews. Thus, Hypothesis H2a is supported. However, when limited fake criticism was mixed in with a large amount of normal commentary, the subject's eye movements did not change significantly, indicating that little cognitive conflict was produced. Consumers could not identify fake comments. Therefore, H2b is not supported.

Although the dominant effect of gender was not significant on the indicators of the fixation dwell time and fixation count, a significant interaction effect between user gender and review polarity was observed, suggesting that consumers' gender can regulate their comment-browsing behavior. Therefore, H3 is partly supported. For female consumers, attention to negative comments was significantly greater than positive ones. Men's attention was more homogeneous, and men paid more attention to positive comments than women. This is attributed to the fact that men and women have different risk perceptions of online shopping (Garbarino and Strahilevitz, 2004). As reported in previous studies, men tend to focus more on specific, concrete information, such as the technical features of mobile phones, as the basis for their purchase decision. They have a weaker perception of the risks of online shopping than women. Women would be worried more about the various shopping risks and be more easily affected by others' evaluations. Specifically, women considered all aspects of the available information, including the attributes of the product itself and other post-use evaluations. They tended to believe that the more comprehensive the information they considered, the lower the risk they faced of a failed purchase (Garbarino and Strahilevitz, 2004; Kanungo and Jain, 2012). Therefore, women hope to reduce the risk of loss by drawing on as much overall information as possible because they are more likely to focus on negative reviews.

The main finding from the fixation count distribution is that consumers' visual attention is mainly focused on reviews containing the following five mobile phone characteristics: running smoothly, battery life, fever condition of phones, pixels, and after-sales service. Considering the behavior results, when they pay more attention to negative comments, consumers tend to give up buying mobile phones. When they pay more attention to positive comments, consumers often choose to buy. Consequently, there is a significant correlation between visual attention and behavioral decision results. Thus, H4 is supported. Consumers' decision-making intention can be reflected in the visual browsing process. In brief, the results of the eye movement experiment can be used as a basis for sellers not only to formulate marketing strategies but also to prove the feasibility and strictness of applying the eye movement tracking method to the study of consumer decision-making behavior.

Theoretical Implications

This study has focused on how online reviews affect consumer purchasing decisions by employing eye-tracking. The results contribute to the literature on consumer behavior and provide practical implications for the development of e-business markets. This study has several theoretical contributions. Firstly, it contributes to the literature related to online review valence in online shopping by tracking the visual information acquisition process underlying consumers' purchase decisions. Although several studies have been conducted to examine the effect of online review valence, very limited research has been conducted to investigate the underlying mechanisms. Our study advances this research area by proposing visual processing models of reviews information. The findings provide useful information and guidelines on the underlying mechanism of how online reviews influence consumers' online shopping behavior, which is essential for the theory of online consumer behavior.

Secondly, the current study offers a deeper understanding of the relationships between online review valence and gender difference by uncovering the moderating role of gender. Although previous studies have found the effect of review valence on online consumer behavior, the current study first reveals the effect of gender on this effect and explains it from the perspective of attention bias.

Finally, the current study investigated the effect of online reviews on consumer behavior from both eye-tracking and behavioral self-reports, the results are consistent with each other, which increased the credibility of the current results and also provides strong evidence of whether and how online reviews influence consumer behavior.

Implications for Practice

This study also has implications for practice. According to the analysis of experimental results and findings presented above, it is recommended that online merchants should pay particular attention to negative comments and resolve them

promptly through careful analysis of negative comments and customization of product information according to consumer characteristics including gender factors. Based on the findings that consumers cannot identify false comments, it is very important to establish an online review screening system that could automatically screen untrue content in product reviews, and create a safer, reliable, and better online shopping environment for consumers.

Limitations and Future Research

Although the research makes some contributions to both theoretical and empirical literature, it still has some limitations. In the case of experiments, the number of positive and negative reviews of each mobile phone was limited to 10 positive and 10 negative reviews (20 in total) due to the size restrictions on the product review picture. The number of comments could be considered relatively small. Efforts should be made in the future to develop a dynamic experimental design where participants can flip the page automatically to increase the number of comments. Also, the research was conducted to study the impact of reviews on consumers' purchase decisions by hiding the brand of the products. The results would be different if the brand of the products is exposed since consumers might be moderated through brand preferences and brand loyalty, which could be taken into account in future research projects.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

TC conceived and designed this study. TC, PS, and MQ wrote the first draft of the manuscript. TC, XC, and MQ designed and performed related experiments, material preparation, data collection, and analysis. TC, PS, XC, and Y-CL revised the manuscript. All authors contributed to the article and approved the submitted version.

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The Formation Mechanism of Impulse Buying in Short Video Scenario: Perspectives From Presence and Customer Inspiration

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It has been found in many cases that consumers are prone to exhibit impulsive buying behavior that is manifested as being immediate, emotional, and irresponsible especially under short video scenario. Supported by the customer inspiration theory, this study explores the psychological mechanism underlying impulse purchase in short videos that differentiates the traditional web shopping by the strong sense of presence in short video marketing. On the basis of a questionnaire survey and three laboratory experiments, this study examines the relationship among presence, customer inspiration, and impulse purchase intention. The empirical results point to the fact that social presence, co-presence, and physical presence have significant positive effects on impulse purchase intention, and customer inspiration mediates the effect of social presence, physical presence, and co-presence on impulse purchase intention. Furthermore, it is indicated that social and co-presence have stronger influences on impulse purchase intention than physical presence, thus proving a stronger effect of social factors on impulse purchase intention than physical factors in short video environment. The research results testify the impact of presence on consumer behavior in the upgrading short video marketing and provide valuable reference for marketing strategies to shorten consumers' decision-making time in short video purchase.

Keywords: short video, presence, customer inspiration, impulse purchase, social factors

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INTRODUCTION

In 2020, when the short video platforms, users, and advertisers were enjoying the visual and audio banquet of short videos, short video marketing was manifesting a rapid and high-quality development. Short videos have been defined as the videos that are played and pushed with high frequency on various new media platforms. Since the length of these short videos usually ranges from seconds to minutes (Bi et al., 2021), they are featured by mobile and short-term leisure viewing, and endowed with unique marketing value compared with traditional video ads. Short videos incorporate social activities such as liking, commenting, and sharing to content communication (Shen, 2018). Additionally, the preference analysis by platforms of short video enables more accurate searches of target users, more intuitive information of products, and consequently a higher marketing efficiency (Sheng, 2021). According to the statistics of China Internet Network Information Center (CNNIC), by the end of December 2020, the number of independent short video users had reached 873 million, accounting for 88.3% of the domestic

Internet users. Furthermore, with an average of 2-h daily online time, the online duration of short video platforms had surpassed that of instant messaging and become one of the most favorable platforms at an alarming rate (China Internet Network Information Center). On the other hand, based on the tremendous traffic flow of short videos, the "short video + e-commerce" model has been exhibiting an astonishing capacity in directing and guiding shopping since its conception. It is calculated that 56.2% of the short video users have purchased goods and services through short video platforms, 40.9% hold very positive attitude toward short video advertisements and pay constant attention to short video ads in varying degrees (Ding et al., 2021). The same is true in e-commerce shopping platforms. A typical case occurred when "Taobao second floor" launched a short video program "Thousand and One Nights." The sales in only one of the short video episodes such as "Chinese Mackerel Dumplings" has risen 150-fold than other graphic web sales by 10 a.m. of the next day after the launch of the program. In most cases, impulse buying accounts for about 80% in all sales; for such an impulsive behavior, it can be catalyzed by short videos that will enable users to make a purchase decision in a few seconds. The purchasing behaviors of the short video users are usually perceived as being immediate, emotional, and irresponsible because most of them do not have any purchase plan or intention, and are therefore categorized as impulsive buyers.

It can be seen that short video is a powerful marketing tool for the brand owners because of its strong promotion capacity and the large base of the short video users who are very likely to be impulsed to buy something while watching short videos. However, we are still unclear about the specific psychological mechanism of impulsive purchase inspired by short videos in spite of the limited literature on the issue (Gao et al., 2020). For example, Guo found that the value and fit of information content in short video e-commerce has a significant positive impact on users' purchase intention through the mediating effect of users' sense of pleasure and arousal (Guo et al., 2021). Shi also verified the positive effect of usefulness and conveniences of short videos on users' purchase intention (Shi et al., 2021). However, factors such as the content integration, usefulness, conveniences are not exclusive to short videos, but featured by all the traditional static graphic methods. The prior literature, therefore, neither explain why the purchase conversion rate of short video products is 20% higher than that of the graphic mode in traditional e-commerce (Dong, 2019) nor explain why impulse buying is so prevalent when consumers are watching short videos. So, what are the direct causes to consumers' instant purchase behavior when they are exposed to an easy and lifelike experience? These issues are of great importance but have so far not received an adequate attention from the academia.

A short video, which differs from the traditional graphic displaying method mainly by its more powerful visual experience, stronger impact forces, and greater sense of immersion, creates a stronger sense of presence, which is defined as users' real perception of the media environment in which an individual may feel completely immersed, and is thus considered as a crucial factor that determines consumers' online shopping decisions (Li and Hua, 2021). Presence in short videos can significantly affect consumers' willingness to follow the commodities by stimulating their perceptions of value and trust (Cai et al., 2020). Therefore, a high-level presence is one of the most important factors to promote consumer impulse purchase in short video scenario. Customer inspiration is introduced as customers' temporary motivational state that facilitates the transition from the reception of a marketing-induced idea to the intrinsic pursuit of a consumption-related goal (Böttger et al., 2017). Such extrinsic marketing stimuli as presence in short video situations are the decisive factors to spark customer inspiration that is conceived as an important antecedent variable arousing customer purchase intention (Dong, 2020), and whose strong motivational state coincides with an overwhelming urge to buy the consumer goods. In this case, the customer inspiration actually works as a channel to transform the external stimulus to the instant buying behaviors. Consequently, this study, based on the customer inspiration theory, aims to explore whether presence will further affect consumers' impulse purchase intention, and the signaling effect of short video customer inspiration between presence and impulse purchase intention.

THEORETICAL BACKGROUND AND HYPOTHESES

Presence in Short Videos and Impulse Purchase

Hailing from "Tele-presence" in communication studies, the concept of presence mainly refers to an experience remotely perceived in a virtual environment (Bulu, 2012). Scholars classified presence into the following three dimensions: Physical presence, social presence, and co-presence (IJsselsteijn et al., 2000; Bulu, 2012). Physical presence is used to describe an individual's subjective experience of being in an environment when the individual is physically in another. In other words, an individuals' experience in virtual environments is almost the same as in real life (Witmer, 1998). Social presence reflects the degree of salience in the interaction between an individual and others (Parker et al., 1976). In a virtual environment, for example, the individuals perceive the medium of communication and connection to each other and create a sense of "warmth," especially (Hassanein and Head, 2007). With a focus on the psychological connection of minds, co-presence is defined as a sense of "being together" in a virtual environment where individuals perceive the accessibility, availability, and subjection to one another (Goffman, 1963), namely, perceiving others and feeling others are, respectively, actively perceiving us and being part of the group (Bulu, 2012). This study on presence in the field of marketing mainly focuses on virtual shopping centers, online shopping decisions, network community construction, etc. similar to the study by Song et al. (2007) who found that when the consumers are buying clothes online, the perceived presence will stimulate their imagination, thus producing effect on the sense of pleasure in shopping. Hassanein and Head (2007) also indicated that presence could positively affect consumers' perceived usefulness,

TABLE 1 | Impact factors of impulse purchase.

Category	Impact factor	Literature
Marketing incentive	Tactile sense	Peck and Childers, 2003
	Price discount	Hong and Zhe, 2015
	Commodity price	Xiong, 2017
	New product trial	Liu and Fan, 2020
Individual characteristic	Impulse purchase intention	Beatty and Ferrell, 1998
	Shopping pleasure	Dholakia, 2000
	Self-discrepancy of consumers	Luna-Arocas, 2008
	Income	Abratt and Goodey, 1990
	Age	Rawlings et al., 1995
Consumption situation	Normative evaluation	Rook and Fisher, 1995
	Presence of others in shopping	Luo, 2007
	Face threat	Yang et al., 2014
	Authenticity, entertainment and visibility of online live-streaming	Liu et al., 2020
	Sense of power	Liu, 2021

shopping pleasure, and customer confidence. However, these studies have been conducted in web shopping environment that is too plain to exhibit stronger properties of socialization and interactivity produced in short videos which, compared with text and graphics, is more conducive for users to perceive goods and exhibitors, and experience the sense of being together with them. In other words, short video is capable of providing a higher level of presence than the traditional graphic marketing.

Impulse buying refers to an unplanned consumption behavior caused by consumers' immediate and sudden impulse (Kollat and Willett, 1967). Research shows that impulse buying is a common behavior that accounts for about 80% of the total sales (Zhao and Cai, 2014). A review of the previous literature has sought to tease out the impact factors of consumers' impulse buying behavior (**Table 1**), which fall into the following three categories: Marketing incentive, individual characteristics, and consumption situation. Marketing incentive refers to the marketing strategies employed by the distributors to attract consumers (e.g., price cut and product trials). Individual characteristics, on the other hand, is the intrinsic determinants of impulsive buying behavior (e.g., consumer buying tendencies). Consumption situation is described as the environment where the consumption occurs (e.g., whether shopping with others or not). Among the controllable marketing incentives, the offline entity marketing is more applicable to tactile and new product trials. Therefore, new incentives that can motivate consumers' impulsive purchase, other than the price discount, need to be further explored for short videos and other online marketing methods alike.

The previous studies have found that the network marketers are skillful in triggering consumers' sense of "being there" by offering fascinating interactive pictures, imaginative product descriptions, and shopping tips. As a result, a positive attitude toward the commodities is promoted among the consumers who would feel easier to make a purchase decision (Jiang and Benbasat, 2007). Some studies explore the influencing mechanism of "atmosphere cues" in live streaming context on "impulse purchase intention" (Gong et al., 2019), and some other studies focus on impulse purchase behavior based on "situation theory". In either case, these studies confirmed that a remote perception in virtual environments may result in impulse purchase, namely, presence leads to impulse buying (Sheng and Zhao, 2018). According to Bulu (2012), social presence has a positive impact on customer satisfaction in virtual environments where individuals are more easily connected to each other and feel more comfortable, less isolated, and consequently are more contented in informal conversation. In addition, co-presence and physical presence will positively affect customer satisfaction. Specifically, individuals are more likely to be inspired to feel satisfied with the product when they feel they are being together with others and being part of the group in a same virtual space (Thrash and Elliot, 2003). Numerous findings have indicated that customer satisfaction can significantly enhance purchase intention, which implies that social presence, co-presence, and physical presence might produce rapid stimuli to customer purchase intention. In their research on web shopping, Jiang et al. discovered that impulse purchase can be stimulated by high-level presence, in which physical presence indirectly affects the impulsive buying behavior of web shoppers, while social presence has both direct and indirect effects on such behavior (Sheng and Zhao, 2018). Similarly, based on the theory of social presence, Chen's (2011) study proved that embedding social cues in shopping websites can improve social presence, positively affect customer pleasure and trust, and ultimately promote the formation of purchase intention. Actually, in the context of short video online shopping, the interaction between customers and platforms, anchors and other customers will bring customers an immersive sense of "being there". The perceived high-level presence may well expect to raise commodity evaluation, reduce perceived risk, and lift trust and pleasure of the customers (Li et al., 2003)—who, therefore, are apt to nurture an immediate and sudden impulse due to these positive perceptions of commodities. On the basis of these findings, we propose Hypotheses H1a–H1c as follows:

H1a: Social presence has a significant positive effect on impulse purchase intention in short video scenario.

H1b: Co-presence has a significant positive effect on impulse purchase intention in short video scenario.

H1c: Physical presence has a significant positive effect on impulse purchase intention in short video scenario.

Mediating Effect of Short Video Customer Inspiration

Short Video Customer Inspiration and Impulse Purchase

As the explosive development of short video constantly catapulting to become a kingpin in web business, there has been a growing attention in customer psychology and behavior in the

scenario of short video. The relevant researches addressed the questions concerning publication marketing (Xie, 2014; Chen, 2019), tourism destination marketing (Li J. Y. et al., 2019; Liu and Gu, 2019; Sun and Zhang, 2019), sporting event marketing (Zhou et al., 2018), film marketing (Tian, 2019), etc. Although most of the existing studies explored short video transmission mechanism (Zhou et al., 2018; Liu and Gu, 2019; Sun and Zhang, 2019), business model (Wang and Sun, 2018; Dong and Bu, 2019; Wang and Guo, 2019), and opportunities and dilemmas brought by short video (Chen, 2019; Tian, 2019), few of them focused on consumer decision-making problems at the micro level of consumer psychology. Studies found that at the cognitive level, the perceived value in short video would positively affect purchase intention, with users' attitude and participation displaying a significant mediating effect (Wang and Huang, 2019). Comparatively, other studies in terms of experience and emotion revealed a significant positive effect of brand experience in short video apps on user loyalty and brand resonance. Also, brand resonance plays a partial mediating role in the impact of behavioral experience and a complete mediating role in intellectual experience on user loyalty (Jia and Hu, 2019). Moreover, both interactive and creative behaviors in short video are found to have a significant positive effect on perceived value and loyalty (Dai and Gu, 2017). In addition, user attitude toward payment is verified to be positively affected by the visual perception created by the content characteristics and emotional perception by the frequency and quality of interaction in short video (Li P. F. et al., 2019). Findings also showed that virtual haptics and pleasure experienced in short video have a significant positive effect on consumers' purchase intention (Guo et al., 2019). In spite of the limited literature in the short history of short video marketing, recent researches on the consumption decision-making mechanism in short video scenario pointed to one of the major characteristics of consumption behavior as having more "human" factors such as "experience," "resonance," and "interaction" during the purchase journey in short video than in traditional graphic web page.

A recently proposed theory of customer inspiration is the integration of traditional inspiration theory and consumer behavior theory in psychology, which contributes to the study of human factors on state transition from seeking and willing to accept new ideas (in experience, resonance, interaction, etc.) to changing consumption habits (e.g., purchase behavior). Inspiration is conceptualized in classic psychology as a unique state of intrinsic motivation characterized by evocation, transcendence, and motivation in social psychology. Evocation refers to the inspiration triggered by external factors than by the recipient. Transcendence, however, describes recipient's positive sense of self-enhancement. Then, motivation happens on the moment when inspiration induces a state that is close to motivation, where the recipient feels compelled to actualize new ideas (Thrash and Elliot, 2003). Based on the theory of "inspiration" and practice in marketing, Böttger et al. (2017) (Sheng and Zhao, 2018) first introduced the concept of "customer inspiration" that is defined as a temporary motivational state that facilitates a transition from the acceptance of marketing-induced ideas to the pursuit of consumption-related goals. Furthermore, Böttger et al. illustrated a two-states customer inspiration scale that consists of "inspired-by" and "inspired-to" states. "Inspired-by" state is related to customers' reception of marketing-induced concepts (i.e., evocation) and awareness of new possibilities (i.e., transcendence). On the other hand, "inspired-to" state is connected with consumers' intrinsic pursuit of relevant goals (i.e., motivation). In this case, the customers are eager to implement new ideas such as buying or using a new product rather than simply keep the idea in their minds. In other words, the customers will undergo a transition from "being inspired by the idea" to "being inspired to purchase the product" when they are converting acquired purchase inspiration into specific behaviors (Hoffman and Novak, 1996; Thrash and Elliot, 2003). In this study, 'short video customer inspiration' is the specific manifestation of customer inspiration in short video context.

The concept of customer inspiration is proposed to connect the reception of activated new ideas to the pursuit of consumption-related goals, and is conducive to further research on the effect of short video on online marketing. Specifically, how to stimulate customers' instant impulsive purchasing behavior while forcefully locking users' attention in the current ever-shortening customer journey. Customer inspiration is usually characterized as a mediating role to facilitate transition from extrinsic marketing stimuli to customer intention and behavior. It has been found by many scholars that customer inspiration has a mediating effect between variables such as perceived product innovation, product localization, vitality of ads, societal compact, and purchase intention (Dong, 2020; Sheng et al., 2020; Tang and Tsang, 2020). In addition, customer inspiration plays a significant impact on customer behavior; for example, it can mediate inspired content and engaged behaviors (Izogo and Mpinganjira, 2020).

Besides, many studies have found evidence that inspiration may lead to customer impulse buying. For example, a large-scale offline questionnaire survey done by Böttger et al. (2017) revealed that the product descriptions with high inspirational content often trigger consumer purchase impulse, while the analysis by Thrash and Elliot (2003) from the perspective of behavior indicated that inspiration elicits intrinsic motivation to the implementation of a new idea that will determine the ultimate behavior, namely, the "inspire by" state. Moreover, the study by Chen et al. (2009) proved that the flow experience components of inspiration will increase the number of unplanned purchases. In general, customers obtain new ideas through the product information cues offered by the marketers. In this process, customers may experience transcendence toward a new mental state that may stimulate an impulse to pursue a relevant goal which is quickly transformed into a purchasing behavior.

Presence and Customer Inspiration

Applied in the field of marketing, inspiration also supplements some of its features to customer inspiration, such as the evocation of inspiration that is commonly triggered by an external information other than customers' personal experience, common sense, or self-induced need (Dong, 2020). Therefore, customer inspiration in short videos is actually incentivized by

the content in videos. On the other hand, some scholars indicated that a new model that immerses consumers in situations (such as exhibition of product operation, visual search at Pinterest, etc.) can help create rich marketing content that might inspire customers, and thus is conceived as important source of customer inspiration (Böttger et al., 2017). Since immersiveness in situation is the manifestation of the concept of "presence" which describes a remote perceptual experience in virtual or real environment (Shen, 2018), presence may be an important source of inspiration for online customers.

Although no direct literature has been found about the relationship between presence and customer inspiration in virtual shopping scenario, other relative researches can be cited as credence to the implication of the study. On the one hand, some studies have confirmed that customer inspiration includes components of flow experience. For example, Schouten et al. (2007) defined flow experience as feelings acquired by total absorption in an activity, with features such as high concentration, loss of self-awareness, and intrinsic pleasure. They further pointed out that the transcendent customer experience is characterized by emotional intensity, epiphany, singularity, and newness of experience, etc. Therefore, the flow experience can be regarded as a manifestation of inspiration. On the other hand, relevant studies have found that presence in the virtual environment will generate flow experience. The stronger the physical presence and social presence generated by customers, the more likely the customer is to receive the perceptual stimulation in the virtual scene, and the more possible the flow experience is induced (Novak et al., 2000; Schouten et al., 2007; Animesh et al., 2011). In addition, Kim et al.'s (2013) work indicated that a higher degree of co-presence will result in a sense by consumers that they are psychologically closer to their shopping partners, their communication is warmer and friendlier; therefore, their social needs and hedonic value will be satisfied. A high level of hedonic value will deepen the sense of immersion and state of inspiration in terms of concentration. In a study on the relationship between inspirational flow experience and consumption purchase, Chen et al. (2009) found that the consumers' remote perception (presence) affects their flow experience in a significant way. Similarly, an empirical research conducted by Dai and Liu (2015) showed that the social presence of WeChat users has a significant positive impact on flow experience. In summary, short video can effectively inspire the customers by creating a rich marketing content. Specifically, by a higher level of presence, the consumers are more likely to be engaged in the virtual scenario and have a real life-like experience by staying and communicating with network anchors. Consequently, there is greater possibility that consumers will be immersed in short videos and acquire customer inspiration that can ultimately promote the impulse purchase. Accordingly, we propose Hypotheses H2a–H2c as follows:

H2a: Customer inspiration plays a mediating role between social presence and impulse purchase intention in short video scenario.

H2b: Customer inspiration plays a mediating role between co-presence and impulse purchase intention in short video scenario.

H2c: Customer inspiration plays a mediating role between physical presence and impulse purchase intention in short video scenario.

In accordance with the formulated hypotheses, a conceptual model is constructed in this study to show the relationship among presence, short video customer inspiration, and impulse purchase intention (**Figure 1**).

STUDY 1: QUESTIONNAIRE SURVEY ON PRESENCE

Data Collection

Research Samples and Data Sources

This study presents the results of a quantitative analysis of the data collected in a questionnaire survey. The first question is "Have you ever bought something after viewing a short video?" If the response is "No," the respondent can stop his/her survey; but if it is "Yes," the follow-up questions will be answered. In the introduction of the questionnaire, the respondent is prompted to "recall an impressive short video ads and answer the questions"; and at the end of the questionnaire, the respondent needs to answer whether he/she "has bought the product promoted in the short video." Through this part of survey, experienced short video consumers can be selected as the research subject in this study. Before the formal investigation, a pilot study was conducted among the consumers with experience of short video ads in six cities in China. The questionnaire was revised in response to the feedback to ensure the content validity of the scale. Then a formal structured questionnaire was designed on WJX, a professional platform working on questionnaire design and data collection. Thanks to the assistance of marketing research association of Chinese universities, the questionnaire data were collected by the council members of the association in Beijing, Shanghai, Guangdong, Shaanxi, Sichuan, Jiangsu, and other provinces in China. The survey lasted for 1 month and collected a total of 420 questionnaires, of which 41 questionnaires with inconsistent answers or those finished in <2 min were taken as invalid and thus eliminated, and 379 questionnaires were found valid for the final analysis, with an effective recovery rate of 90%.

The demographic characteristics of the subjects are listed in **Table 2**. Age characteristics show that the young consumers are in the majority; those between 18 and 25 years of age are accounting for the highest proportion (63%). The gender characteristics reflect almost equal proportion between male and female, in spite of a slightly higher proportion of female by 2.12%. As to education characteristics, the majority of consumers have higher education qualifications, in which bachelor's degree makes up the highest percentage (57%). In addition, in the characteristics of online shopping times, the largest ratio goes to those whose online shopping times are <6. Finally, the characteristics of monthly income reveal that the low-income group is in large number; those with an income of $<3{,}000$ yuan are accounting for the highest proportion (56%).

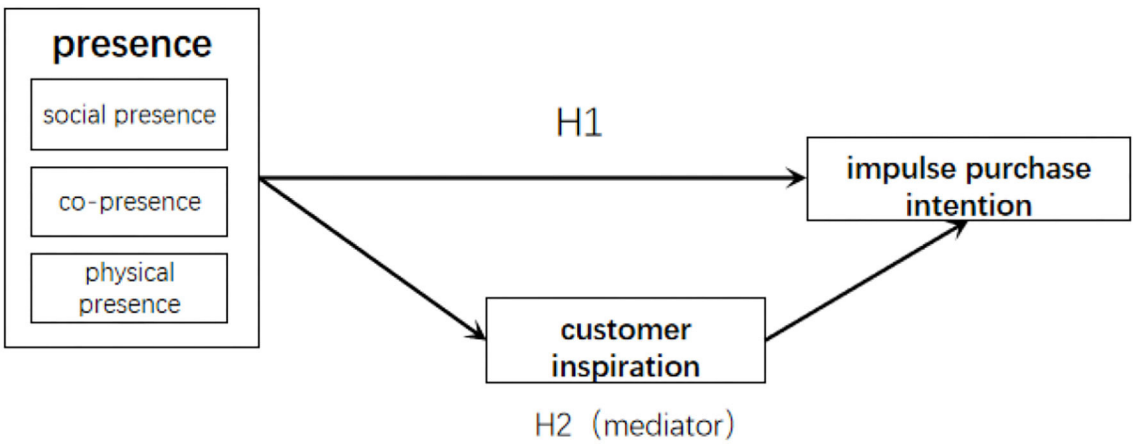

FIGURE 1 | Conceptual model.

TABLE 2 | Sample characteristics.

Characteristics	Category	Percentage	Characteristics	Category	Percentage
Age	0–18	2%	Gender	Male	48.94%
	18–25	63%		Female	51.06%
	26–30	10%	Number of online purchase	0–3	48%
	31–40	19%		4–6	32%
	40+	6%		7–10	9%
Education background	Master degree or above	37%		10+	11%
	Bachelor degree	57%	Monthly	¥0–3,000	56%
	Associate degree	4%		¥3,000–6,000	13%
	High school degree or less	2%		6,000-10,000	18%
				¥10,000	13%
Total					100%

Measurement of Variables

To ensure the reliability and validity of measurement, this study employed the scale derived from the relevant concept of authority and 7-point Likert scale to measure the variables involved. First, to fully depict the concept of presence, we adapted phrasing in the preexisting scales from Klein, Bulu, Hassanein, and Head (Vijayasarathy, 2002; Klein, 2003; Hassanein and Head, 2007). Social presence, co-presence, and physical presence include three items, individually. Second, customer inspiration, in accordance with two-state 10-item scale of customer inspiration by Böttger et al. (2017) can be categorized into the following two dimensions: Cognitive activation and customer intention, namely, the dimension of "inspired-by" and of "inspired-to," each of which contains five items. Third, impulsive purchase intention was measured by a rephrased scale derived from the research of Vijayasarathy (2002); three items involved in the measurement. Furthermore, all translated scales in the questionnaire were back-translated to validate the accuracy of phrasing in each item.

Reliability and Validity Test

Reliability Test

In this study, the reliability of the variables was tested by Cronbach's α coefficient with a threshold of >0.7. The corrected item-to-total correlation coefficients (CITC) were calculated between each item and global item score with statistical significance set at >0.5, as suggested by Churchill. The reliability values of each variable are listed in **Table 3**.

It can be seen from the reliability analysis that the *Cronbach's* α coefficients of all variables in the model are >0.8, and the CITC are >0.7, fully satisfying the criteria that *Cronbach's* α is >0.7 and CITC is >0.5, suggesting that the reliability of the questionnaire and the internal structure consistency of variables are high.

Validity Test

Validity analysis is to test the rationality and validity of the questionnaire. The high validity level indicates that

TABLE 3 | Results of reliability analysis.

Variable	Indicator	Cronbach's α	CITC	Cronbach's α if item deleted
Social presence	sp1	0.878	0.759	0.832
	sp2		0.776	0.817
	sp3		0.758	0.832
Co-presence	cp1	0.845	0.703	0.792
	cp2		0.759	0.737
	cp3		0.674	0.821
Physical presence	pp1	0.878	0.779	0.815
	pp2		0.821	0.778
	pp3		0.698	0.886
Customer inspiration	ci1	0.937	0.742	0.930
	ci2		0.680	0.933
	ci3		0.770	0.929
	ci4		0.725	0.931
	ci5		0.642	0.935
	ci6		0.745	0.930
	ci7		0.786	0.928
	ci8		0.802	0.927
	ci9		0.773	0.929
	ci10		0.790	0.928
Impulse purchase intention	ibm1	0.911	0.705	0.900
	ibm2		0.749	0.895
	ibm3		0.717	0.898
	ibm4		0.691	0.901
	ibm5		0.763	0.893
	ibm6		0.755	0.894
	ibm7		0.726	0.897

the measurement results are in good agreement with the measurement targets. In this study, the rationality and validity of the questionnaire were tested through construct validity (including convergent validity and discriminant validity) that refers to the extent of consistency between the theory and the data. Convergent validity is to assess whether the data of items in one dimension point to the same variable and correlations between different items are high. The discriminant validity refers to the assumption that the items having no correlation with the variables do have no correlation with the variables. Furthermore, the factor analysis was conducted in this study to evaluate the construct validity of the questionnaire.

The Kaiser–Meyer–Olkin (KMO) measure of variables and the Barlett test of sphericity are required before the factor analysis. The KMO statistic is used to test the partial correlation between the variables. Ranging between 0 and 1, a KMO value >0.9 is considered adequate for the factor analysis. On the other hand, Bartlett test of sphericity is used to assess the independence between the variables. The significance of probability (p) is used to judge the adequacy for factor analysis. The results of KMO measure and Bartlett test of sphericity of each variable are listed in **Table 4**.

It can be seen that the KMO values of all variables are >0.7, and the probability p-values of χ^2 in Bartlett test of sphericity

TABLE 4 | Results of KMO measure and bartlett test of sphericity.

	KMO value	KMO criterion	*P*-value in Bartlett Test (sig)
Physical presence	0.715	0.7	0.000
Social presence	0.743		0.000
Co-presence	0.716		0.000
Customer inspiration	0.915		0.000
Impulse purchase intention	0.897		0.000

achieve the criteria of significance, indicating that the factor analysis can be performed.

Convergent Validity Test

In this study, confirmatory factor analysis (CFA) was used to test the convergent validity of the model. The results of the measurement model are listed in **Table 5**. The standard deviation (STD) scores of all latent variables are >0.7; the composite reliability (CR) scores are higher than 0.8; and the scores of average variance extracted (AVE) are >0.5. Therefore, the reported results fulfill the criteria of convergent validity (STD > 0.5; CR > 0.6; AVE > 0.5); thus, suggesting a good convergence validity of the tested model.

Discriminant Validity Test

In this study, the discriminant validity was tested using the method of AVE, in which when the square root of AVE ($\sqrt{AVE}$) obtained from the variables is greater than the correlation coefficient between the variables, the scale has good discriminant validity. It can be seen from **Table 6** that the correlation coefficients between the variables are <0.5 while $\sqrt{AVE}$ of each variable is greater than the correlation coefficient of other variables, which meets the requirements of the discriminant validity test, indicating a good discriminant validity of the scale.

Model Validation Analysis

Main Effect Test and Analysis

Main Effect Test

We used generalized least squares (GLS) method to test the mediating effect by constructing the structural equation model. Model 1, which includes exogenous (co-presence, social presence, and physical presence) and endogenous variables (impulse purchase intention), is to verify Hypotheses H1a, H1b, and H1c. The results are listed in **Table 7**, that social presence, co-presence and physical presence have significant impact on impulse purchase intention. Therefore, H1a, H1b and H1c are all supported.

Main Effect Analysis

It can be seen from the results that the social presence has a significant positive impact on impulse buying intention, which supports Hypothesis H1a and is consistent with conclusions from

TABLE 5 | Convergence validity test of measurement model.

Variable	Indicator	Estimate	S.E.	C.R.	*P*	STD	CR	AVE
Social presence	sp1	1				0.832	0.878	0.7063163
	sp2	0.979	0.065	15.144	***	0.858		
	sp3	0.968	0.065	14.834	***	0.831		
Co-presence	cp1	1				0.788	0.845	0.650988
	cp2	1.152	0.09	12.86	***	0.884		
	cp3	0.998	0.082	12.098	***	0.742		
Physical presence	pp1	1				0.858	0.878	0.7154763
	pp2	1.049	0.062	16.805	***	0.928		
	pp3	0.856	0.061	13.966	***	0.741		
Customer inspiration	ci1	1				0.791	0.937	0.6780494
	ci2	0.961	0.081	12.445	***	0.796		
	ci3	0.926	0.084	12.99	***	0.796		
	ci4	0.964	0.078	11.746	***	0.719		
	ci5	0.933	0.075	11.886	***	0.737		
	ci6	0.992	0.078	10.179	***	0.748		
	ci7	1.238	0.092	13.389	***	0.881		
	ci8	1.261	0.092	13.774	***	0.915		
	ci9	1.285	0.095	13.54	***	0.9		
	ci10	1.329	0.096	13.8	***	0.919		
Impulse purchase intention	ibm1	1				0.734	0.911	0.5935749
	ibm2	1.001	0.079	12.659	***	0.781		
	ibm3	0.974	0.081	12.068	***	0.751		
	ibm4	0.99	0.085	11.686	***	0.719		
	ibm5	1.191	0.092	12.926	***	0.811		
	ibm6	1.108	0.087	12.782	***	0.81		
	ibm7	1.047	0.085	12.337	***	0.782		

****Significant when $p < 0.001$.*

TABLE 6 | Discriminant validity test between variables.

Variable	Social presence	Co-presence	Physical presence	Customer inspiration	Impulse purchase intention
Social presence	**0.8404**				
Co-presence	0.479***	**0.8068**			
Physical presence	0.470***	0.421***	**0.8459**		
Customer inspiration	0.264***	0.293***	0.454***	**0.8234**	
Impulse purchase intention	0.333***	0.406***	0.316***	0.336***	**0.7704**

****Significant when $p < 0.001$, the values on the diagonal in bold are $\sqrt{AVE}$, and the values in lower triangle are Pearson correlation coefficients between the variables.*

the prior studies that social presence directly promotes impulse buying (Jiang et al., 2014). Contrary to the findings of the recent researches, social presence in the form of short video marketing does not result in the information degradation caused by the information overload. The information overload describes the state when information deteriorates because of overabundance of information source (Lin and Liu, 2007; Roetzel, 2019). Increasing the number of redundant information diminishes the marginal line between important and unimportant information when excessive stimuli occur, which might lead to the degradation of information in form of mediocrity (Lin and Liu, 2007; Roetzel, 2019); in other words, the previously important information becomes less important. Comparatively, in spite of the instant exposure of a large amount of visual and auditory information to short video consumers, the information related to social presence plays the same significant role as it does in the traditional web marketing (Jiang et al., 2014)—a direct impact on impulse purchase intention, as shown in the results of this study.

Similarly, the results also suggest that Hypothesis H1b holds true as co-presence has a significant positive impact on impulse

TABLE 7 | Results of main effect calculation and goodness of fit.

Model	Variable		Estimate	S.E.	C.R.	Hypothesis	CMIN/ DF	NFI	RFI	IFI	CFI	RMSEA
	Exogenous	Endogenous										
M1	Social presence	Impulse purchase intention	0.330***	0.079	3.939	H1a	2.706	0.912	0.893	0.943	0.943	0.080
	Co-presence	Impulse purchase intention	0.373***	0.117	3.332	H1b						
	Physical presence	Impulse purchase intention	0.241**	0.112	2.820	H1c						

***Indicates significance level P < 0.01, ***Indicates significance level P < 0.001.*

buying intention. There are two levels in co-presence as follows: One level is to feel the virtual existence of others, that is, to perceive others; the other level is to feel that others are actively perceiving us, or accepting us being part of a group (Slater, 1999). This implies that when consumers perceive being part of the consumer group with others in the virtual world, their impulsive purchase intention may be easily triggered. Therefore, it can be inferred from the light of the conclusion of Hypotheses H1a and H1b that presence of human and social elements (Shi et al., 2021) may be a crucial driver of the consumption impulse in online shopping.

In addition, the findings also support Hypothesis H1c since the direct effect of physical presence on impulsive purchase is significant. However, compared with the findings in Hypotheses H1a and H1b, the direct effect of physical presence on impulsive purchase is significantly smaller than that of social presence and co-presence, which implies that social factors (social presence and co-presence) may produce stronger impact on impulsive purchase than physical factors (physical presence). It also confirms the findings in the prior studies that the most obvious inferiority of e-commerce to traditional face-to-face business is the absence of human feeling (Shi et al., 2021) and interaction (Gefen and Straub, 1997), anonymity and automation (van der Heijden, 2003; Wang and Emurian, 2003), which, to some extent, may impede the online transaction. For these reasons, the approaches to the enhancement of presence in managerial practice such as dynamic graph and 3D display fail to "make a product in vogue" or "create a sales myth" instantly as short videos have done. Another verified conclusion by the findings, as already shown in the previous work, is that physical presence, co-presence, and social presence do not always correlate with each other (Slater et al., 1999; Rui and Wang, 2008).

Mediating Effect Test and Analysis

Mediating Effect Test

Models 2–4 are constructed to test Hypotheses H2a, H2b, and H2c. Model 2 includes social presence (exogenous variable), customer inspiration (mediating variable), and impulse purchase intention (endogenous variable); Model 3 includes co-presence (exogenous variable), customer inspiration (mediating variable), and impulse purchase intention (endogenous variable); and Model 4 physical presence (exogenous variable), customer inspiration (mediating variable), and impulse purchase intention (endogenous variable). Bootstrapping technique and product of coefficients methods were employed to calculate the mediating effect. The results are listed in **Table 8**. Specifically, the non-standard indirect effect of Model 2 shows that $0 <$ lower $<$ upper ($0 < 0.243 < 0.509$) and $z \geq 1.96$, which indicates the existence of the mediating effect; thus, Hypothesis H2a holds. Similarly, in model 3, the non-standard indirect effect shows $0 <$ lower $<$ upper ($0 < 0.260 < 0.586$) and $z \geq 1.96$, indicating a mediating effect, and Hypothesis H2b holds. Finally, the non-standard indirect effect of Model 4 shows $0 <$ lower $<$ upper ($0 < 0.278 < 0.579$) and $z \geq 1.96$, so the mediating effect exists and Hypothesis H2c proves true.

Mediating Effect Analysis

According to the results of this empirical study, inspiration plays a mediating role in the impact of physical presence, social presence, and co-presence on impulse buying, which confirms Hypotheses H2a, H2b, and H2c. As addressed by the previous studies, inspiration is in the position to change views and perceptions (Oleynick et al., 2014; Figgins et al., 2016), and plays a mediating role between antecedent variables and outcome variables (Thrash et al., 2010). Our results verify inspiration as a motivational state that brings ideas to fruition (Oleynick et al., 2014). The obtainment of physical presence, social presence, and co-presence allows consumers to be better informed of the product and imagine its influence on their off-line life (Rauschnabel et al., 2019), which may well lead to an inspiring moment of "Aha" that facilitates a rapid transition of behavior (Böttger et al., 2017). The above conclusion confirms customer inspiration as a key concept in the explanation of consumer behavior (Böttger et al., 2017; Rauschnabel et al., 2019), which is especially important for understanding impulsive purchase behavior in short video context.

Study 1 examines the influencing mechanism of presence on impulse purchase intention by a questionnaire survey. Next, an experimental research was conducted to further testify the robustness and universality of the findings in Study 1. One of the advantages of experimental method is to measure more accurately the two temporary psychological and intentional

TABLE 8 | Results of mediating effect.

Model	Hypothesis	Variable		Effect	Estimates	Product of coefficients		Bootstrapping				Conclusion
		Exogenous	Endogenous					Bias-corrected 95% CI		Percentile 95% CI		
						SE	Z	Lower	Upper	Lower	Upper	
M2	H2a	Social presence	Impulse purchase intention	Total effect	0.589	0.068	8.662	0.460	0.728	0.455	0.725	Social presence→ **Customer inspiration→**
				Indirect effect	0.364	0.068	5.353	0.243	0.509	0.237	0.503	Impulse purchase intention **Mediating effect exists**
M3	H2b	Co-presence	Impulse purchase intention	Total effect	0.702	0.078	9.000	0.553	0.860	0.547	0.857	Co-presence→ **Customer inspiration→**
				Indirect effect	0.410	0.084	4.881	0.260	0.586	0.257	0.583	Impulse purchase intention **Mediating effect exists**
M4	H2c	Physical presence	Impulse purchase intention	Total effect	0.557	0.069	8.072	0.418	0.693	0.423	0.700	Physical presence→ **Customer inspiration→**
				Indirect effect	0.411	0.076	5.408	0.278	0.579	0.276	0.573	Impulse purchase intention **Mediating effect exists**

variables, customer inspiration, and impulse purchase intention in short video scenario. On the other hand, the causal relationship between presence and impulse purchase intention can be validated. The experiment in this study consists of a pilot study and three experimental studies. The pilot study is to test whether the selected short video material would successfully stimulate presence of the subject. Studies 2, 3, and 4, respectively, examine the main effects of social presence and physical presence on impulse purchase intention, and the mediating effects of customer inspiration.

PILOT STUDY: PRETEST

Manipulation Materials for Presence

A pretest was conducted in this study to verify the validity of presence manipulation in the experiment. As already known, social presence highlights the sense of communication and interaction with others in the media environment; co-presence refers to a sense of being together with others in the shared space (Horvath and Lombard, 2010); and physical presence addresses a sense of immersion and realism of the virtual environments (Bulu, 2012). Accordingly, two marketing experts and a team of graduate students worked together to script and shoot three groups of short videos, namely, Groups A, B, and C, respectively, to trigger social, physical, and co-presence. We selected fascia gun, hoodie, and office chair as the objects introduced in the three groups of videos. Each group had two videos (e.g., A1 and A2) which should maintain consistent in the introduction of properties of product such as appearance, material, and function, but different in stimulation of presence. For example, video A1 performed better than video A2 in terms of communication and interaction, that is, A1 could trigger high social presence while A2 could trigger low social presence. Similarly, video B1 generated higher sense of being together than video B2. So, videos B1 and B2 stimulated high and low co-presence, respectively. Since video C1 evoked more sense of immersiveness than video C2, high and low physical presence were stimulated, respectively.

Manipulation Test

Sixty subjects were recruited on the Credamo platform, including 16 males and 44 females, who were randomly divided into two groups, and asked to watch videos A1 and A2. Afterward, they were required to fill out the questionnaire for social presence. Independent sample *t*-test shows that the social presence triggered by watching video A1 ($M_{highsocialpresence} = 4.88$, SD = 1.40) is significantly higher than that by video A2 [$M_{lowsocialpresence} = 3.12$, SD = 1.82; $t(58) = 4.20$, $p = 0.000$]. So, the manipulation on social presence was successful.

Likewise, another 60 subjects, 17 males and 43 females, were recruited on the Credamo platform and randomly divided into two groups. After watching videos B1 and B2, their co-presence was measured by the relevant questionnaire. Independent sample *t*-test indicates that the co-presence ($M_{highco-presence} = 4.80$, SD = 1.26) produced by watching video B1 is significantly higher

FIGURE 2 | A1 Screenshot of high social presence.

FIGURE 3 | A2 Screenshot of low social presence.

than that produced by video B2 [$M_{lowco-presence} = 4.02$, SD $= 1.21$; $t(58) = 2.43$, $p = 0.018$]. Thus, the manipulation of co-presence was successful.

The same procedure was repeated by the researchers to recruit another 60 participants (26 males and 34 females) on the platform as the subjects of test on physical presence. Also, they were divided into two groups, and watched videos C1 and C2, respectively. Consequently, the independent sample *t*-test of the data from physical presence questionnaire shows that video C1 ($M_{highphysicalpresence} = 5.12$, SD $= 1.40$) triggers higher physical presence than video C2 does [$M_{lowphysicalpresence} = 4.22$, SD $= 1.21$; $t(58) = 2.66$, $p = 0.010$], so the physical presence was successfully manipulated.

STUDY 2: EXPERIMENT ON SOCIAL PRESENCE

Study 2 aims to verify the positive impact of social presence on impulse purchase intention in short video context and the mediating effect of customer inspiration.

Experimental Design

Videos in Group A in the pretest were selected as the short video material in Study 2. Based on the experimental procedure suggested by Rook and Fisher (1995), a single-factor experiment on social presence (high *vs.* low) was designed as follows:

Experimental situation: You are going to buy a pair of socks online.

Financial condition: Currently your spare money for living is 500 yuan, and still have 5 days to go before the 2000 yuan for living expenses next month added to your account.

Shopping discovery: You are to buy socks introduced in a short video before you happen to see another video about a fascia gun, a kind of vibration massage device to relax muscles. You have been longing to have such a gun, and the present discount price for sales is 299 yuan.

The fascia guns in video A1 and video A2 were exactly the same in properties such as appearance, material, and price, but

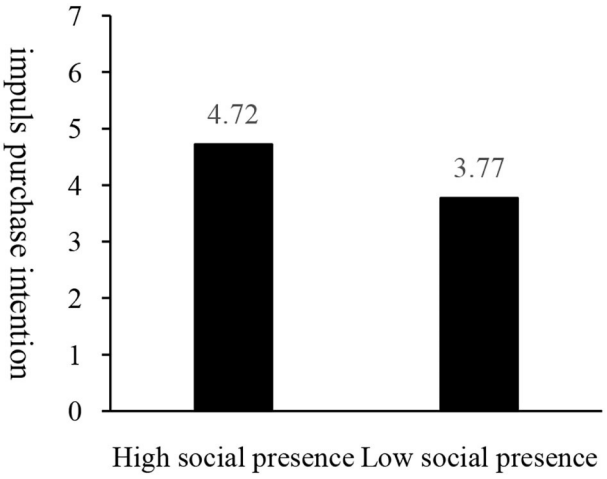

FIGURE 4 | Impact of social presence on impulse purchase intention.

the anchor showed better communication skills in A1 than in A2. Therefore, A1 tended to motivate high social presence, while A2 low social presence. The financial constraints were designated in this scenario to highlight the conflict so that the seduced buying behavior in case of a shortage in cash can be confidently identified as impulsive purchase.

Experimental Procedure

A total of 150 participants (62 males and 88 females) recruited on the Credamo were randomly arranged to watch videos A1 and A2 after reading the condition described in Study 2 (screenshots of videos A1 and A2 are shown in **Figures 2**, **3**). Then the researchers measured their social presence, perceived customer inspiration, and impulse purchase intention. The measurement items on impulse purchase intention were adapted from Yong et al. (2013): "While watching the video, even if the fascia gun is not in my shopping list, I have an impulsive buying desire, I want to buy it, and I am inclined to buy it." Other items in the questionnaire were kept consistent with the previous ones in this study. Additionally, the participants needed to answer a question to see whether they have watched the entire video so that the eligible questionnaires could be sorted out. Finally, questions concerning demographic information including gender, age, education, the average monthly frequency of short video shopping were answered by the participants.

Experimental Results Analysis

Social Presence Manipulation Test

We first tested whether videos A1 and A2 successfully stimulate social presence of the subjects. It is shown by a one-way analysis of variance (ANOVA) that social presence triggered by video A1 ($M_{highsocialpresence} = 4.65$, SD = 1.31) is significantly higher than that by video A2 [$M_{lowsocialpresence} = 3.45$, SD = 1.57; $F_{(1, 148)} = 26.410$, $p = 0.000$]. The significant difference indicates a success of manipulation on social presence.

Main Effect Test

The ANOVA results show a significant higher impulse purchase intention in the group with high social presence ($M_{highsocialpresence} = 4.72$, SD = 1.57) than that with low social presence [$M_{lowsocialpresence} = 3.77$, SD = 1.64; $F_{(1, 148)} = 13.264$, $p = 0.000$] as shown in **Figure 4**, indicating a significant main effect of social presence on impulse purchase intention, thus Hypothesis H1a being verified.

Mediating Effect Test

A one-way ANOVA with customer inspiration as dependent variable indicates that customer inspiration of the high social presence group ($M_{highsocialpresence} = 4.83$, SD = 1.29) is significantly higher than that of the low social presence group [$M_{lowsocialpresence} = 4.02$, SD = 1.45; $F_{(1, 148)} = 13.057$, $p = 0.000$]. Then the mediating effect of customer inspiration was tested by Bootstrapping. In specific, Bootstrap procedure was performed with 5,000 samples on model 4 in which social presence was assessed as independent variable, impulse purchase intention as dependent variable, and the customer inspiration as mediating variable. The results show that the mediating effect of customer inspiration is significant (0.6428) when the 95% confidence interval does not contain 0 (LLCI = 0.4925, ULCI = 0.8020), which verifies Hypothesis H2a that the customer inspiration plays a mediating role in the impact of social presence on impulse purchase.

STUDY 3: EXPERIMENT ON CO-PRESENCE

Study 3 aims to verify the positive impact of co-presence on impulse purchase intention in short video context and the mediating effect of customer inspiration.

Experimental Design

Videos in Group B in the pretest were used as the materials in Study 3. A single-factor experiment on co-presence (high vs. low) was constructed.

Experimental situation: You are going to buy a pair of socks online.

Financial condition: Currently your spare money for living is 500 yuan, and still have 5 days to go before the 2000 yuan for living expenses next month added to your account.

Shopping discovery: You are to buy a pair of socks introduced in a short video before you happen to see another video about a hoodie that is really a kind of your favorites, and the present discount price for sales is 256 yuan.

The experimental design was identical to that of Study 2. In spite of the consistency of the basic properties of hoodies in videos B1 and B2, the short video anchor showed a better sense of togetherness in video B1 than in video B2. That is, video B1 stimulated high level of co-presence while B2 low level.

Experimental Procedure

A total of 150 participants were recruited on the Credamo platform, including 61 males and 89 females. After reading the experimental condition in Study 3, they were randomly exposed

FIGURE 5 | B1 Screenshot of high co-presence.

FIGURE 6 | B2 Screenshot of low co-presence.

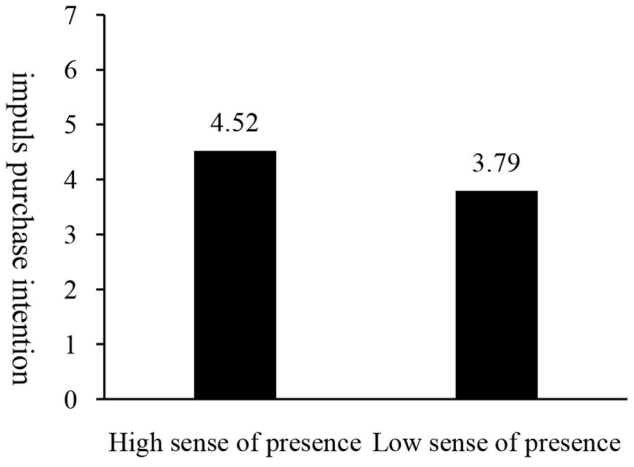

FIGURE 7 | Impact of co-presence on impulse purchase intention.

to videos B1 or B2 (screenshots of videos B1 and B2 are shown in **Figures 5**, **6**). The participants' impulse purchase intention, as well as their perceived co-presence and customer inspiration were measured sequentially afterward. All measurement items were the same as in Study 2. Similarly, a question about the short videos watched in Study 3 and questions about the demographic information of the subjects were also included in the questionnaire.

Experimental Results Analysis

Co-presence Manipulation Test

We firstly tested whether videos B1 and B2 successfully inspire the subjects' co-presence. A one-way ANOVA shows that the level of co-presence stimulated by video B1 ($M_{highco-presence} = 5.23$, SD = 1.01) is significantly higher than that by video B2 [$M_{lowco-presence} = 3.40$, SD = 1.44; $F_{(1, 148)} = 49.85$, $p = 0.000$], indicating that the manipulation on co-presence was successful.

Main Effect Test

ANOVA indicates that the impulse purchase intention ($M_{highco-presence} = 4.52$, SD = 1.48) in high co-presence group is significantly higher than that in the low co-presence group ($M_{lowco-presence} = 3.79$, SD = 1.54; $F_{(1, 148)} = 8.71$, $p = 0.004$). As shown in **Figure 7**, thus, the main effect of co-presence on impulse buying intention is significant, and Hypothesis H1b verified.

Mediating Effect Test

First, one-way ANOVA was performed with customer inspiration as the dependent variable. The result shows that the customer inspiration ($M_{highco-presence} = 4.69$, SD = 1.12) in the high co-presence group is significantly higher than that in the low co-presence group [$M_{lowco-presence} = 4.02$, SD = 1.38; $F_{(1, 148)} = 10.72$, $p = 0.001$]. The mediating effect of customer inspiration was then tested by Bootstrapping with 5,000 samples on model 4 considering co-presence as independent variable, impulse purchase intention as dependent variable, and customer inspiration as mediating variable. The result indicates that the effect of mediation was significant (0.6126) if the 95% confidence interval does not contain 0 (LLCI = 0.4446, ULCI = 0.7884), which again verifies Hypothesis H2b, namely, customer inspiration acts a mediating role in the impact of co-presence on impulse purchase.

STUDY 4: EXPERIMENT ON PHYSICAL PRESENCE

Study 4 aims to verify the main effect of physical presence on impulse purchase intention and the mediating effect of customer inspiration in short video context.

Experimental Design and Procedure

Videos in Group C in the pretest were used as the materials in Study 4, and a single-factor experiment on physical presence (high *vs.* low) was adopted. The features of the office chairs introduced in videos C1 and C2 maintained consistent, although video C1 could more effectively arouse the sense of immersiveness than video C2. Thus, it can be asserted that video C1 and C2 stimulated high and low physical presence, respectively. A total of 160 participants recruited on the Credamo platform, including 71 males and 89 females, watched the videos and answered the questionnaire identical to that in Study 3. Screenshots of videos C1 and C2 are shown in **Figures 8**, **9**.

Experimental Results Analysis

Physical Presence Manipulation Test

Likewise, stimulation test on physical presence was conducted on the subjects after they had watched videos C1 and C2. A one-way ANOVA shows that the physical presence inspired by video C1 ($M_{highphysicalpresence} = 4.71$, SD = 1.24) was significantly higher than that by video C2 [$M_{lowphysicalpresence} = 4.12$, SD = 1.27; $F_{(1, 158)} = 8.78$, $p = 0.004$]. Such a significant difference indicates a success of manipulation on physical presence.

Main Effect Test

The ANOVA test shows a higher intention of impulse purchase in the high physical presence group ($M_{highphysicalpresence} = 4.29$, SD = 1.66) than in the low physical presence group [$M_{lowphysicalpresence} = 3.60$, SD = 1.67; $F_{(1, 158)} = 6.82$, $p = 0.010$]. As shown in **Figure 10**, therefore, the main effect of physical presence is significant and Hypothesis H1c verified.

Mediating Effect Test

First, one-way ANOVA was conducted with customer inspiration as the dependent variable. It is shown that customer inspiration of the high physical presence group ($M_{highphysicalpresence} = 4.53$, SD = 1.40) is significantly higher than that of the low physical presence group [$M_{lowphysicalpresence} = 3.91$, SD = 1.52; $F_{(1, 158)} = 7.04$, $p = 0.009$]. Second, the mediating effect of customer inspiration was analyzed by Bootstrapping with 5,000 samples on model 4, taking physical presence as independent variable and impulse purchase intention as dependent variable. The result confirms a significant mediating effect (0.8653) when the 95% confidence interval does not contain 0 (LLCI = 0.7348, ULCI = 1.005), which verifies Hypothesis H2c that customer inspiration plays a mediating role in the impact of physical presence on impulse buying.

FIGURE 8 | C1 Screenshot of high physical presence.

FIGURE 9 | C2 Screenshot of low physical presence.

CONCLUSION AND IMPLICATION

Conclusion

This study focuses on the psychological mechanism of impulsive purchase in short video. Through a questionnaire survey and three situational experiments, the study tests the relationship among presence, short video customer inspiration, and impulse purchase intention. The empirical results show that the following:

(1) Social presence, co-presence, and physical presence have significant positive impacts on impulsive purchase intention.
(2) Customer inspiration plays a mediating role in the impact of physical, social, and co-presence on impulsive purchase.
(3) Social and co-presence have a stronger impact on impulse purchase intention than physical presence, which confirms that social factors produce stronger influence on impulsive purchase in short video environment than physical scenes.

Implications for Theoretical Field

"Short video + e-commerce" has presented a comparatively better capacity to guide shopping and marketing than graphs and text in traditional e-business. However, the previous studies on consumer purchasing decision in short video context neither clearly explain why the purchase conversion rate of short video is much higher than that of graphic mode nor clearly explain the psychological mechanism of impulsive purchase. For these reasons, this study, based on the theory of presence—a core difference between short video and traditional graphic displaying, tends to explore from the perspective of customer inspiration the specific mechanism in which the extrinsically stimulated motivation can be transformed to an instant purchasing behavior. It contributes to the theoretical field in the following two aspects:

(1) By testing the direct effect of presence—namely, social presence, co-presence, physical presence—on impulse purchase in short videos, the study validates the effect of "presence," a traditional e-commercial element, on consumer behavior in the booming short video marketing environment. The findings suggest that social presence, co-presence and physical

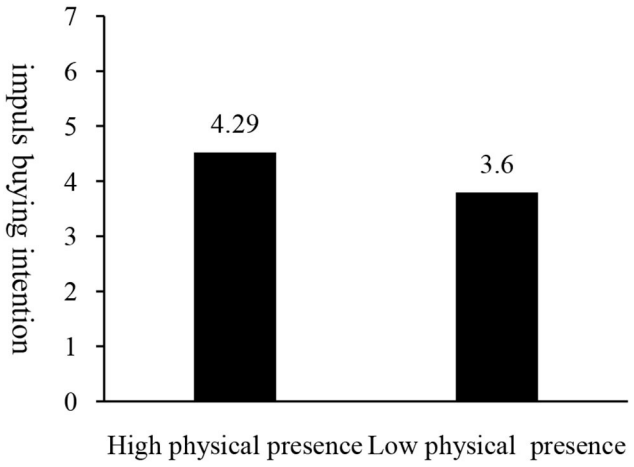

FIGURE 10 | Impact of physical presence on impulse purchase intention.

presence have significantly positive impacts on impulse purchase intention, but the influence coefficient indicates social factors (co-presence and social presence) produce stronger impact on impulse purchase than situational factors (physical presence) in short video context, and thus supporting the prior studies in that the roles of physical presence, co-presence and social presence do not always correlate (Slater et al., 1999; Rui and Wang, 2008).

(2) This study depicts the mediating mechanism of customer inspiration between presence and customer impulse purchase in the context of short video marketing. It is apparent that short videos create a better user experience with rich and dimensional content than the traditional displaying methods such as text and graphs. The behavioral shift from being attracted to being impulsed to buy, however, requires psychological motivation. Customer inspiration involves the motivation to expand the qualities embodied in the summoned object (Thrash and Elliot, 2003). Therefore, this study innovatively introduces the concept of customer inspiration to analyze the impulse buying behavior of short video viewers. It is shown in the findings that customer inspiration mediates the impact of physical, social and co-presence on impulse purchase, which demonstrates the significance of customer inspiration in the short customer journey from "being inspired by" to "being inspired to" under short video marketing scenario. It confirms that inspiration, as noted in many studies, is an emerging and promising key construct in marketing research that can be applied to further interpretation of consumer behavior (Böttger et al., 2017; Rauschnabel et al., 2019).

Implications for Marketing Practice

In short video e-commercial mode, consumers are allowed to place their orders in the purchase page while they are watching the short video. Such an "check out" mode successfully facilitates the transition from customer inspiration evoked by sense of presence in short videos to a temporary buying behavior. The short video ads can be very effective to this transition especially when they are perceived with a higher degree of involvement and immersion. The official statistics from Taobao revealed a 20% higher purchase conversion rate by short videos than the traditional graphic mode (Dong, 2019), and the annual advertising revenue of TikTok was estimated to amount to 20 billion yuan in 2018.

Implications for Consumers

Since social presence, co-presence and physical presence produce significant positive impacts on impulsive purchase intention, as indicated by the results, consumers who are watching short videos are suggested to raise their purchase rationality and make reasonable decision in line with their actual needs and purchasing power, which is especially true when there is such high interactivity between short video anchor and audiences as conversational or responsive communication, explosion of likes or comments, and other similar situations.

Implications for Short Video Anchors and Brand Owners

It is suggested to increase presence of consumers by enhancing their viewing experience with smooth pictures and lifelike features, so that the time for decision-making can be effectively reduced and the purchase conversion rate thus improved. More precisely, the enhancement of physical, social, and co-presence in short video will elicit customer inspiration that can be converted into buying behavior over a short period of time. Therefore, technologies such as virtual and augmented reality (Rauschnabel et al., 2019), digital signage, and online tools (Böttger et al., 2017) could be used in the production of short videos to create quasi-reality experience for consumers and thus increase physical presence. Similarly, social elements could be inserted to short videos through immersive visual content and interactive expressions to increase social and co-presence that can inform customers with better knowledge about the product, enrich their imagination on its practical uses, stimulate customer inspiration, and facilitate actual conversion from an idea to purchasing behavior.

LIMITATIONS AND FUTURE RESEARCH

In spite of the contributions, this study has several limitations. First, this study explores the effects of short video (short video presence) on customer inspiration and impulsive purchase intention based on the previous theories on inspiration and characteristics of short video. Unfortunately, despite the antecedents of customer inspiration, other possible drivers of customer inspiration deserve further research that would possibly bring new insight to short video marketing. Second, the this study mainly focuses on the behavioral outcomes from customer inspiration, but lays little emphasis on the impact of customer inspiration on emotion and attitude. Future research could investigate the relationship between customer inspiration and existing marketing constructs (e.g., the effect of customer inspiration on satisfaction and loyalty). Third, this study does not explore the boundary conditions for customer inspiration in short video. Although the prior studies once

suggested the moderating effect of inspiration recipient's traits on customer inspiration, it is still not clear what and how the specific traits of the recipient will moderate inspiration in short video context.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

PG: conceptualization, methodology, writing—review and editing, supervision, funding acquisition, and writing—original draft. YZ: investigation and resources. YC: data curation and visualization. All authors contributed to the article and approved the submitted version.

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When the Counterpart Chooses the Opposite: The First Mover's Anticipation and Evaluation of the Final Feedback in Gambles

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This research examines the effect of response (in)consistency on the first mover's anticipation and evaluation of the performance feedback in gambles. In a two-player gambling task, the participant played as the first mover while the confederate served as the second mover, who made their gambles in sequence. A more pronounced feedback-related negativity (FRN) was observed when the first mover noticed that the second mover chose a different option from him/her. An enlarged stimulus-preceding negativity (SPN) was observed when the first mover was anticipating the final feedback in this condition. Interestingly, consistent responses gave rise to a more pronounced FRN difference wave (d-FRN) during the feedback stage. Taken together, these results suggest that response discrepancy would modulate the first mover's anticipation and evaluation of the final feedback in gambles.

Keywords: social information, choice inconsistency, anticipation, outcome evaluation, event-related potentials (ERP), feedback-related negativity (FRN), stimulus-preceding negativity (SPN)

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INTRODUCTION

During our social interactions with others in daily lives, we receive varied social information, such as others' viewpoints, behaviors and so on. Social information is ubiquitous, which heavily influences one's thinking and actions. Imagine you are visiting a popular cake store, which is promoting two kinds of blind boxes. Given the high uncertainty, it is difficult to figure out which box contains the more delicious cake. You decided to buy one of the two blind boxes and made your choice by yourself, after which you happened to learn about the choice of another customer. How would you feel if you found that his or her decision was different from yours? Would this social information of choice inconsistency influence your subsequent cognitive reactions to the decision outcome (i.e., whether your cake was yummy and to your taste)? These questions are attracting researchers' attention but have not been fully resolved in existing literatures.

On the one hand, some previous research has examined the influence of social information on one's behaviors and the neural mechanisms underlying one's evaluation of such social information. It was found that when individuals find out that they provide an inconsistent choice with others, a negative signal in the brain would be generated, which would guide them to perform subsequent

behaviors in a certain manner, such as showing conformity (Klucharev et al., 2009; Campbell-Meiklejohn et al., 2010; Schnuerch and Gibbons, 2014). For example, Klucharev et al. (2009) conducted a facial attractiveness judgment task, and found that when individuals find their own opinion to be different from the group's, they would change their own rating in the direction of the group's rating. Thus, consistent social information is generally regarded as a reward signal (Campbell-Meiklejohn et al., 2010; Zaki et al., 2011), while social information on inconsistency with others may bring about emotional and cognitive conflicts (Klucharev et al., 2011; Yu and Sun, 2013). This conflict would be processed as a negative feedback and then reflect in the magnitude of the feedback-related negativity (FRN) (Wang et al., 2019; Zheng et al., 2021). In early studies the valence effect on FRN was demonstrated mainly in studies adopting monetary rewards tasks (Gehring and Willoughby, 2002; Yeung and Sanfey, 2004; Liao et al., 2011; San Martín, 2012), with the loss condition eliciting a larger FRN than the gain condition (Yu et al., 2007; Ma et al., 2011; Wang Y. et al., 2016; Qi et al., 2018). In recent years, more and more studies found FRN to be sensitive to the inconsistency in social information. For example, in a recent study, the researchers asked two anonymous same-sex players to work on a knowledge quiz task, and found that inconsistent answers with the partner make the participants feel more uncertain about their own responses, resulting in a larger FRN (Wang et al., 2018). Similarly, Zheng et al. (2021) modified the task of Klucharev et al. (2009) by introducing the crowdfunding context and found that deviation of the individual rating from the group rating evokes a significantly more negative FRN. Given that the above findings are illuminating, most existing studies examined the (in)consistency effect by comparing one's behavior or opinion with the whole group's. However, whether consistency between paired individuals would produce a similar social influence needs further examination.

On the other hand, some researchers resorted to the FRN to examine whether the consistency in choices would affect the evaluative processing of decision outcomes (Yu et al., 2007; Kimura and Katayama, 2013; Fu et al., 2017; Kimura et al., 2018). For example, Kimura et al. (2018) found that consistent choices with the group in a cooperative context elicit a smaller d-FRN (FRN $_{loss}$ minus FRN $_{gain}$) than inconsistent choices. Since all participants' choices contribute to and determine each one's outcome in a cooperative context, the researchers attributed this result to the diffusion of responsibility for the outcome, which makes the outcome less relevant to each participant and decreases the motivational value of the outcome. Another study reported similar results that reduced d-FRN is elicited during outcome evaluation when the participants make the same decision as others (Yu and Sun, 2013). The authors speculated that individuals would experience less negative emotion toward the loss outcome when they are consistent with the crowd. However, a contrary finding was reported by Fu et al. (2017), who explored how the participants would respond to the consistency of choice between themselves and the other player. In their study, consistent choices increase the participants' motivational significance over the outcomes regardless of who make the choice first, as reflected in a more pronounced d-FRN. Taken together, the relationship between decision consistency and outcome evaluation has not reached a consistent conclusion, which might depend on the specific social context involved.

To sum up, decision consistency with others is a piece of important social information. Previous studies have begun to uncover the evaluation process of such social information itself (Klucharev et al., 2009; Nook and Zaki, 2015; Wang et al., 2019; Zheng et al., 2021) as well as its influence on the following outcome evaluation (Gehring and Willoughby, 2002; Yeung and Sanfey, 2004; Bellebaum et al., 2010; Foti et al., 2011; Liao et al., 2011; San Martín, 2012). Our study aims to extend this line of studies by examining the effect of decision consistency in a social context where individual decisions are compared to those of the counterpart rather than a whole group. In addition to probing its outcome evaluation consequence, we explore whether this decision consistency would influence one's anticipation level for the outcome, which was seldomly investigated in previous studies. Anticipation for the outcome is an important cognitive process in one's decision-making, which can be tracked by the stimulus-preceding negativity (SPN). The SPN is a typical ERP component generally observed when one is waiting for the outcome of his/her choice to be revealed (Damen and Brunia, 1987; Foti and Hajcak, 2012), whose magnitude increases steadily as the outcome approaches (Brunia et al., 2012; Foti and Hajcak, 2012; Wang et al., 2017). The SPN is widely adopted to measure one's motivational significance toward the upcoming outcome (Damen and Brunia, 1987; Masaki et al., 2006; Brunia et al., 2011; Murphy, 2016). For instance, Meng et al. (2016) explored how the task challenge level affects participants' anticipation for performance results. It was found that in the optimal challenge condition, the participants have stronger intrinsic motivation to win and exhibit a higher expectation for the performance feedback, resulting in a larger SPN amplitude.

To achieve our research aims, we designed a two-player gambling task, in which two participants faced the same binary choice and were asked to make the decision in turn. The first mover made the binary choice without any prior social information, while in his/her view the choice he/she had made may serve as *a priori* information for the second mover to make a decision. We explored the first movers' evaluation of social information and decision outcomes by recording their electroencephalogram (EEG) data. We mainly focused on three stages, including evaluation of the other's choice (i.e., social information), feedback anticipation and feedback evaluation. In line with prior studies, we analyzed magnitudes of the FRN, SPN and d-FRN to learn about one's cognitive processing in these stages, respectively. We predicted that when the first movers learned that their choices were inconsistent with their counterparts', the underlying cognitive processes would be similar to those involved when they were inconsistent with the whole group. To be specific, an enlarged FRN would be observed when the first mover noticed that the second mover chose a different option. As for the SPN in the feedback anticipation stage, we predicted that the first mover would pay more sustained anticipatory attention to feedback when previous choices were inconsistent, which would produce a more pronounced SPN. Finally, we predicted that when the first mover noticed that the

second mover followed his/her choice, he/she would perceive a higher sense of responsibility for the outcome, giving rise to a significantly more pronounced d-FRN in the outcome evaluation stage.

MATERIALS AND METHODS

Participants

A total of 25 students (18 males, M_{age} = 22.84, SD_{age} = 2.54) from Zhejiang University participated in our experiment. All of them reported right-handedness with corrected to normal vision. They signed informed consent before the experiment and were properly paid for their participation. EEG of three participants were not fully recorded due to equipment malfunction. Another three participants' EEG data were excluded because of too many artifacts. Finally, data of 19 participants were included in the analysis. This study was approved by the Ethics Commitment of Neuromanagement Laboratory at Zhejiang University.

Materials and Procedure

There were two players in our experiment, namely the first mover and the second mover. In each trial, the players were first told to choose between two red packets presented on the left and right side of the screen. One of the red packets contained ¥50, and the other one contained ¥0. The first mover had the priority to choose one of the two red packets first. It is worth pointing out that while the first mover was granted the authority to make a choice ahead of the counterpart, the second mover could freely select either of the two red packets, even if it had been chosen by the first mover. In our study, two participants took part in the experiment at the same time and were told that their roles in the task were randomly determined by drawing lots according to the cover story. In fact, one of the participants was played by an experiment assistant, while the real participants whose EEG were recorded always played the role of first mover.

The experiment consisted of 3 blocks with a total of 140 trials. Each trial was divided into four stages, including choice, choice evaluation, feedback anticipation, and feedback evaluation (see **Figure 1**). The choice stage started with a fixation (800 ms) at the center of the screen, and then two red packets appeared on the left and right sides of the screen. The first mover (i.e., the real participant) was instructed to choose one of the two red packets at his/her pace by pressing 1 or 3 on the keyboard correspondingly. After the participant pressed a button, the chosen option would be highlighted by showing a triangle under the selected red packet. Then, the participant waited for the second mover to make a decision. The mean waiting time was programed to be 1,000 ms. Once the second mover finished selection, choices of both players were presented for 1,200 ms (i.e., the choice evaluation stage). Depending on whether the choices were consistent with each other, the trial fell into either the consistent or inconsistent choice condition. Then it came to the feedback anticipation stage, at which the participant should wait for 2,000 ms before the feedback outcome was revealed. Finally, both red packets were opened and outcomes were shown to the participants for 1,200 ms. Four kinds of feedback outcomes for the choice combinations of the two players (consistent/gain, inconsistent/gain, consistent/non-gain, inconsistent/non-gain) were provided at this feedback evaluation stage. The number of trials in these conditions was kept the same and the trials were randomly presented to the participants. The experimental task was prepared by the E-Prime 2.0 software package (Psychology Software Tools, Pittsburgh, PA, United States).

All participants were comfortably seated in a dimly lit, sound-attenuated, and electrically shielded room. Before the formal experiment, participants were asked to read the instructions and to complete five exercise trials to familiarize with the task procedure. The participants were informed that both players would be paid ¥35 for their participation, and three trials would be randomly selected. Their extra payoff would be calculated on a 1/10 scale based on their own outcomes in these three trials.

Electroencephalogram Data Acquisition

We used the Neuroscan Synamp2 Amplifier (Scan 4.5, Neurosoft Labs, Inc., Sterling, VA, United States) with a cap of 64 scalp sites to record the EEG data (bandpass 0.05–70 Hz, sampling rate at 500 Hz). The electrode on the cephalic region was set as ground, and the left mastoid was set as an online reference. Besides, we recorded the horizontal Electrooculogram (EOG) by placing the electrodes at the left and right orbital rim, and the vertical EOG by placing the electrodes above and below the left eye. In addition, during the whole experiment, electrode impedance was maintained below 5 kΩ.

Electroencephalogram Data Analyses

We pre-processed raw EEG data offline with Scan 4.5 and EEGLAB (Delorme and Makeig, 2004). Firstly, we re-referenced the EEG data to the average of the left and the right mastoids, filtered them with a 30 Hz low-pass filter (24 dB/Octave), and corrected the ocular artifacts. In addition, we excluded the epochs containing an amplifier clipping, bursts of electromyography activity, or an extreme amplitude (which exceeds $\pm$ 80 μV).

We were interested in how the first mover would evaluate the social information (the second mover's choice), and then anticipate and evaluate the feedback of his/her choice. At choice evaluation and feedback evaluation stages, we focused on the FRN. EEG were segmented into epochs of 1200 ms, which lasted from 200 ms before the choice (or feedback) onset to 1,000 ms after their onset, with the first 200 ms serving as the baseline. Additionally, we averaged the EEGs by consistency (consistent vs. inconsistent) for choice evaluation, and by consistency $\times$ feedback (consistent/gain, inconsistent/gain, consistent/non-gain, and inconsistent/non-gain) for feedback evaluation. At the feedback anticipation stage, we focused on the SPN. EEG were segmented into epochs of 2,200 ms, which lasted from 2,200 ms before the onset of feedback to its onset, with the first 200 ms serving as the baseline. Similarly, we averaged the EEGs by choice consistency (consistent vs. inconsistent) for feedback anticipation.

As shown in **Figures 2**, **3**, a frontal-distributed FRN-like component was observed both after choice and feedback presentations. The typical FRN appears at the frontal-central area and begins at about 200 ms after the outcome stimuli

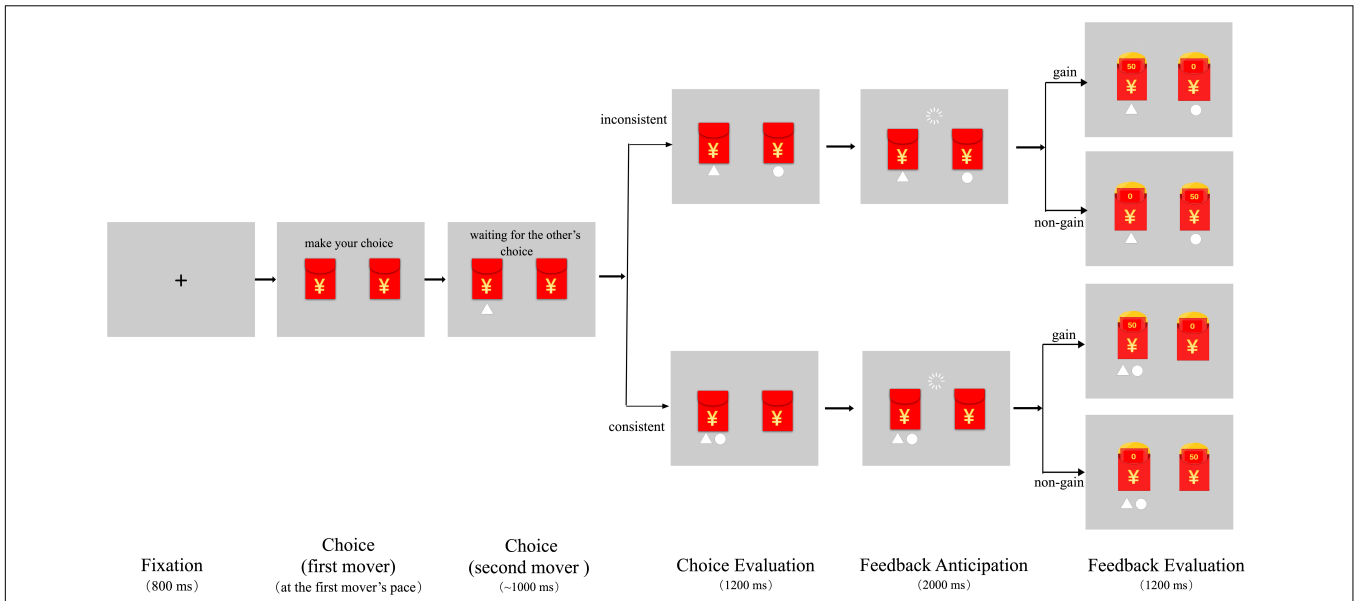

FIGURE 1 | Timeline of a typical trial in the gambling task.

(Gehring and Willoughby, 2002; Zhou et al., 2010; Chen et al., 2012; Wang L. et al., 2016; Zheng et al., 2021). Therefore, the FRN during 250 ms to 350 ms at the fronto-central area (F1, Fz, F2, FC1, FCz, and FC2) was chosen for analyses of choice and feedback evaluations. Besides, as shown in the topographical map of **Figure 4** and according to previous studies (Meng and Ma, 2015; Wang et al., 2018), we chose the SPN during −300 ms to feedback onset at the fronto-central region (F1, Fz, F2, FC1, FCz, and FC2) for the analysis of feedback anticipation.

Finally, the within-participant repeated measures ANOVA on the mean amplitudes of FRN (in the choice evaluation stage) and d-FRN with (consistency: consistent, inconsistent) × (electrodes: F1, Fz, F2, FC1, FCz, and FC2), FRN with (consistency: consistent, inconsistent) × (feedback valence: gain, non-gain) × (electrodes: F1, Fz, F2, FC1, FCz, and FC2), and SPN with (consistency: consistent, inconsistent) × (electrodes: F1, Fz, F2, FC1, FCz, and FC2) were conducted. Greenhouse–Geisser correction was applied when necessary.

RESULTS

Feedback-Related Negativity at the Choice Evaluation Stage

During the choice evaluation stage, the ANOVA results showed that the main effect of consistency was significant [$F_{(1,18)}$ = 11.782, p = 0.003, η^2 = 0.396]. When the first movers noticed that the second movers chose the inconsistent option with them, a more negative FRN amplitude was elicited ($M_{inconsistent}$ = 4.693 μV < $M_{consistent}$ = 6.417 μV). Besides, the main effect of electrode was significant [$F_{(5,90)}$ = 3.846, p = 0.026, η^2 = 0.176], while the interaction effect of consistent × electrode was not significant [$F_{(5,90)}$ = 0.120, p = 0.923, η^2 = 0.007].

Stimulus-Preceding Negativity at the Feedback Anticipation Stage

During the feedback anticipation stage, the ANOVA results showed that the main effect of consistency was significant [$F_{(1,18)}$ = 18.232, p < 0.001, η^2 = 0.503]. The SPN amplitude following inconsistent choices was more negative than that in the consistent choice condition ($M_{inconsistent}$ = −1.619 μV < $M_{consistent}$ = −0.816 μV). Besides, the main effect of electrode was significant [$F_{(5,90)}$ = 3.840, p = 0.018, η^2 = 0.176], while the interaction effect of consistency × electrode was not [$F_{(5,90)}$ = 1.731, p = 0.170, η^2 = 0.088].

Feedback-Related Negativity at the Feedback Evaluation Stage

During the feedback evaluation stage, the ANOVA results showed that the main effect of consistency was marginally significant [$F_{(1,18)}$ = 4.193, p = 0.055, η^2 = 0.189] and the main effect of feedback valence was significant [$F_{(1,18)}$ = 10.956, p = 0.004, η^2 = 0.378]. The loss feedback elicited a more negative FRN amplitude (M_{gain} = 5.940 μV > M_{loss} = 4.607 μV). Besides, the interaction effect of consistency and feedback valence was significant [$F_{(1,18)}$ = 4.475, p = 0.049, η^2 = 0.199]. However, the main effect of electrode [$F_{(5,90)}$ = 2.597, p = 0.094, η^2 = 0.126], the interaction effect of consistency × electrode [$F_{(5,90)}$ = 0.748, p = 0.494, η^2 = 0.040], feedback × electrode [$F_{(5,90)}$ = 1.716, p = 0.193, η^2 = 0.087], and consistency × feedback × electrode [$F_{(5,90)}$ = 0.746, p = 0.537, η^2 = 0.040] were not significant.

We conducted a follow-up simple effect analysis and found that in the consistent condition, loss feedback elicited a more negative FRN amplitude [M_{gain} = 5.671 μV, M_{loss} = 3.552 μV, $F_{(1,18)}$ = 20.875, p < 0.001, η^2 = 0.537]. However, the effect of electrode [$F_{(5,90)}$ = 1.766, p = 0.187,

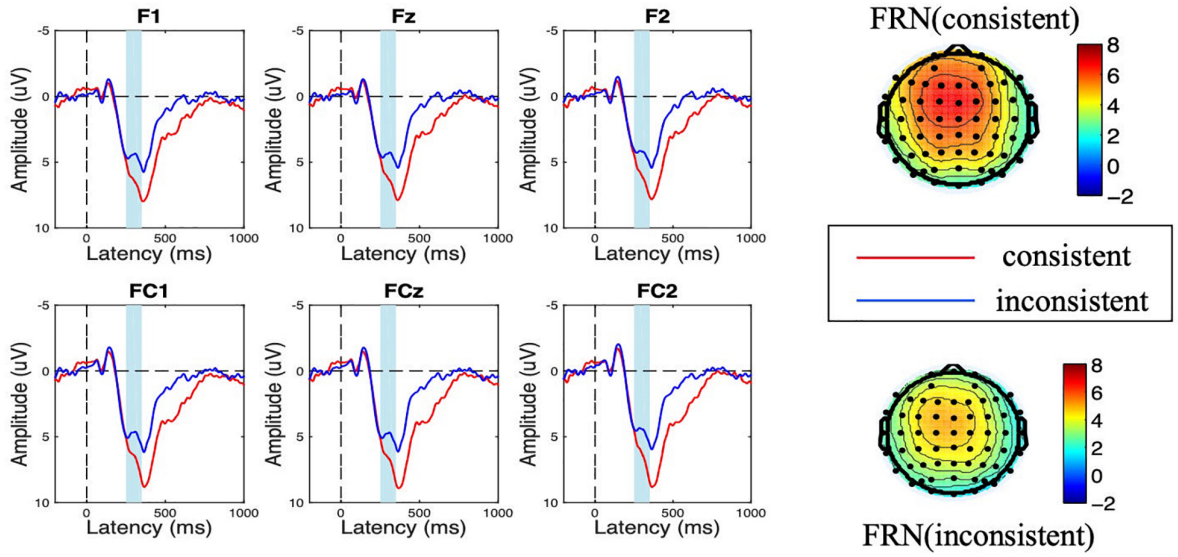

FIGURE 2 | Amplitude of feedback-related negativity (FRN) at the choice evaluation stage for consistent vs. inconsistent conditions. The scalp topographic distribution of the FRN is provided.

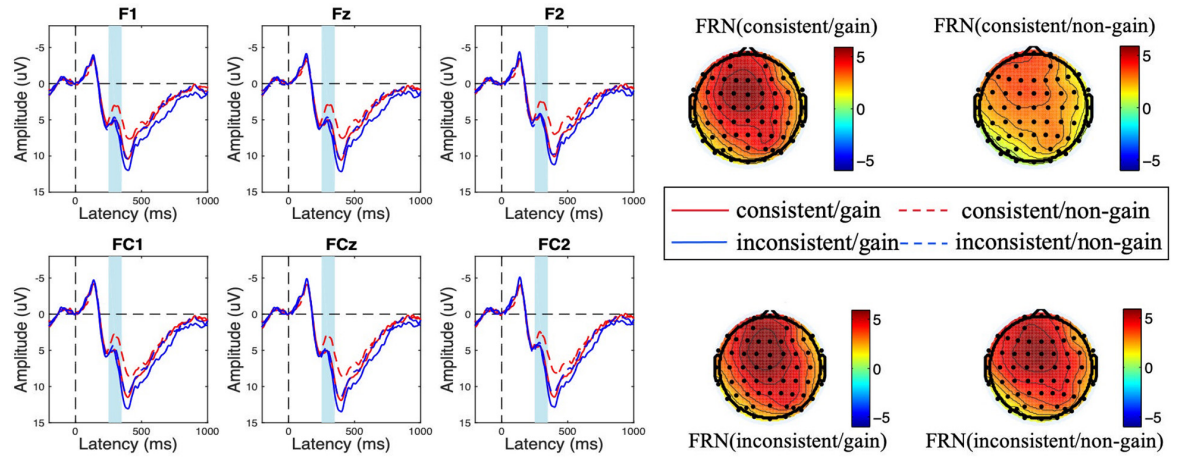

FIGURE 3 | Amplitude of feedback-related negativity (FRN) at the feedback evaluation stage for consistency (consistent vs. inconsistent) and outcome valence (gain vs. non-gain) conditions. The scalp topographic distribution of the FRN is provided.

$\eta^2 = 0.089$] and the interaction effect of valence × electrode [$F_{(5,90)} = 5.590$, $p = 0.618$, $\eta^2 = 0.032$] were not significant. In the inconsistent condition, the valence effect did not reach significance [$M_{gain} = 6.208\ \mu V$, $M_{loss} = 5.662\ \mu V$, $F_{(1,18)} = 0.772$, $p = 0.391$, $\eta^2 = 0.041$]. Besides, the effect of electrode [$F_{(5,90)} = 3.152$, $p = 0.054$, $\eta^2 = 0.149$] and the interaction effect of valence × electrode [$F_{(5,90)} = 2.334$, $p = 0.088$, $\eta^2 = 0.115$] were not significant.

To clearly show the difference in feedback evaluation between consistent and inconsistent conditions, we conducted a 2 (consistency: consistent, inconsistent) × 6 (electrode: F1, Fz, F2, FC1, FCz, and FC2) repeated measure ANOVA on the d-FRN (FRN upon non-gains minus FRN upon gains). The results showed that the main effect of consistency was significant [$F_{(1,18)} = 4.475$, $p = 0.049$, $\eta^2 = 0.199$]. Specifically, the d-FRN was significantly more negative in the consistent condition ($M_{consistent} = -2.119\ \mu V < M_{inconsistent} = -0.546\ \mu V$). The main effect of electrode [$F_{(5,90)} = 1.716$, $p = 0.193$, $\eta^2 = 0.087$] and the interaction effect of consistency × electrode [$F_{(5,90)} = 0.746$, $p = 0.537$, $\eta^2 = 0.040$] were not significant.

DISCUSSION

In this study, we designed a dual-player gambling task in a social comparison context to probe how individuals would evaluate the social information of consistency in their decisions, and how this social information would affect the following anticipation and evaluation of the feedback of their choice. Compared with the situation in which the second mover made the same choice

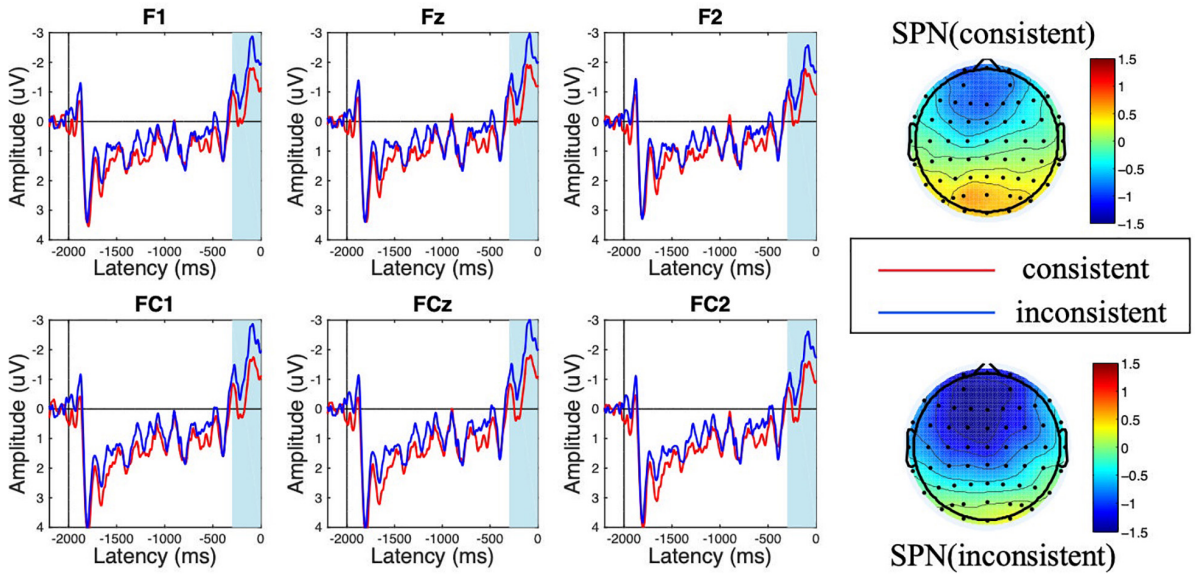

FIGURE 4 | Amplitude of stimulus-preceding negativity (SPN) at the feedback anticipation stage for consistent vs. inconsistent conditions. The scalp topographic distribution of the SPN is provided.

as the first mover, when the second mover made a different choice, the first mover exhibited a more pronounced FRN in choice evaluation, an enlarged SPN in feedback anticipation, and a less pronounced d-FRN in feedback evaluation. These results indicate that people indeed care about the other player's decisions in a social context, and that their reactions to the outcome of their own decisions would be heavily influenced by such social information, even though their outcomes are fully independent of the others' decisions.

At the choice evaluation stage, we found a larger FRN when the participants (the first mover) noticed that the second mover made the opposite choice, suggesting that they regarded this inconsistency in choice as a conflict. This result is in line with previous studies which reported that individuals perceive the consistent choice with others as a recognition and reward (Klucharev et al., 2009; Nook and Zaki, 2015; Wang et al., 2019). Previous studies indicated that the FRN may originate from the anterior cingulate cortex (Kiehl et al., 2000; Holroyd et al., 2004; San Martín, 2012), and distinguishes between positive and negative feedback (Holroyd and Coles, 2002; Cohen et al., 2007; Meng et al., 2021). Besides the valence of the feedback, positive and negative feedback can be defined in terms of the discrepancy between the feedback and one's expectation. Accordingly, previous studies consistently reported that the greater extent that the feedback deviates from what one expects, the larger the conflict, and the more negative FRN amplitude is evoked (Kim et al., 2012; San Martín, 2012; Hauser et al., 2014; Qi et al., 2018; Wang et al., 2019). In previous electrophysiological studies involving social interactions, the FRN has been identified as a signal that characterizes the evaluation of social information. Specifically, when people observe that their own opinions or behaviors are different from those of others, this social information would be regarded as a negative outcome and then elicit a larger FRN (Cialdini and Goldstein, 2004; Klucharev et al., 2009; Shestakova et al., 2012; Kimura and Katayama, 2013; Wang et al., 2019; Zheng et al., 2021). Such inconsistency indicates a deviation from the social norm (Cialdini and Goldstein, 2004), and represents the loss of a potential social reward (Kim et al., 2012). To sum up, the FRN is a neural signature of prediction error, which mirrors the conflict detection of human behaviors (Gehring and Willoughby, 2002; Holroyd et al., 2002; Nieuwenhuis et al., 2004; San Martín, 2012). Our result is in line with these previous studies, revealing that the FRN could track the conflict in choice behaviors between first and second movers. While we predicted to observe the same pattern if the two players made their choices independently, we consider that the sequential decision-making design might have enhanced the conflict perception. In this study, the first mover made the choice independently, while the second mover made the choice after observing the first mover's decision. When the second mover chose a different option with the first mover, it seemed that the second mover trusted their own beliefs more and did not rely on the prompt given by the first mover. In such a situation, the first mover might receive a more negative signal, resulting in a more significant FRN in the choice evaluation stage.

At the feedback anticipation stage, we found a more pronounced SPN when waiting for the upcoming outcome feedback after inconsistent choices had been made. According to previous studies, the SPN is an index that can reflect the extent to which people look forward to the upcoming feedback, and a larger SPN will be elicited with higher anticipation (Damen and Brunia, 1987; Masaki et al., 2006; Brunia et al., 2011; Murphy, 2016). Our result indicated that the first mover exhibited a higher level of anticipation for the following outcome when the second mover chose the opposite red packet. Previous studies have suggested this anticipation to be modulated by the motivational

significance of the feedback. For instance, Wang et al. (2017) measured the SPN when the participants were waiting for their outcomes after completing the multiplication task or the addition task. The researchers found that a larger SPN was evoked after completing the multiplication task compared with the addition task, and attributed this enhanced anticipatory state to the increased motivational significance of feedback after exerting greater effort. The current study set up a gambling task in a social context, where a social comparison should naturally occur. Since nobody would like to behave worse than others, the inconsistent choice would strengthen the perceived motivational significance of the feedback (Wang et al., 2018), and thus increase the anticipatory attention to the following outcome in our study.

Our SPN result in feedback anticipation could also be explained by the uncertainty level. Prior studies have found that uncertainty would modulate subjective anticipation toward the subsequent feedback (Foti and Hajcak, 2012; Seidel et al., 2015; Novak et al., 2016), and an enhanced SPN is generally observed when participants are more uncertain about their task performance (Catena et al., 2012; Meng et al., 2016; Wang et al., 2018). For example, in a previous study the researchers found that when the participants were more confident in completing the task, they felt lower uncertainty. Thus their anticipation of the result would be weakened, which was reflected in a smaller SPN (Novak et al., 2016). In another study, two players tried to resolve several knowledge quizzes in sequence (Wang et al., 2018). The authors manipulated the participants' uncertainty by adjusting the difficulty of the questions. The results showed that in case of high uncertainty, the first mover was more looking forward to the other's answer, resulting in a larger SPN. In addition, when the second mover's choice was different from that of the first mover, a larger SPN was observed when the first mover waited for the outcome. This is because in the inconsistent condition, the uncertainty of the first mover would be further amplified and the eagerness of giving correct answers becomes stronger. Our study replicated the findings of these studies to a large extent. All in all, the motivational significance and uncertainty would both be increased when the first mover saw the second mover making the opposite choice, and then higher anticipation for the upcoming feedback was induced as manifested in an enlarged SPN.

At the feedback evaluation stage, our results demonstrated a larger FRN for negative (non-reward) feedback than positive (reward) feedback, which is consistent with a vast amount of previous studies revealing the feedback valence effect on the FRN (Gehring and Willoughby, 2002; Yeung and Sanfey, 2004; Bellebaum et al., 2010; Foti et al., 2011; Liao et al., 2011; San Martín, 2012). More relevant to the scope of this study, some studies indicated social factors to dramatically modulate outcome evaluation (Leng and Zhou, 2010; Kimura and Katayama, 2016). In line with these studies, our study also found that social information, i.e., the second mover's choice, would affect the first mover's outcome evaluation. To be specific, in the inconsistent condition we did not find a significant difference in FRN toward gains and non-gains. However, the consistent choice between the two players gave rise to a more pronounced FRN discrepancy (d-FRN). According to the motivational significance theory of FRN, the amplitude of d-FRN reflects one's subjective evaluation of feedback. The more people care about the feedback, the larger d-FRN would be elicited (Gehring and Willoughby, 2002; Ma et al., 2011; Meng and Ma, 2015). For example, when the outcome of a decision is more motivationally relevant to the decision-maker, a larger d-FRN would be observed (Li et al., 2010; Ma et al., 2011; Yu and Sun, 2013; Koban and Pourtois, 2014; Kimura and Katayama, 2016; Fu et al., 2017). In our study, the second mover made the decision after the first mover and could see the choice made by the first mover. Thus, the first mover might believe that the second mover's decision was influenced by his/her own. Once a consistent choice had been made, the first mover might feel responsible for the second mover's outcome, and then integrate their outcomes together in outcome evaluation, which increased the eagerness and significance to receive a positive outcome (Fu et al., 2017). In other words, to the first movers, observing a consistent choice means that the second mover might have followed their choice. Thus, the first movers cared more about the overall outcome of the two players and regarded it as highly motivationally significant, resulting in a larger d-FRN. This explanation gets supported by several previous studies. For example, a study found that in the lower responsibility condition, the motivational significance of feedback results was weakened, resulting in a smaller d-FRN (Li et al., 2010). Besides, Kimura and Katayama (2016) suggested that in the non-cooperative situation, participants had higher responsibility for their own payoff, and thus exhibited a significantly larger d-FRN when evaluating the feedback. In conclusion, the perceived responsibility of the first mover in the consistent choice condition resulted in higher concern about the outcome feedback and thus elicited a more pronounced d-FRN.

Our study extends the existing literature on social influence and outcome evaluation by deepening our understanding in terms of how choice inconsistency would moderate the three stages of decision making. Specifically, our study reveals the cognitive process of participants' anticipation for the outcome, which provides further evidence for the insight that inconsistency would enlarge uncertainty and anticipation for the positive outcome and is a major contribution of this study. In addition, our results indicate that even the social information provided by a single person could yield a similar effect with that of a group, which helps enrich the theory of social influence. Practically, our findings suggest that one's follow-up decision-making experience could be modulated by the revelation of the other player's choice, which is illuminating for the design of the decision procedure. However, it is worth noting that in this study we neglected to collect the subjective reported data of the participants' motivation level, which could help support our hypotheses and enhance our conclusions. Besides, our study only examined the social influence of a single person. Future researchers can extend this study and directly compare the influence of one person with that of a group.

CONCLUSION

In summary, in this study a dual-player gambling task was designed to examine how first movers would evaluate the social information regarding decision inconsistency, and how this inconsistency would influence their anticipation

for and evaluation of the monetary outcome associated with the decision. The results revealed that inconsistency with the counterpart made the first mover perceive a conflict (as reflected in a more negative FRN), and had higher anticipation to learn about the outcome (as reflected in a more significant SPN). Besides, we found a larger d-FRN upon feedback in the consistent condition, indicating increased motivational significance during outcome evaluation, which might be the result of the participants' higher responsibility perception for the outcome. Taken together, these results verify that the social information inferred by a single person's behavior could exert similar influence on one's cognitive processing with the social information inferred by a whole group's behaviors. Besides, in addition to social information and outcome evaluation stages, our results show that the anticipation of outcomes is also heavily affected by the consistency in social information.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Commitment of Neuromanagement Laboratory at Zhejiang University. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JZ: research conception, experiment design, data collection, data analysis, and writing the initial and final draft. LW: research project supervision, writing, and reviewing the final draft. LM: research conception, experimental design, data analysis, and writing the initial and final manuscript. All authors contributed to the article and approved the submitted version.

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Bibliometric-Based Evaluation of the Neuromarketing Research Trend: 2010–2021

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Neuromarketing has become a new and important topic in the field of marketing in recent years. Consumer behavior research has received increasing attention. In the past decade, the importance of marketing has also been recognized in many fields such as consumer behavior, advertising, information systems, and e-commerce. Neuromarketing uses neurological methods to determine the driving forces behind consumers' choices. Various neuroscience tools, such as eye movements, have been adopted to help reveal how consumers react to particular advertisements or objects. This information can be used as the basis for new advertising campaigns and brand promotions. To effectively explore the research trends in this field, we must understand the current situation of neuromarketing. A systematic bibliometric analysis can solve this problem by providing publishing trends and information on various topics. In this study, journals that focused on neuromarketing in the field of marketing between 2010 and 2021 were analyzed. These journals were core journals rated by the Association of Business Schools with three or more stars. According to the data analysis results, neuromarketing has 15 main journals with relevant papers. Based on the data collected by the Web of Science (WOS), this study mainly collected 119 references and analyzed the most productive countries, universities, authors, journals, and prolific publications in the field of neuromarketing *via* Citespace. Through the analysis of knowledge maps, this study explored the mapping of co-citation, bibliographic coupling (BC), and co-occurrence (CC). Moreover, the strongest citation bursts were used to study popular research at different time stages and analyze the research trends of neuromarketing research methods and tools. This study provides an overview of the trends and paths in neuromarketing, which can help researchers understand global trends and future research directions.

Keywords: neuromarketing, bibliometric, neuroscience, citespace, marketing

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INTRODUCTION

The neuromarketing field has grown exponentially in recent years, and studies in marketing academic journals using neuroscience methods have increased significantly (de Oliveira and Giraldi, 2017; Lee et al., 2018). In the early period, it was controversial among researchers whether this mixed field was beneficial to its parent disciplines (consumer psychology and neuroscience)

and how these research results would be reintegrated into these disciplines (Plassmann et al., 2012; Fortunato et al., 2014; Rawnaque et al., 2020). Moreover, most reviewed papers were from lower-ranking journals, and in early studies, different researchers understood the concept of "neuromarketing" differently. This created a lack of clear guidance regarding positives and negatives in defining neuromarketing research (Plassmann et al., 2012; Lee et al., 2018). Therefore, Plassmann et al. (2012) put forward opinions on the analytical direction of the definition of future research to promote the development of guided studies on concept definition and research classification. de Oliveira and Giraldi (2017) analyzed and collated the definitions of neuromarketing in previous studies and summarized and provided a more accurate definition of neuromarketing.

Neuromarketing uses the non-invasive brain signal recording technology to directly obtain consumers' feedback on marketing stimuli, instead of traditional investigation methods (Fortunato et al., 2014; Lee et al., 2017; Nilashi et al., 2020; Rawnaque et al., 2020). These technologies are used to study attention, emotional memory, and user experiences in the field of advertising (Bakalash and Riemer, 2013; Adil et al., 2018; Clark et al., 2018). Simultaneously, several studies on the feasibility of applying new equipment and methods in this field are constantly emerging (Venkatraman et al., 2012; Zhang et al., 2020). While brain data can be used to predict consumer behavior (e.g., Knutson and Genevsky, 2018; Krampe et al., 2018; Motoki et al., 2020; Tong et al., 2020), compared to traditional marketing measurement methods, the application of neuroscience is more scientific in predicting consumers' marketing behavior (Berkman and Falk, 2013; Smidts et al., 2014; Lee et al., 2018). Examples include the advertising effect (Ramsøy, 2019; Grigsby and Mellema, 2020) and purchasing behavior (Çakir et al., 2018; Kim and Lakshmanan, 2021). However, as traditional measurement methods are only used to understand cognitive behavior subjectively, there are still weaknesses in many behavior predictions. However, predictions made by combining neuroscience with traditional measurement methods, and analyzing brain activity through neuroscience, can explain consumer behavior more effectively (Motoki et al., 2020).

As there are many branches of research concepts in neuroscience, and marketing is a branch of neuroscience, researchers often lack the knowledge to conduct research in this field. Therefore, the effective systematic induction and summary of neuromarketing research are of great significance for researchers who have newly entered the research field or wish to engage in related studies. In developing the trend of neuroscience, Yeung et al. (2017) applied bibliometrics and Bradford's law to explain research development in neuroscience. The core cited literature originated from a few core journals, which also advanced a specific discussion on the overall trend of neuroscience. Later, Kocak et al. (2019) discussed the trend analysis of neuroscience research by Turkish research institutions and authors in the top journal, *Scientometrics*, in the bibliometric analysis field. They subsequently proposed the main research directions and future research threads *via* cluster analysis and atlas. In the management and entrepreneurship field, Cucino et al. (2021) also conducted a relevant literature analysis. Their research results established five future research topics, namely, the cultivation of dynamic capability of entrepreneurs in the process of innovation and development, the development of leadership, the construction process of leadership, the perspective of leadership in biology, and the application of neuroscience in the ecosystem. The abovementioned neuroscience research demonstrates that there are no relevant studies on neuromarketing. Therefore, through a summary of core journals, researchers who have a preliminary understanding of neuromarketing can learn about the research and development status of this field and gaining entry to this field.

For the literature analysis of neuromarketing in this study, CiteSpace was primarily used as a tool for bibliometric analysis. The visualization software was used to analyze literature groups and data. This can highlight potentially important patterns and trends, and the theory of scientific changes can guide the exploration and visualization of knowledge structures and the interpretation of dynamic patterns (Chen, 2017). Among the data analysis software commonly used in bibliometrics, such as VOS Viewer, SALSA, and PRISMA, CiteSpace is user-friendly, can generate a burst detection algorithm and time zone view according to the time change, and can conduct research trend prediction and related exploration of hot spot mutations (Xu et al., 2021). In this study, bibliometrics was used to study and analyze the research process and future development trends of this field using the CiteSpace software. We hoped to address the following problems: (1) understanding the current research situation in neuromarketing, including the source areas and authors of main articles, high-frequency keywords, and keyword evolution; and (2) the research methods, experimental methods, and research focus used in neuromarketing in recent years.

LITERATURE REVIEW

The word "neuromarketing" was first proposed in June 2002 by an Atlanta advertising company in the United States. In its report, a new department conducted marketing research using functional magnetic resonance imaging (fMRI) (Fisher et al., 2010). Lee et al. (2007) defined neuromarketing as the application of neuroscience methods, including psychophysics and direct brain activity, to analyze and understand human behaviors related to marketing practice. Therefore, neuromarketing is an interdisciplinary research field. It uses various tools traditionally used for neural feedback, biofeedback, and metabolic process measurement in medicine, psychiatry, and psychology, combined with traditional marketing tools. It aims to elucidate the reactions of conscious and unconscious economic agents of the most diverse emotional, cognitive, physiological, and psychological types, and the behaviors and thoughts related to typical problems in marketing and its various subfields (de Oliveira and Giraldi, 2017).

The neuromarketing technology has been used to explore consumer preferences (Murphy et al., 2008), which has aroused a great interest in marketing research companies and has also created discomfort in some individuals. However, this

has not thwarted the curiosity of academic researchers (Lee et al., 2007; Murphy et al., 2008). In neuromarketing, non-invasive brain signal recording techniques are used to directly obtain consumer feedback on marketing stimuli to replace traditional investigation methods (Fortunato et al., 2014; Lee et al., 2017; Nilashi et al., 2020; Rawnaque et al., 2020). These techniques include fMRI, positron emission tomography (PET), magnetoencephalography (MEG), transcranial magnetic stimulator (TMS), electroencephalogram (EEG), galvanic skin response (GSR), and eye tracking. These techniques are used to study attention, emotional memory, and user experience in advertisements (Bakalash and Riemer, 2013; Adil et al., 2018; Clark et al., 2018). For example, Krampe et al. (2018) used fNIRS to study consumers' neural responses to different marketing communication strategies at the point of sale (PoS) and proved that the experimental results were consistent with those of previous studies using other methods. Çakir et al. (2018) studied the development of a neurophysiological information-purchasing behavior model based on fNIRS measurements. Cerf et al. studied the possibility of using single-neuron recordings in research on marketing and consumer-related fields.

In this study, the core journals in marketing were selected for literature analysis. We aimed to elucidate the development trend of this field by analyzing related studies on neuromarketing, to promote researchers' understanding of this topic, and to provide pathways for future research.

DATASET AND RESEARCH METHODOLOGY

Dataset

All articles in this study were obtained from the citation databases of the Science Citation Index (SCI) and Social Science Citation Index (SSCI) and were obtained from the Web of Science (WOS) created by the Institute of Science Information (ISI). Thus, high-quality literature datasets were provided, which can be used in bibliometric research and scientific research (Vílchez-Román et al., 2020; Su et al., 2021; Tang et al., 2021; Jia et al., 2022). Despite the growing importance of neuroscience in the field of marketing, to date, less research has been conducted on the application of bibliometric methods in the field. Moreover, only Barros et al. (2018) discussed the topic of trend analysis in the literature related to neuromarketing between 2010 and 2016. However, the duration of his study and the scope of his analysis were relatively short. Therefore, this study aimed to expand the scope and duration of and provide a more in-depth analysis of trends in neuromarketing. In addition, a search of the WOS for relevant keywords revealed that the number of core journals issued before 2010 was low and only increased significantly from 2009. We also selected 2010 for the literature analysis in this study because there was only one highly cited paper before 2009 for several years (Wedel and Pieters, 2000; Pieters and Wedel, 2004; Chandon et al., 2009). However, from 2010 onward, it is likely that there would be several highly cited papers annually (Pieters et al., 2010; Reimann et al., 2010). In summary, 2010 was used as the data selection criterion in this study. The retrieval period was from 2010 to 2021 to ensure the rationality and importance of the retrieved data. This study mainly referred to the Chartered Association of Business Schools, a joint organization of British business schools that publishes the Academic Journal Guide every 3 years. The data acquisition mainly referred to the benchmark obtained by taking the journals rated above three stars in marketing in 2021 as samples; there were 20 major marketing journals in total. In the method of selecting keywords, this study focused directly on marketing journals. Therefore, the following retrieval methods were used for the keywords: TS = [("FMRI" OR functional magnetic resonance imaging) OR (eye tracking) OR (event-related) OR (electroencephalography OR "EEG") OR (eye fixation related potential OR "EFRP") or (neuroscience) OR (Neuromarketing OR Neuro-marketing)]. Finally, 126 papers were preliminarily obtained.

However, some problems remained regarding the papers obtained through WOS. For example, the subject and keywords described the text; however, they were not directly related. Therefore, follow-up data cleaning can improve the quality of samples and the reliability of bibliometric analysis results (Cobo et al., 2011). However, data cleaning cannot be judged by other analysis tools or keywords and must be filtered manually. Therefore, in this study, based on the practices of Wang and Ngai (2020) and Jia et al. (2022), the collected samples were filtered manually. In filtering, two assistant university professors and two researchers of this study jointly read the abstract of the paper and confirmed whether the research topic and content were consistent with this research topic in multiple ways. If there was no relevance, then the articles were deleted. Following the above process, seven articles were deleted, and 119 articles were consistent with the topic direction. Reasons for deletion included the research content being contrary to this study and the research type coinciding with this study.

Research Methodology

A visual atlas reflects the knowledge network in a specific research field, through which the research status and hotspots can be understood, and the research frontier in the subject field can be explored (Chang, 2017; Muñoz-Leiva et al., 2021). The information visualization software (CiteSpace 5.7) developed by Professor Chen Chaomei of Drexel University in the United States was used to draw the knowledge map of the neuroscience research literature. In the CiteSpace interface, the time span was set from 2000 to 2021, the time slice was set to 1, the node types were author, institution, and keyword, respectively, and the selection criteria were G-index, with k = 25. The neuroscience research literature was analyzed using the knowledge map obtained in this study, and the process framework of this study was organized, as shown in **Supplementary Material 1**.

RESULTS

Publication Trends

The period was limited to 2010–2021, and the article type was limited to Article. Finally, 119 papers met the inclusion criteria.

FIGURE 1 | Annual publishing: 2010–2021.

The annual number of publications is shown in **Figure 1**. The annual publication number of journals reflects the research and development levels of this discipline. The publication status from 2010 to 2021 indicates that more than one paper was published on this topic each year and that neuromarketing was still emerging. According to the summary of publication numbers, there were three periods when neuroscience research was published more prominently, namely, in 2012, 2015, and 2018, mainly due to special issue calls for papers. In 2012, 12 studies on neuroscience were collected in the special issue of the *Journal of Consumer Psychology*, under the title, "Brand Insights from Psychological and Neurophysiological Perspectives." In 2015, 10 articles were collected in the special issue of the *Journal of Marketing Research*, with the topic of "Neuroscience and Marketing." In 2018, nine articles were collected in the special issue of the *European Journal of Marketing*, with the topic of "Neuromarketing." However, since 2016, neuromarketing research has shown steady growth. Specifically, 13 papers were retrieved and published by the end of 2021, indicating that the mixed discipline of neuroscience and marketing has become a popular topic and research frontier in marketing.

According to 119 articles in neuromarketing obtained from WOS data (refer to **Table 1**), the statistical description and analysis of the publication number of journals can reflect the development of subject knowledge structure in neuromarketing and provide guidance for later researchers to submit relevant papers. The *Journal of Marketing Research* has contributed the most to the field of neuromarketing. A total of 22 pieces of literature were published, with a total of 1,106 citations, and a citation rate of 50.27 per article. Most works focused on the relationship between the preference of consumer decision-making behavior and marketing choice and model, while others focused on the assessment of the advertisement model and the benefit of information search for the market. The *Journal of Advertising Research* ranked second in publication numbers, with a cumulative citation rate of 191 and an average citation rate of 11.24. The *European Journal of Marketing* ranked third, with a publication number of 15 articles. Compared to the second-ranking journal, its cumulative citation rate of 191 was identical; however, the average citation rate of 12.73 was higher. In particular, the *Journal of Consumer Psychology* contained only 13 articles, but its average citation rate was the highest among all journals, totaling 80.54. According to the relevant articles, among the top six papers cited in marketing from 2010 to 2021, three were from this journal [Schmitt (2012), Reimann et al. (2010), and Milosavljevic et al. (2012)]. It can be inferred that the *Journal of Consumer Psychology* was the core

TABLE 1 | Summary of journals details.

Rank	Journals	Documents	TC	D|TC
1	Journal of marketing research	22	1106	50.27
2	Journal of advertising research	17	191	11.24
3	European journal of marketing	15	191	12.73
4	Journal of consumer psychology	13	1047	80.54
5	Journal of advertising	11	172	15.64
6	Journal of interactive marketing	9	111	12.33
7	Journal of consumer research	7	332	47.43
8	Marketing letters	6	115	19.17
9	Marketing science	5	139	27.80
10	Journal of marketing	3	273	91.00
11	Journal of the academy of marketing science	3	62	20.67
12	Industrial marketing management	3	9	3.00
13	Journal of retailing	2	133	66.50
14	International journal of research in marketing	2	26	13.00
15	Marketing theory	1	6	6.00

TC, total citations; D|TC, average number of citations per article.

reference journal for most researchers studying neuromarketing-related issues.

Author's Cooperation Network

The authors' co-occurrence (CC) had 214 nodes and 307 connections in the map, and the network density was 0.0135. This indicates that the cooperative network density between the authors is low, the author's cooperative relationship is not close enough, and the research authors are relatively scattered. Price's law suggests that only core authors post more than 50% of the total collaboration in the field (Price, 1963), which proves that authors have a strong cooperative relationship. According to Price's law, the M-value of the core author's post volume is 1.498. In this study, we set two posted articles as the criteria for viewing an author as the core author. In this study, 55 of the 76 core authors accounted for 46.22% of the 119 posts, indicating that the authors did not cooperate sufficiently. As shown in **Supplementary Materials 2, 3**, the cooperation of existing authors is also mainly based on external cooperation. For example, for Reimann, Martin, Bechara, and Antoine, all from the University of Southern California, the published relationship between them is weak. Other authors with more published articles have a wide range of institutions.

According to the authors and organizations with more than three publications, **Supplementary Material 3** shows that there are nine scholars with more than three publications, accounting for 4.20% of the total number of scholars. The highest number of publications was four, while authors with one publication accounted for 64.49%. Comparing Lotka's law in the three Bibliometrics laws, the total number of authors of n papers was one-nth of the total number of authors of a published paper, that is, the inverse square law of scientific productivity. Moreover, the total number of authors who published only one paper was approximately 60% of all authors (Lotka, 1926; Su et al., 2020). Therefore, the publication number of this study accorded with the concept of Lotka's law, and most researchers published only one study. This shows that there were few outstanding high-yield core authors in the field of "neuroscience," and most scholars were new to the field. Although there were no scholars with a high number of publications in this field, regarding the cited frequency, the article published by Venkatraman et al. (2015) was the most cited paper for studying neuromarketing (the top 1% cited globally), with a cited frequency of 191. Therefore, there is an opportunity for the continuous development of neuromarketing.

Regarding the citation rate of authors, according to the WOS database analysis, there were six pieces of literature with a high citation rate (>150). Among these, the most cited paper was conducted by Venkatraman et al. (2015), which was the only study with a high citation rate. In this study, a neurophysiological method was used to assess consumers' response evaluation to TV advertisements. Traditional self-reports, implicit measures, eye tracking, biometrics, electroencephalography, and fMRI were used to make predictions to determine the influencing factors of advertisement benefit evaluation. In addition, five other pieces of literature had high citation rates, and the main research topics were neural measurements combined with consumers' reactions to explore what factors can better influence consumers' visual attention (Atalay et al., 2012; Milosavljevic et al., 2012). Notably, Pieters et al. (2010) have the highest current citation rate. This may be related to their research content, and it is essential to eliminate the interference of advertisement complexity in the follow-up experiments. Similarly, Schmitt's (2012) model can be integrated from empirical research on brand consumers' psychology and personal construction (e.g., brand classification, emotion, personality, symbol, and attachment). Unlike most studies, Reimann et al. (2010) explored the factors influencing consumers' decision-making from the perspective of package design, rather than the mainstream advertisement communication model itself. This also provides an interesting guide for follow-up research (refer to **Supplementary Material 4**).

Countries and Institutions

Analyzing publishing organizations can reflect high-yield research institutions and cooperation in this field. The CC atlas of publishing organizations was drawn using CiteSpace, and statistical information on the publishing situation of research institutions was obtained. According to Price's law, the value of M was calculated to be 2.81, and the integer was 3. That is, research institutions with more than three publications were regarded as core research institutions. The research institutions with the highest number of publications were Michigan University (11 articles), Erasmus University Rotterdam (8 articles), Duke University (6 articles), and other universities, indicating that these organizations played a key role in neuroscience research. Regarding the types of research institutions, nine universities had published more than five articles among 218 universities or research institutions. This indicates that neuromarketing research was not being conducted by a few universities; moreover, it had spread gradually. Geographically, the research institutions were mainly distributed in developed countries, such as the United States and the Netherlands, which is closely related to the degree of neuroscientific development in those countries. There were 170 nodes and 221 connections in the CC atlas of publishing organizations, and the network density was 0.0154. Most nodes were distributed sporadically, and the connections between nodes were few and thin, which indicates that research institutions were scattered, except for the United States. Moreover, cooperative research results were few, and an academic research team with mutual integration and development had not yet been formed, which also reflected the dominant position of the United States in neuroscience. The existing cooperation among research institutions has mainly focused on the close cooperation of several universities. Examples include cooperation between Michigan University and Erasmus University Rotterdam, Tilburg University, and the University of Maryland (refer to **Supplementary Material 5**).

From 2010 to 2021, 30 countries have conducted related studies on neuroscience, and 10 countries have published at least five articles. Regarding published articles, almost all

were conducted in a cooperative way, and there were many close cooperative relationships between universities in the United States and the Netherlands, which published more articles. The United States has the highest productivity in the field of neuroscience. A total of 61.9% (78 publications) were by Dutch authors. The Netherlands has the second-highest output in neuroscience, accounting for 18.3% (23 publications were from Dutch authors) (refer to **Supplementary Materials 6, 7**).

Analysis of Methodological and Neuroscience Tools

In this study, the research tools and methods used in the resulting literature are categorized and summarized to better demonstrate the application of neuroscience methods in the field of marketing. We thusly concluded that neuromarketing has mainly been studied using eye tracking, fMRI, EEG/ERPs, and a combination of these tools. **Supplementary Material 8** shows a summary of the research tool classification.

Eye tracking accounted for the highest proportion of tool used in neuromarketing research and is commonly used to study the impact of advertising graphics on consumers. For example, Mittal et al. (2021) studied individual differences in holistic and analytical thinking and plastic surgery preferences. Eye tracking was used to record the trajectory of women viewing neutral photographs of themselves. They found that focusing on specific body parts was associated with the desire to undergo relevant cosmetic surgery. Russell et al. (2017) tested the hypothesis that exposure to advertisements prior to TV episodes would increase attention to the location of product displays within the episodes and obtained conclusions consistent with this hypothesis. This tool has also been applied to studies on the impact of decisions regarding the nutritional value of food (Thomas et al., 2021).

However, the use of fMRI in this field cannot be ignored. It has been used mainly in studies on consumers' physiological responses to marketing behaviors and in predicting consumer behavior through the relationship between the two variables and behavioral decisions. Of the 22 studies in which fMRI was used, half were related to branding and advertising. In contrast, Berns and Moore (2012) examined the possibility of using neuroimaging in smaller populations to predict the prevalence of culture. They found that the neural responses of the tested individuals could be applied to the general population. Although music sales cannot be predicted, they can be used to predict popularity. In contrast, Casado-Aranda et al. (2018) studied the relationship between risky and secure e-payments starting with neural means and analyzed the unconscious origin of consumers' choice of payment system.

Using fMRI methods, this study found that EEGs/ERPs were used in neuromarketing in a direction similar to the main research themes. Barnett and Cerf (2017) used EEG to calculate the relative levels of neural similarity and cross-brain correlation (CBC) in audience movie trailers and demonstrated the role of these data in predicting future commercial data for movies. Pozharliev et al. (2015) examined brain responses to negative perceptions of luxury and basic brands alone or accompanied by another person. The results suggested that the presence of other people amplified the affective effects of the brand type. This is consistent with the results of De Vries et al. (2018), who used fMRI. Notably, only five studies used neurophysiological measures alone. They were mostly introductory experiments to new methods with no apparent thematic bias. Two of these studies used fNIRS to measure consumer-informed consumption behavior and consumer neural responses to different merchandise communication strategies at the PoS (Krampe et al., 2018; Çakir et al., 2018). Cerf et al. (2015) designed a series of experiments to explore the effects of food purchase/selection on food-related environmental odors in children and adults. Klesse et al. (2015) conducted five correlational experiments and found that speaking triggered more indulgent choices than manual expression patterns when consumers made requests, but not when using a foreign language. Cerf et al. (2015) presented a method for single-neuron recording in humans and discussed the relevance of this method to marketing and consumer behavior.

Finally, the remaining hybrid tools focused on the analysis of experimental data by combining two or more methods. This included fMRI and neurophysiological measures used to assess the role of "customer orientation" (CO) and "sales orientation" (SO) in personal selling from a biological perspective (Bagozzi et al., 2012). Moreover, EEG, skin conductance, and neurophysiological measure methods have been used to understand the impact of different ad placements and delivery tools on the mobile user experience (Clark et al., 2018). Varan et al. (2015) used data analysis from EEG, fMRI, facial coding, EMG, and biometrics studies and concluded that neuromarketing was not a reliable measure of advertising effectiveness. Devices, such as biometrics and skin conductance, are commonly found in hybrid tools.

Among the research methods used, the neuromarketing approach was mainly based on an experimental design, which accounted for 103 studies. Regarding other research, only 10 studies used a mixed research approach and six literature review studies (refer to **Supplementary Material 9** for the Results). The review and methodology categories comprised six studies, as listed below. Rick (2011) collated and discussed three aspects of loss aversion. Chang (2017) discussed trends in advertising and marketing methodologies. Ramsøy (2019) explored the collation of research categories and concepts of neuroscience research on advertising effects and provided a framework for validating metrics based on neurosciences. Schmitt (2012) integrated empirical research and personal constructs into a framework model and provided criteria and methods for use. Venkatraman et al. (2015) proposed a method of mapping between cognitive processes and traditional marketing data based on neurosciences to improve consumer-product matching with traditional demographic methods. Yoon et al. (2012) proposed that neuroscience could shape future theories and models in consumer decision-making and that neuroscience methods could be used in decision-making research. These studies demonstrate that trends in the adoption of neuromarketing and research design guidelines continue to progress. However, the relevant developments only comprise the construction of research guidelines, frameworks, categories, and scopes of research.

Keyword Analysis

The timeline graph provides an overall view of the cluster timespan and how these clusters are connected. The results are shown in **Supplementary Material 8**. The keyword CC atlas can directly reflect the frequency of keywords in a research field. In this study, seven clusters were formed. The nodes in each row represent the keywords in each cluster and the links represent the relationships among the different keywords. In addition, the results showed that all seven clusters were closely connected. Cluster 0 was the largest because it contained the most articles. The continuous large nodes and extensive links in this cluster proved its activity, and the label of Cluster 0 represented the most noteworthy topic. Clusters 0 to 3 also had large nodes, indicating that they were relatively prominent topics in neuromarketing. In the CiteSpace interface, the keyword was taken as the node type and the time slice was set to 1. The G-index was used as the selection criterion and k = 25 was set. After running the software, the keyword CC atlas (**Figure 2**) was obtained. The atlas contained 233 nodes and 1195 connections, and the network density was 0.0442. Keywords with a frequency greater than or equal to 4, and centrality greater than or equal to 0.1, were listed (refer to **Supplementary Material 8**).

Cluster 0 was marked as "Consumer neuroscience," meaning that the study of this cluster could be summarized as the study of consumer neuroscience. However, by reviewing the keywords of this classification, we found that the words with strong relationships included attention, neuroscience, activation, choice, reward, emotion, EEG, representation, neural response, amygdala, individual difference, cognition, and prefrontal cortex. These words reflected that the consumer neuroscience method analysis was mainly based on EEG tools, studying the prefrontal cortex and neuro response (Barnett and Cerf, 2017), and extracting the variables that influence consumers' choices. The influence of emotion (mostly), attention, imagination, and other factors on consumers' individual differences was focused on, and more importantly, the perspective of marketers (Venkatraman et al., 2012; Rampl et al., 2016).

Cluster 1 was marked as "Complexity," meaning that the study of this cluster could be summarized as a study on complexity. However, by reviewing the keywords of this classification, words with strong relationships were found to include memory, attitude, advertisement, meta, analysis, and recognition. This popular vocabulary emphasizes the application of neuroscience in studies related to the effects of complex advertisements. For example, the study conducted by Pieters et al. (2010) found that advertisers affect consumers' attention and attitude toward advertisements through the control of visual complexity to attract consumers' attention. Others, such as Cian et al. (2014), used the effect of static vision to make consumers accustomed to it and induce consumers' participation and attitude through dynamic images. Kuisma et al. (2010) used neuroscience technology to predict the value of advertisements and compared the unique preference (e.g., attitude) information between individuals and the whole population, especially from observing subjects' reactions toward advertisements (e.g., eye movement).

Cluster 2 was marked as "fMRI," meaning that the study in this cluster could be summarized as the study on fMRI. However, by reviewing the keywords of this classification, words with strong relationships were found to include fMRI, conflict, perspective, experience, decision-making, and response. These

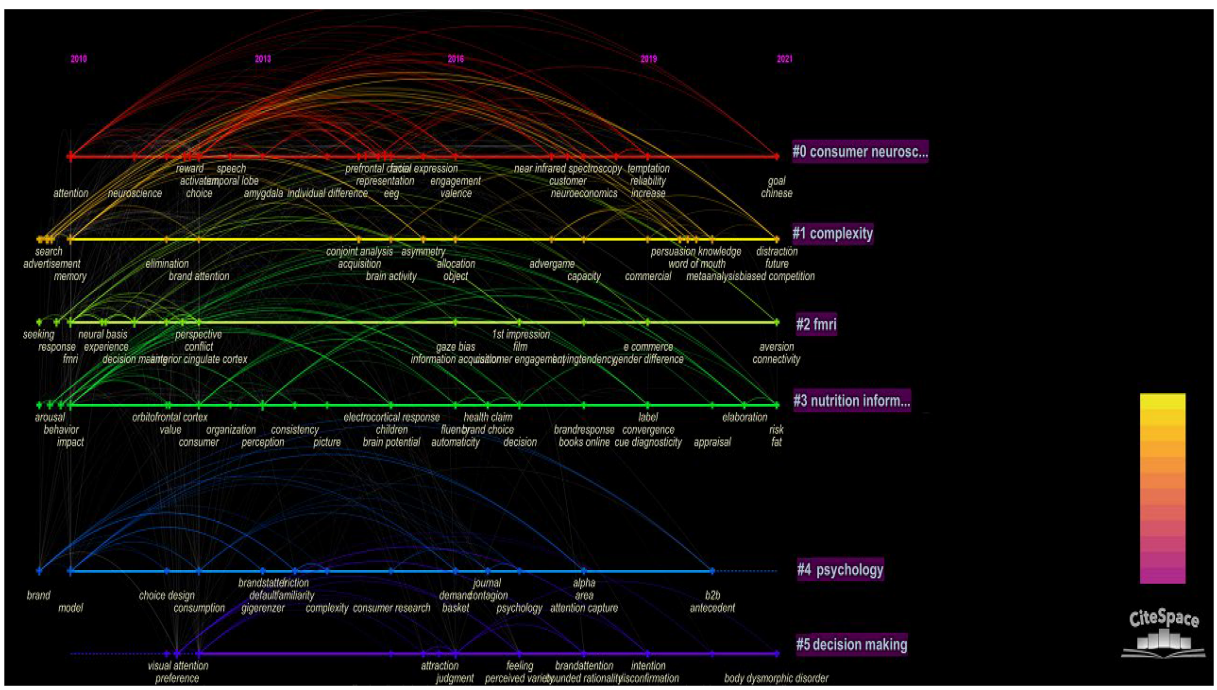

FIGURE 2 | Timeline of the "Neuromarketing" cited network.

words show that the fMRI method was mainly used for study, including the evaluation of TV advertisements. Researchers have proposed a comprehensive program that combines a visual scale with fMRI to measure emotional responses to TV advertisements (Shen and Morris, 2016). Reimann et al. (2012) provided new insights into brand building by studying the psychological and neurophysiological mechanisms of how consumers relate to their favorite brands. Through three experimental studies, they found that emotional arousal decreased with the span of brand relationships. However, the degree of brand integration increased over time. Jai et al. (2021) analyzed consumers' online purchase decisions based on the SOR theory and used fMRI image decisions to understand consumers' purchase decisions and predict their purchasing behaviors by designing shoppers' display products. According to the above studies, fMRI neuroscience tools can be used to analyze consumers' behavior patterns in order to understand consumers' purchasing behavior.

Cluster 3 was marked as "Nutrition information," meaning that the study of this cluster could be summarized as the study on nutrition information. The main words included impact, perception, behavior, consumer, arousal, decision, health, and claims. These words reflect that this topic explored nutritional information. For example, Zou and Liu (2019) explored the influence of nutrition information on consumers' decision-making to explore whether the label disclosing food ingredients by offline stores should be strengthened for the consumption of healthy food. Furthermore, Labban et al. (2021) studied the influence of commodity displays and healthy/unhealthy food on consumers' purchase decisions. Some researchers have also discussed the influence of food health evaluations on consumers' choice of packaged food through neuroscience experiments (Thomas et al., 2021). According to Cluster 3, the category of nutrition information was mainly discussed after 2019. Moreover, the issue of early food safety on consumers' purchasing behavior was gradually changing from the traditional experimental and investigation research method (Baker, 1999; Ortega et al., 2014), to experimenting with and application of neuroscience.

Cluster 4 was marked as "Psychology," meaning that the study of this cluster could be summarized as the study on psychology. However, by reviewing the keywords of this classification, words with strong relationships were found to include model, brand, and consumption. Unlike Cluster 0, this cluster no longer focused only on the advertisement itself. The study extended to the psychological influence of brand consumers (Albanese, 2015) and constructed a more accurate influence factor model by comparing neurophysiological responses in different advertisements (Venkatraman et al., 2015). The clustering direction mainly focuses on the influence of brand presentation on consumer psychology.

Cluster 5 was marked as "Decision making," meaning that the study of this cluster could be summarized as the study on decision-making. The keywords of this classification mainly focused on the influence of the coherent application of eye tracking to consumer decision-making. The core popular words included brain, bias, visual attention, preference, judgment, and eye tracking. In the application of clustering, visual attention and eye tracking were mainly used to elucidate consumers' subjective initiative consciousness and to understand the influence of consumers' preferences on their judgment when they respond to brands (Milosavljevic et al., 2012; Telpaz et al., 2015; Yang et al., 2018; Shi and Trusov, 2021).

In addition, all data from 2000 to 2021 were comprehensively analyzed, and all keywords were extracted to detect any keyword outburst. Keyword outbursts show the frequent occurrence of any keyword in a specific period. This information not only shows the evolution of research hotspots over time but also shows the research trend in recent years and may indicate future developmental trends (Mou et al., 2019). The ten keyword outbursts identified by the analysis results are shown in **Figure 3**. Combining the evolutionary path diagram

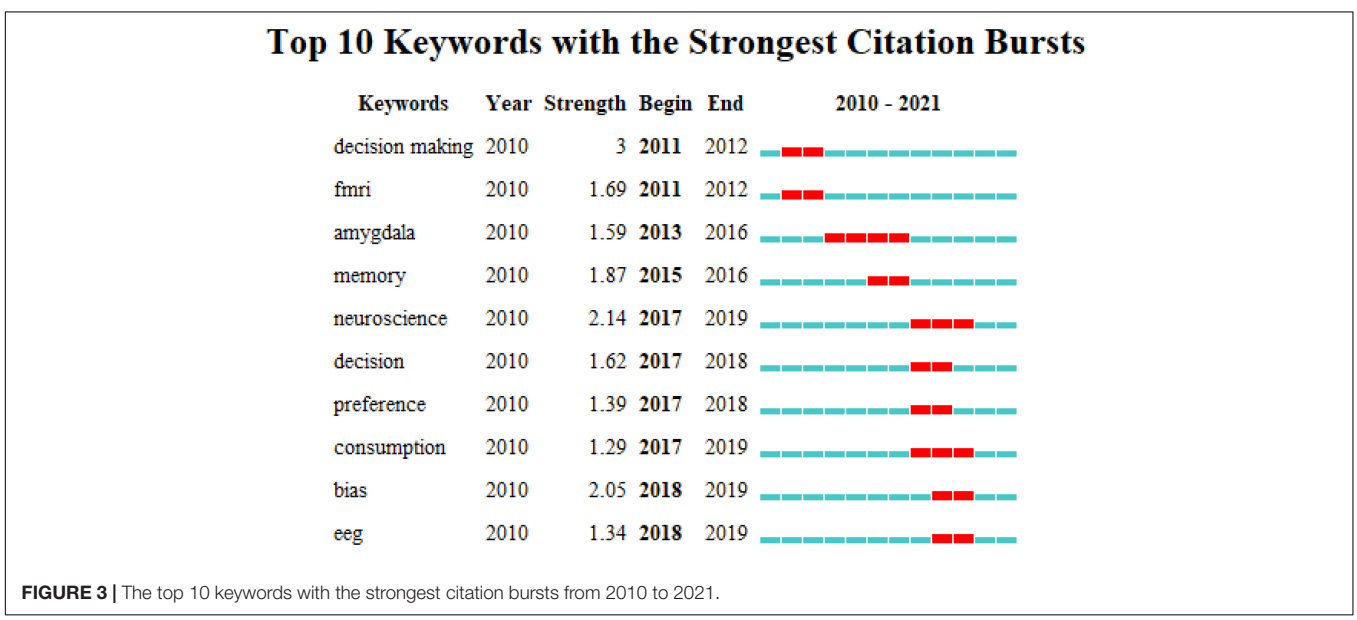

FIGURE 3 | The top 10 keywords with the strongest citation bursts from 2010 to 2021.

with the keywords with high outburst intensity, we concluded the following key meanings. First, in 2010, there were many studies on neuroscience, among which keywords, such as fMRI, memory, information, attention, and model, received extensive attention at that time. This indicates that the studies focused on the relationship between human physiological response and consumers (Aribarg and Schwartz, 2020; Kuisma et al., 2010; Reimann et al., 2012). With the deepening of experiments, an increasing number of research tools have shifted to other tools such as EEG. Especially after 2017, in-depth studies were conducted on the relationship between substances in the brain and specific actions or reactions of people, which was more targeted (Barnett and Cerf, 2017; Barwise et al., 2020). In addition, words, such as decisions and preferences, have been discussed in more topics since 2017. For example, Çakir et al. (2018) investigated the neural correlates of purchase behavior using fNIRS. Simultaneously, the influence of the job satisfaction of salespeople was further discussed (Bagozzi and Verbeke, 2020). Therefore, for application in neuromarketing, the analysis methods of neuroscience gradually became diversified. These comprise not only the early eye tracking or fMRI methods but also extended to neurophysiology methods in recent years to predict the physiological status of consumers' EEG for decision-making analysis of marketing behavior.

DISCUSSION AND IMPLICATIONS

Research Discussion

According to our research on neuromarketing articles from 2010 to 2021 in journals with an AJG rating of 3 and above, neuroscience equipment can be applied to marketing experimental research and has profound development prospects (de Oliveira and Giraldi, 2017). The analysis results showed the following conclusions and effects:

Regarding publication trends, two journals in the field of marketing, i.e., the *Journal of Consumer Psychology* and the *Journal of Marketing Research*, continue to publish special issues of neuromarketing. These are also two leading journals in the ABS 4*marketing field. This indicates that the marketing field is also beginning to take a neuroscience approach seriously. Specifically, these two journals are among the top five in terms of publications as well as citation status (average citation rates of 50.27 and 80.54%, respectively). In particular, the *Journal of Consumer Psychology* is among the top six most-cited journals for the period of 2010–2021, with three papers by Schmitt (2012), Reimann et al. (2010), and Milosavljevic et al. (2012). This journal has the highest number of highly cited papers. The journal with the highest average citation rate per paper is the *Journal of Marketing*. It is also a top journal with an ABS rating scale of 4*. This indicates the journal's impact. Notably, Pieters et al.'s (2010) study was the most cited journal after 2010. The number of citations in this study was 217. The impact of excluding complex ad-hocness on experiments proposed by this study is also paving the way for subsequent studies on the indicative nature of advertising experiments. Regarding trends, the main journals receiving articles in neuromarketing continue to have a bias toward consumer psychology.

In contrast, regarding institutional and national publication status, the United States has the highest number of publications, followed by the Netherlands. However, the collaboration networks among Michigan University, Erasmus University Rotterdam, Tilburg University, and the University of Maryland are reflected in the top journals of the *Journal of Marketing Research* and *Journal of Marketing*, respectively. It has collaborated on topics such as advertising effectiveness (Aribarg et al., 2010; Pieters et al., 2010; Teixeira et al., 2012; Smidts et al., 2014; Pozharliev et al., 2015) and consumer behavioral decision-making (Bagozzi et al., 2012; Yoon et al., 2012; Pozharliev et al., 2015; Bagozzi and Verbeke, 2020). It can be concluded that neuromarketing is not deeply collaborative among countries. At present, only a few research institutions have strong collaborative relationships.

The cluster analysis results regarding domain user keywords indicated that the most dominant clusters were "Consumer neuroscience," "Complexity," " fMRI," "Nutrition information," "Psychology," and "Decision making." Research hotspots focused on consumer decision analysis (Yang et al., 2018; Shi and Trusov, 2021), hybrid neuroscience tools (e.g., applying EEG, fMRI, fNIRS, neurophysiology, and so forth) (Clark et al., 2018; Jai et al., 2021); complexity (Pieters et al., 2010), and nutritional information (Labban et al., 2021; Thomas et al., 2021) as leading research frontiers. To further understand the time-varying hot topics, this study analyzed the keyword progression for keyword emergence. The results revealed a high level of interest in the relationship between human physiological responses and consumers from 2010 to 2015. After 2017, there has been a multifaceted discussion of consumer satisfaction, which is more focused on or elicited from an indirect correlation experimental approach. The keywords derived from either the cluster analysis or keyword-emergent analysis methods were consistent. These keyword clusters closely matched the elements of the neurosciences of human feedback to stimuli. Simultaneously, it reflects the importance of the consumer, a key object in the marketing field. It shows a clear difference in tendency between the two phases, which may stem from the updating of the experimental equipment and methods. It was originally introduced to marketing in the field of neuroscience, when the research was more akin to the field of medicine. With the introduction of new equipment and the accumulation of antecedent studies, researchers have delved deeper or expanded their research horizons.

Implications for Academic Research

The nature of neuromarketing studies relates to consumers. This topic increases in importance as the field of marketing science evolves. Through the collation of bibliometric coupling, keyword emergence, and the manual reading of research articles, including the use of research methods and neuroscience tools, this study presents the following promising themes to offer future researchers for further discussion.

First, the integration of multiple neuroscience tools or methods is a future research trend, based on the embodiment of research results. Gradual diversification in the use of neuroscience tools has been observed. For example, studies by Clement et al. (2017), Grewal et al. (2018), Bellman et al. (2019), and Bagozzi and Verbeke (2020) have not only used neuroscience experiments, but also have incorporated survey research parties or multiple neuroscience experimental tools. Therefore, the impact of consumer behavioral decisions can be discussed through hybrid studies in the future, which can more accurately predict and explore the impact of consumer behavioral decisions.

Regarding the topic direction, researchers can approach it from two perspectives, namely, nutrition information and decision-making. The former focuses on food safety information, particularly on the issue of product information disclosure. Related studies include those of Labban et al. (2021) and Thomas et al. (2021). These studies have focused on the orientation of consumer behavioral decisions extended by traditional food safety (Ortega et al., 2014). In a follow-up study, the analysis can be conducted in terms of the impact of food passports or origin history on consumer purchasing decisions and through neuroscience experiments. Within the topic of consumer behavioral decision-making, most research in neuromarketing continues to discuss experiments related to consumer decision-making, including studies such as Barwise et al. (2020), Huang et al. (2021), and Jia et al. (2022). However, in the field of marketing, the design of marketing plans by employes or decision analysis by supervisors in the corporate sector is also important research topics that influence the effectiveness of marketing behavior drivers. Therefore, further research could be conducted in the neurosciences to investigate issues related to marketing decisions in companies. This research can also address the gaps in traditional business leaders' cognitive reactions, decision-making, and emotional expressions that are not easily measured and observed when making marketing decisions, to elucidate information processing and decision-making at the corporate level.

Research Limitation

As the keyword nodes presented by CiteSpace can only appear qualitatively, there are some limitations to this study. From a quantitative perspective, the value represented by the nodes comes from the number of times the keyword appears in the entire literature dataset. If the software could weigh the number of times the keywords and author order appeared in the literature, then the study would be more convincing. In contrast, the data analysis refers to ABS 3-star journals in the marketing field as the source of data acquisition. *Behavioral and Brain Sciences*, *Frontiers in Neuroscience*, *Frontiers in Behavioral Neuroscience*, and *BMC Neuroscience* have all included the analyzes of consumer behavioral decisions. There are also many neuromarketing-related topics in marketing seminars organized by the American Marketing Association and other marketing societies. None of the studies in this section have been considered. This may also be a limitation of this study.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

ZZ, YS, and YJ designed the research, provided guidance throughout the entire research process, collected the references, did the literature analysis, and wrote the manuscript. KJ and C-LL helped with translation and offered modification suggestions. C-LL and XL participated in the literature collection, analysis, and organization. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.872468/full#supplementary-material

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Roles and Research Trends of Neuroscience on Major Information Systems Journal: A Bibliometric and Content Analysis

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Over the past decade, neuroscience has been integrated into information systems as a new methodology and perspective to study and solve related problems. Therefore, NeuroIS has emerged as a new cutting-edge research field. This review aimed to identify, summarize, and classify existing NeuroIS publications through knowledge mapping and bibliometric analysis. To effectively understand the development trend of NeuroIS, this study referred to the journal selection index of the Association of Business Schools in 2021 and journals above three stars in the field of information management as the main selection basis. A total of 99 neuroscience papers and their citation data were included from 19 major information systems journals of SCI/SSCI. This study analyzed bibliometric data from 2010 to 2021 to identify the most productive countries, universities, authors, journals, and prolific publications in NeuroIS. To this end, VOSviewer was used to visualize mapping based on co-citation, bibliographic coupling, and co-occurrence. Keywords with strong citation bursts were also identified in this study. This signifies the evolution of this research field and may reveal potential research directions in the near future. In selecting research methods and analysis tools for NeuroIS, content analysis was used to further conclude and summarize the relevant trends. Moreover, a co-citation network analysis was conducted to help understand how the papers, journals, and authors in the field were connected and related, and to identify the seminal or pioneering major literature. For researchers, network maps visualized mainstream research and provided a structural understanding of NeuroIS. The review concludes by discussing potential research topics in this field.

Keywords: NeuroIS, neuroscience, bibliometric study, management information systems, VOSviewer

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INTRODUCTION

The application of cognitive neuroscience in information management is a new research approach in the field of information management developed in recent years and is also known as the neural information system. Dimoka et al. (2012) defined a neural information system by combining theories, methods, and tools of cognitive neuroscience (such as EEG, fMRI, and ERP) to investigate problems in the field of information systems. Such a practice can overcome the shortcomings of conventional questionnaire surveys in explaining behavioral science and enable people to understand the factors influencing their deeper-layer behaviors through brain waves or EEG

technology (vom Brocke and Liang, 2014). Since 2010, information systems have been discussed in many top journals on information systems, such as MIS Quarterly, to investigate neuroscience. For example, Dimoka (2010) investigated the online trust mechanism using neuroscientific methods, and Riedl et al. (2010) explored the differential influence of gender on trust, both of which were innovative studies in this field. Moravec et al. (2019) conducted behavioral experiments on social media users by means of EEG or brain waves to understand whether they could detect fake news on social media and whether the signs of fake news would affect their cognition and judgment. More accurate physiological data were acquired with cognitive neuroscientific methods to examine the behavioral variables in information management and e-commerce in the past, which was conducive to more accurate scientific findings and effectively compensated for the shortcomings of conventional research approaches in social behavioral science.

In the past years, information system researchers have mainly conducted questionnaire surveys to analyze the investigation and interview data for the final research results. However, affected by social expectations and subjective prejudice, respondents could not answer the questionnaires based on their true feelings (Liang and vom Brocke, 2014). Compared with the experimental design of neuroscience, some problems are still seen in the traditional experimental design, such as a certain degree of bias between the experimental environment and the real situation, which leads to reduced external validity. In addition, because the measurement objects are people whose behaviors vary greatly, it is difficult to have appropriate measurement tools, which can easily cause errors. However, NeuroIS is mainly used to complement existing IS research and neurophysiological tools to provide reliable data difficult or impossible to acquire from conventional ones (Dimoka et al., 2012). In recent years, NeuroIS has received increasing attention in the field of information management. For example, the Journal of the Association for Information Systems released a special issue titled "Methods, Tools, and Measurement in NeuroIS Research" in 2014, which contributed to the NeuroIS methodology. The Journal of Management Information Systems also released a special issue titled "Neuroscience in Information Systems Research" in the same year, defining the future focus in the discussion on rigorous NeuroIS research methods.

NeuroIS is an emerging discipline that has been attached with importance in the past 10 years, but beginners of NeuroIS often know nothing about where to start their research in this field. In reviewing previous studies on neuroscience, there have been studies on the application of neuroscience in management and entrepreneurship, although only coupling analysis and Co-Citation analysis were used (Cucino et al., 2022). Then, there have been articles explaining the development approach and core citation of neuroscience with applied bibliometrics and Bradford's law released in the core journal, putting forward a specific statement for the overall approach of neuroscience (Yeung et al., 2017). Later, Kocak et al. (2019) discussed the trend analysis of research institutes and authors in Turkey in Scientometrics, a journal on bibliometrics, and the research approach and future research context by means of the knowledge graph. It can be learned that there have been a lot of literature discussions on neuroscience. As the application of information systems in neuroscience is a brand-new discipline, and relevant development has never been discussed in previous studies, this study investigates the current development of NeuroIS, and the methods applied in this field. Bibliometrics methods and VOSviewer software will be used in this study to analyze the research process and future development trends in this field. This study intends to solve the following problems: (1) To understand the current situation of NeuroIS, (2) to investigate the research approaches, experimental methods, research focuses, keyword evolution, keyword prominence, and other trends in NeuroIS in recent years, and (3) to investigate the co-citation of literature on NeuroIS. By reference to important journals, this study will give NeuroIS researchers an introduction to the current research development of NeuroIS and how to enter this field.

LITERATURE REVIEW

Bibliometrics is the study of the external characteristics of bibliographic data and involves using mathematical and statistical methods to analyze the quantitative relation, distribution structure, and variation law of specific literature. Such analytical methods are often used to infer quantitative changes in a particular research discipline and are therefore useful for identifying publishing patterns on a certain topic and publishing trends within a discipline (De Bakker et al., 2005; Lee and Hew, 2018). Bibliometric analyses enable scholars to visualize data and observational results obtained from the literature, ensuring the high quality of the analysis and providing ample opportunities to utilize the information of all documents (De Rezende et al., 2018).

Many well-developed tools, such as VOSviewer, CiteSpace, SALSA, and PRISMA, are available for bibliometric analysis. Applicability and operability must be considered when selecting bibliometric analysis tools (Xu et al., 2021). Compared to SALSA and PRISMA, VOSviewer and CiteSpace are easier to operate and do not require programming skills; thus, these two tools are popular for rapid bibliometric analysis (Aria and Cuccurullo, 2018). VOSviewer can manage large amounts of data, has an excellent mapping function, and meets various research requirements (Donthu et al., 2020). CiteSpace can generate burst detection algorithms and time-zone views that change over time, supporting investigations into future research predictions and hotspot mutations (Kleinberg, 2003). These tools have been applied in a series of analyses, including those related to publishing and citation trends (Cunill et al., 2019).

In terms of bibliometric research, Su et al. (2020) applied Lotka's law and Bradford's law to explain the development status and application of social networks, analyzing the distribution of research productivity among researchers in the field of social network analysis. Zhang et al. (2020) discussed the research hotspots and development directions of the ecotourism economy, and Wu et al. (2021) applied bibliometrics to explore China's COVID-19 pandemic policy patterns. Tang et al. (2021) systematically reviewed the publishing patterns of artificial intelligence and online learning research, focusing specifically

on core periodicals, countries, discipline development, and cocitation network analysis. Galvez-Sanchez et al. (2021) analyzed research progress in the field of financial inclusion and conducted bibliometric analyses to identify scientific knowledge, trends, and future research directions with regard to financial inclusion. Furthermore, Mumu et al. (2022) applied bibliometric methods to analyze the development of the literature on e-commerce trust. Dolhey (2019) performed bibliometric analyses to discuss research trends related to entrepreneurial intention. These studies demonstrate how bibliometrics have been widely applied in various disciplines to address different issues (Miau and Yang, 2018; Kocak et al., 2019; Song et al., 2020; Gao et al., 2021). The current study focused on analyzing the Neuro-Information-Systems (NeuroIS) literature, with in-depth knowledge graph mining used to determine research hotspots and evolution trends.

DATA COLLECTION

Since 2009, the NeuroIS Retreat Conference has been held every year to promote the development of NeuroIS (Riedl and Léger, 2016). At the International Conference on Information Systems, Dimoka et al. (2009) delivered a speech entitled "NeuroIS: Hype or hope?" The introduction of the conference paper explains in detail how NeuroIS should help scholars in the information systems field to conduct important studies. Riedl et al. (2010) further explained this definition of NeuroIS. Because NeuroIS has been valued and studied by the information systems field since 2009, the time period covered was limited from 2010 to 2021. Journals of SSCI and SCI included in the Web of Science (WOS) were the main literature data resources. The WOS offers high-quality literature and is frequently used in bibliometric research (Su et al., 2020; Jia et al., 2022). The search term rules in this study are as follows: TS = [("fMRI" or functional magnetic resonance imaging) or (eye-tracking) or (event-related) or (electroencephalography or "EEG") or (eye fixation related potential or "efrp") or (neurois) or (Neuroscience) or (neuro information systems) or (neuro information systems)]. All keywords were connected by an OR. To ensure high quality of literature, the research scope of journals is limited to journals with more than three stars in the field of Information Management in the Academic Journal Guide, which was proposed by the Chartered Association of Business Schools (ABS) in 2021. As a result, 20 information systems journals were searched, and 101 articles were obtained.

Moreover, the type of literature is limited to "articles" only. To reduce errors in the keyword search, irrelevant papers were excluded. The deletion rule is based on Wang and Ngai (2020) and Jia et al. (2022). The method in which Taskin and Al (2019) conducted a standardized process of data cleaning, including the standardization process of author names, was used as a reference in this study. Since different journals present author names in different ways, errors may occur during data collection. Therefore, author names were uniformly verified, and improper author names were unified. Additionally, in some cases, publications without DOI may cause consistency in the calculation of cocitation analysis using the software. To ensure the consistency of the most cited publications in the dataset, several integrations were conducted to unify repetitive publications. Moreover, the consistency of keywords is also an important part of the data analysis. In particular, there are problems such as plural, verb change, or part-of-speech difference in some keywords, such as behavioral intention, behavior intention, and behavior intention. The step was to examine the abstract of each paper manually with the target subject through two-way confirmation. Irrelevant articles would be deleted. Finally, two papers that did not conform to the theme were removed, leaving a total of 99 articles. Subsequent data analysis was based on 99 papers. The process framework of this study is illustrated in **Figure 1**.

RESULTS

Publication Trends

First, by comparing the number of published papers, the change in popularity of this topic can be revealed. **Figure 2** shows the number of articles published annually from 2010 to 2021 in the field of NeuroIS. It can be found that from 2010 to 2013, the number of papers per year was less than six, indicating that NeuroIS was at the beginning of exploration and the stage of establishing the basic framework. In 2014, there was a great increase in the number of studies, reaching 14 years of age. This phenomenon was related to the launch of Brain Research through Advancing Innovative Neuroethologies and the Human Brain Project by the US and the EU, respectively, in 2013. More importantly, the Journal of the Association for Information Systems published a special issue in 2014 with the theme of "Methods, tools, and measurement in NeuroIS research," which contributed to NeuroIS methodology. Professor Ting-Peng Liang, the late former president of the Information Systems Society, also published "Special Issue: Neuroscience in Information Systems Research" in the Journal of Management Information Systems in 2014. Its purpose is to discuss the key methods of NeuroIS research in the future (Liang and vom Brocke, 2014). The NeuroIS Society was established in Austria in 2018 to fund more scholars and research projects in this field. In 2019, the number of published papers peaked at 16. Among the 16, six papers were published in the Journal of the Association for Information Science and Technology. Overall, from 2010 to 2021, the number of published studies increased gradually. The intersection of neuroscience and information systems has been a hot topic and a research frontier in these two fields.

Descriptive Analysis

Table 1 lists the number of published papers and citations in the selected journals. Among them, the Journal of the Association for Information Science and Technology (JASIST) has the most papers (20 papers), and most of them have been published after 2015. In the field of information science, this journal focuses on the production, discovery, recording, storage, representation, retrieval, presentation, manipulation, dissemination, use, and evaluation of information. Tools and technologies for processing

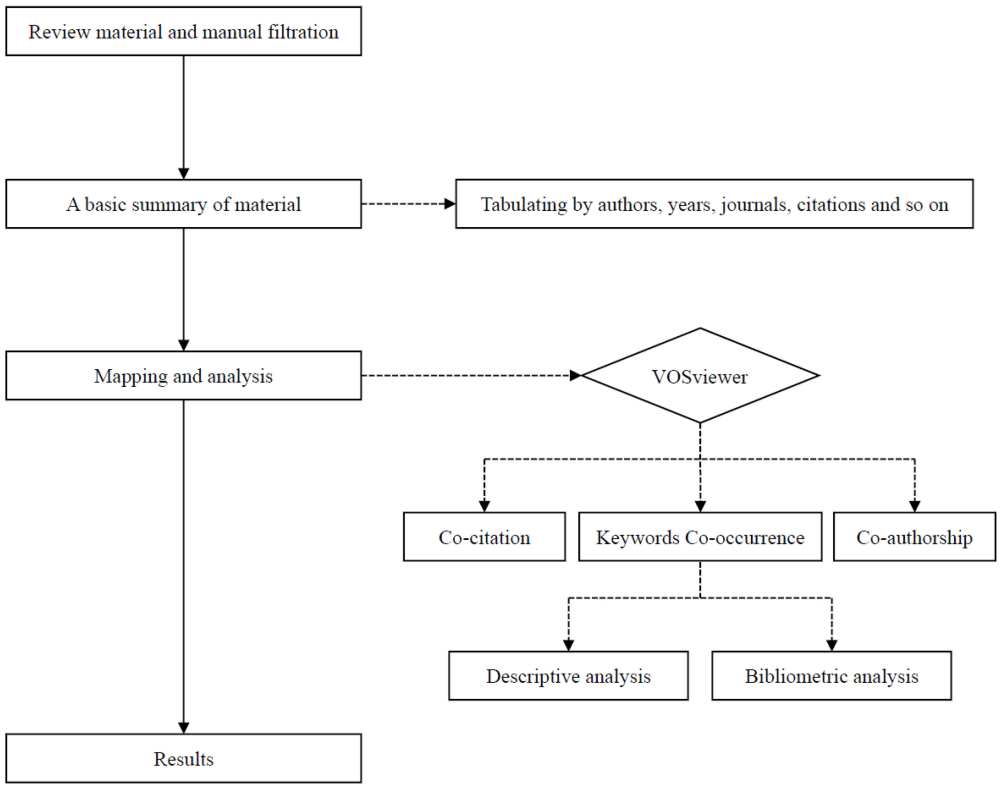

FIGURE 1 | The article selection process for bibliometric mapping analysis.

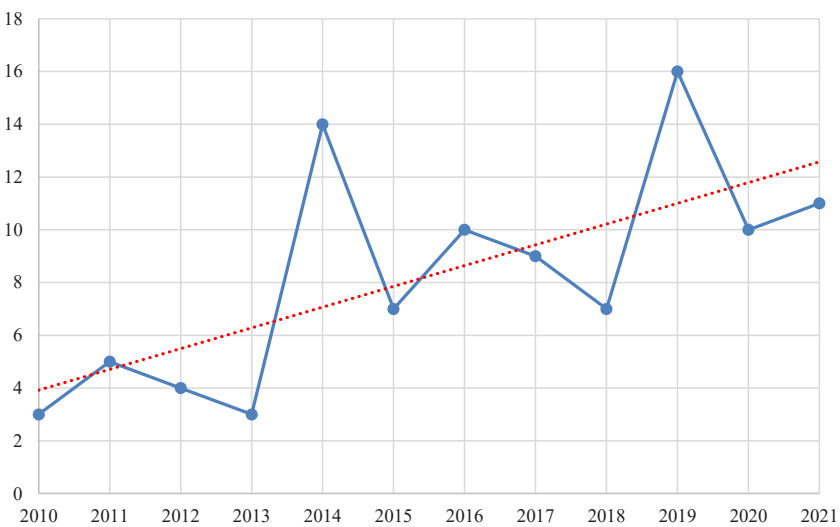

FIGURE 2 | Number of publications per year from 2010 to 2021.

were also included. The impact factor for this journal in 2020 was 2.687. After JASIST, the Journal of Management Information Systems published 19 papers, and the citations were 832, far ahead of those of other journals. Nine papers in this journal were published in the special issue "Neuroscience in Information Systems Research" in 2014. This journal is included in the FT50 as one of the top journals in the field of information systems. MIS Quarterly, another top-level journal of information systems, evaluated as a four-star journal by ABS and listed in UTD-24, has published 10 papers with 686 citations. It is ranked No. 1 in the rank of the average number of citations per article. The most interesting journal is Decision Support Systems, which

ranks third in terms of the number of papers published in one journal. The number of published articles was the most stable among all the journals. Every year, it publishes papers on neuroscience. This means that this journal has the highest acceptance of NeuroIS studies, and researchers can consider this journal when attempting to publish.

Co-author Network

Researchers contribute the most to research achievements and actively find innovative research directions in the field. **Table 2** displays the authors who have published more than three articles and their citation counts. According to the statistics in the table, the number of published articles differs among scholars. Seventeen scholars published more than three articles, accounting for 2.91% of the total. Seven articles were published by one author. Of course, when reviewing the rules of Lotka's law, it is found that the number of authors producing n papers is approximately $1/n^2$ of those producing one paper. This is the inverse square law of scientific productivity: another rule in this law is that of all authors in a given field, 60% will have produced only one paper (Lotka, 1926; Su et al., 2020). However, in the present study, this proportion was 82.5%. Therefore, compared with the definition of Lotka's law, the results of this study are consistent with the conclusion that many scholars have only one publication. The fact that few scholars have high yields in NeuroIS studies indicates that this is the first time that most scholars have entered the field of NeuroIS. In terms of citations, Angelika Dimoka has published four articles that have been cited 548 times, ranking first. Riedl and René (No. 2) published six papers with citations of 428. Kirwan and Brock have published the most (seven papers) among these authors.

By listing the research topics, it can be seen that the tools and methods used in NeuroIS research were the main focus. According to these results, high-yield authors contributed significantly to the NeuroIS study. Two interesting conclusions were drawn based on the authors' productivity. First, among the top five high-yield authors, three are from Brigham Young University. This means that this university has greatly invested in the research of NeuroIS, especially in core research institutions, such as the Neurosecurity Lab for Neuroscience Studies.

Second, Professor Fred D. Davis, the original author of the technology acceptance model, also began NeuroIS studies in 2009 and published a series of papers on the research design, tools, and methods (Dimoka et al., 2011, 2012). He even co-founded the NeuroIS Society and held a NeuroIS Retreat every year to collect papers on NeuroIS and discuss relevant research in NeuroIS.

Figure 3 shows the corresponding author collaboration network. It can be seen obviously that these authors are grouped into six categories, and there is little cooperation among teams. The two teams were relatively conspicuous. The first was the team of Bonnie Brinton Anderson, Jeffrey L. Jenkins, Anthony Vance, C. Brock Kirwan, and David Eargle. Studies include those by Vance et al. (2014, 2018), Anderson et al. (2016a,b,c), and Jenkins et al. (2016). These studies were mainly applied to information security, risk profile, and other topics, which were analyzed using electroencephalography (EEG), fMRI, eye-tracking, and other tools. The second is the work of Angelika Dimoka, Ren é Riedl, Fred D. Davis, and others, who have published Dimoka et al. (2011, 2012) and Riedl et al. (2014). These studies discussed the definition of NeuroIS, tools, and methods and explored measurements of cognitive neuroscience.

In the analysis of citation rates, seven papers with high citation rates (more than 100 times) were screened through WOS. However, only the study of Turel (2016) is a highly cited paper. This study mainly investigates what drives the problematic use of social networks based on the dual-systems theory borrowed from cognitive neuroscience. This article contributes to the study of the dark side of IS use by conceptualizing problematic IS use and explaining its drivers and consequences. The results show that dual-systems theory is an appropriate theoretical perspective to explain problematic IS use, which is better than planned behavior-based models. In addition to the highly cited articles, the three most frequently cited articles are Dimoka (2010); Dimoka et al. (2012) and Riedl et al. (2010), with 232, 185, and 137 citations, respectively. Among them, Dimoka (2010) and Riedl et al. (2010) were both published in MIS Quarterly, the top journal of information systems. These two articles explored the problem of trust and were the earliest studies found in this study. Dimoka (2010) complemented psychometric measures of trust and distrust by observing the location, time, and level of brain activity. Trust and distrust activate different areas of the brain with different effects, explaining why they are different constructs associated with different neurological processes. In addition, using fMRI, Riedl et al. (2010) studied the biological factors in the difference between women and men in their decisions regarding trust. The results show that the brain areas that encode trustworthiness differ between women and men. The two articles both explored biological factors of human behavior in information systems research, contributing significantly to subsequent studies. The paper written by Dimoka et al. (2012) discussed the function of commonly used neurophysiological tools (e.g., EKG, eye-tracking, fMRI, and EEG) in information system research and their major strengths and weaknesses. It proposes some potential thematic areas and research topics: (1) development and use of systems, (2) IS strategy and business outcomes, and (3) group work and decision support. This article also provides some suggestions for the development of NeuroIS. Meanwhile, the study by Dimoka (2012), which was published simultaneously, focused on the application of fMRI in NeuroIS.

Co-citation Network

A co-citation means that one paper is cited in two documents simultaneously. The co-citation network visualizes the relationship between cited articles and their source journals in the selected literature. Through the co-citation of articles, it is clear to see the key literature and pioneering literature referenced by different research methods on NeuroIS. The selected 99 articles cited 6,378 references from 2,644 journals. **Figure 4** categorizes references into three groups. This study extracted articles that cited one of the three kinds of references to analyze their commonalities.

TABLE 1 | The top 10 productive journals from 2010 to 2021.

Ranking	Journals	Documents	TC	D| TC
1	Journal of the Association for Information Science and Technology	20	226	11.3
2	Journal of Management Information Systems	19	832	43.79
3	Decision Support Systems	17	323	19
4	Journal of the Association for Information Systems	11	280	25.45
5	MIS Quarterly	10	686	68.6
6	European Journal of Information Systems	5	50	10
7	Information Systems Research	5	172	34.4
8	Internet Research	4	35	8.75
9	Information Systems Frontiers	3	15	5
10	International Journal of Electronic Commerce	2	111	55.5
11	Journal of Computer-Mediated Communication	2	42	21
12	Information Systems Journal	1	3	3

TC, total citations; D| TC, average number of citations per article.

TABLE 2 | Authors with more than three papers and their citations.

Ranking	Name	Research subject	Documents	Citations
1	Kirwan, C. Brock	Memory, Learning, fMRI	7	212
2	Riedl, René	NeuroIS, Technostress, Digital Transformation, Human-Computer Interaction, Trust in Technology	6	428
3	Anderson, Bonnie Brinton	NeuroIS, Behavioral Information Security, Social Networks, Software Adoption, Women in Technology	6	211
4	Vance, Anthony	Security, Usable Security, NeuroIS, Behavioral Information, Security, Information Security	6	211
5	Jenkins, Jeffrey L.	Human-computer Interaction, Information Systems Security	6	169
6	Eargle, David	Behavioral Information Systems Security, Human-Computer Interaction, Neuroscience Applications to HCI and information Security	5	181
7	Dimoka, Angelika	Decision Neuroscience, Neuroeconomics, Neuromarketing	4	548
8	Davis, Fred D.	Technology Acceptance, NeuroIS	4	355
9	Vom Brocke, Jan	Organizational Design, Digital Strategy, Process Innovation, Enterprise Architecture, Business Engineering	3	182
10	Burgoon, Judee K.	Interpersonal and Non-verbal Communication, Deception, New communication technologies	3	163
11	De Guinea, Ana Ortiz	IT use and impacts, Data analytics, Research methods	3	122
12	Gedeon, Tom	Responsive AI, Neural/Deep Learning, Responsible AI, Multimodal Signal Processing, Affective Computing	3	87
13	Nunamaker, Jay F., Jr.	Systems Analysis and Design, Collaboration Technology, Deception Detection	3	76
14	Djamasbi, Soussan	Human Technology Interaction, UX Research, Decision Support Systems, NeuroIS, Eye Tracking	3	71
15	Twyman, Nathan W.	Information Systems, Deception Detection, Collaboration, Transformative Technologies, HCI	3	61
16	Gregor, Shirley	Information Systems, Decision Support, Philosophy of Technology, Adoption of Technology, Innovation	3	53
17	Riaz, Amir	Knowledge Production, Knowledge Utilization, Human-Computer Interaction, Neuro-IS, Neuro-Management, Social Entrepreneurship	3	53

The first category (green) of citations is the literature review. For example, Straub et al. (2004) discussed the rigor of information systems research methods. In all the literature retrieved, there were 10 references of this kind, and most of them explored the potential research directions in NeuroIS at the overall level. vom Brocke et al. (2020) categorized future research of information systems into (1) IS design, (2) IS use, (3) emotion research, and (4) neuro-adaptive systems. This paper also presents possible challenges in these four fields and potential research directions in the future. Riedl et al. (2014) proposed that editors, reviewers, and authors should carefully consider reliability, validity, sensitivity, diagnosticity, objectivity, and intrusiveness.

The second category (red) focuses on research methodology. For example, Astor et al. (2013) introduced biosignals into information systems research, and Hevner et al. (2004)

TABLE 3 | Citations of documents (>100).

Rank	Author (Year)	Title	Citations
1	Dimoka (2010)	What Does the Brain Tell Us About Trust and Distrust? Evidence from a Functional Neuroimaging Study	232
2	Riedl et al. (2010)	Are There Neural Gender Differences in Online Trust? An fMRI Study on the Perceived Trustworthiness of eBay Offers	185
3	Dimoka (2012)	On the Use of Neurophysiological Tools in IS Research: Developing a Research Agenda for NeuroIS	137
4	Turel and Qahri-Saremi (2016)	Problematic Use of Social Networking Sites: Antecedents and Consequence from a Dual-Systems Theory Perspective	135
5	Wang et al. (2014)	An eye-tracking study of website complexity from \ cognitive load perspective	123
6	Dimoka et al., 2011	Research Commentary—NeuroIS: The Potential of Cognitive Neuroscience for Information Systems Research	121
7	Nunamaker et al. (2011)	Embodied Conversational Agent-Based Kiosk for Automated Interviewing	114

Source: Web of Science.

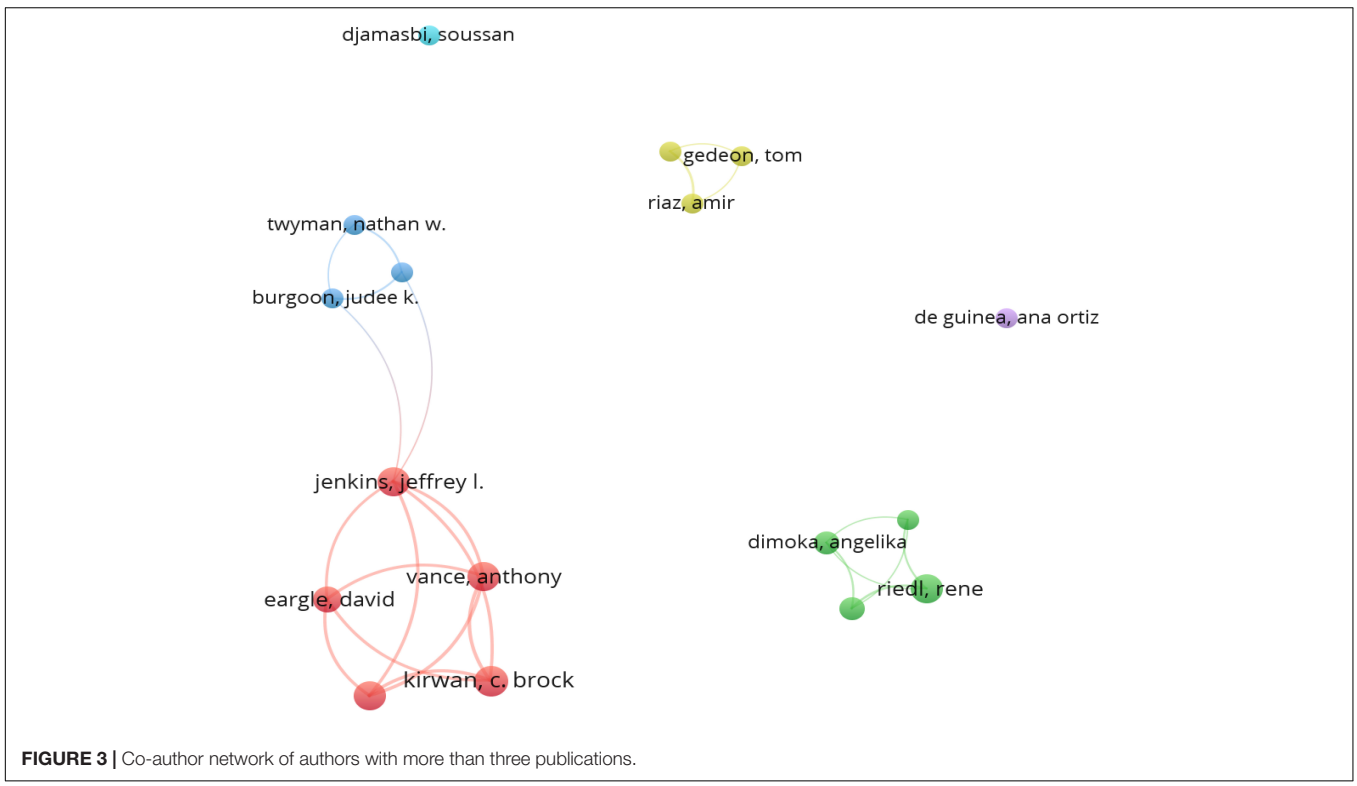

FIGURE 3 | Co-author network of authors with more than three publications.

summarized design science in information systems. Eight articles cited this kind of literature, focusing on the introduction and improvement of research methodology. Hariharan et al. (2017) introduced the structure and function of the NeuroIS experimental platform Brownie according to the features of NeuroIS experiments. Leger et al. (2014) introduced the method of eye fixation-related potential (EFRP) to synchronize eye-tracking with electroencephalogram (EEG), and designed guidelines for researchers to use EFRP.

TABLE 4 | Countries (regions) with more than four documents and their citations.

Ranking	Name	Documents	Citations
1	United States	49	1,846
2	Germany	16	529
3	Mainland China	16	353
4	Australia	14	327
5	Austria	9	456
6	Canada	9	310
7	South Korea	6	268
8	Taiwan	4	129

Source: Web of Science.

The keywords in the third category (blue) citations were eye-tracking or eye movements. Rayner (1998) reviewed research on eye-tracking in information processing, such as reading. Cyr et al. (2009) used eye-tracking to explore how Internet users regard human images as an element of website design in the context of e-commerce websites. Thirteen articles cited this type of literature, focusing on the mechanism of information processing by eye-tracking. For example, Hong et al. (2021) used eye-tracking to identify the role of animated banner ads in online marketing, whereas Jaeger and Eckhardt (2021) used eye movements to examine the safety awareness of phishing users. It is worth noting that many articles cited in these papers were set

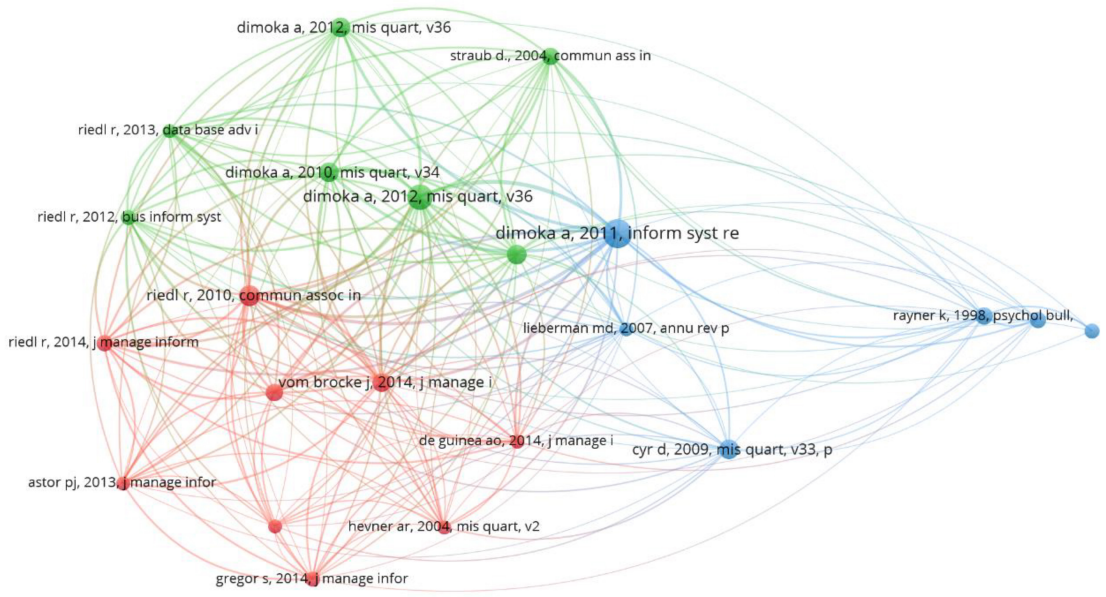

FIGURE 4 | Co-citation Network (Citations ≥ 8).

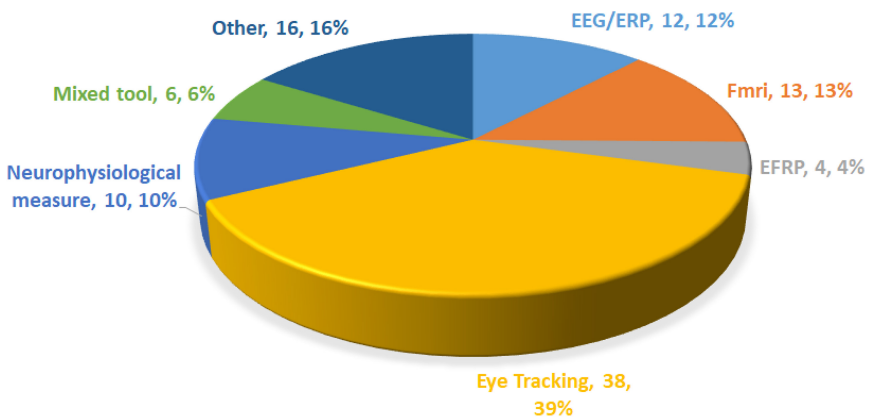

FIGURE 5 | Analysis of neuroscience tools from 2010 to 2021.

on the background of online marketing and searches (e.g., Huang and Kuo, 2011; Kim et al., 2015, 2016; Cheung et al., 2017; Xu and Zhang, 2019; Pfeiffer et al., 2020; Hong et al., 2021).

Country (Region) and Institution Cooperation Network

According to the co-country network, this study analyzed data from 2010 to 2021. A total of 171 research institutions and 24 countries have conducted relevant research on NeuroIS, and eight countries (regions) have published at least four articles. Most articles were written by US researchers. American scholars participated in 49.49% (49 articles) of the publications cited 1,846 times. Mainland China and Germany ranked second in this field, accounting for 16.16% (16 articles), with 529 and 353 citations, respectively. Fourth, Australia has a number of published articles, accounting for 11.57% (14 articles), with 327 citations. Other countries are Austria (9), Canada (9), South Korea (6), and Taiwan (4). According to the comparison of the co-country network, the number of documents published and cited by the United States exceeds the sum of those of the second to fourth countries, proving the leading position of the United States in NeuroIS.

From the perspective of scholars, it can be seen that the countries of highly cited research institutions coincide with the countries of the most cited authors. For example, Angelika Dimoka is from Temple University (United States), Ren é Riedl is from the University of Applied Sciences Upper Austria and the University of Linz (Austria), and Bonnie Brinton Anderson, Jeffrey L. Jenkins, Anthony Vance, and C. Brock Kirwan are from Brigham Young University (United States).

TABLE 5 | Institutions with more than four documents and their citations.

Ranking	Name	Documents	Citations
1	Brigham Young University	10	245
2	University of Pittsburgh	6	197
3	Karlsruhe Institute of Technology	6	96
4	Temple University	5	595
5	University of Linz	5	421
6	Australian National University	5	99
7	Zeppelin University	4	389
8	University of Arkansas	4	355
9	University of Arizona	4	190
10	Zhejiang University	4	135
11	HEC Montréal	4	129
12	University of Michigan	4	107
13	The University of Texas at Austin	4	67
14	Texas Tech University	4	55

Source: Web of Science.

Analysis of Methodological and Neuroscience Tools

In the application of the neuroscience method to information systems, the use of tools is an important reference basis and criterion for NeuroIS researchers to select reference research tools. Bibliometric analysis cannot explore the use of tools in neuroscience. As an improvement, a literature review was conducted in this study through the content analysis method. Bibliometric and content analyses were adopted by referring to the approach of Nagariya et al. (2021) in their research on the sharing economy in the hotel and tourism industry. The adoption of multiple analytical methods aimed to help reduce the bias associated with traditional literature reviews and expert interviews by complementing each other in a holistic, objective, and responsible manner. On the content analysis, this study was conducted in a case-by-case literature review. Two university professors and three research members were divided into two groups to read documents. First, three researchers conducted preliminary literature induction and classification, followed by a review by two university professors to ensure that the classification was accurate. **Figure 5** shows the classification results for the research tools. This study found that neuroscience tools used in information systems mainly include eye-tracking, fMRI, EEG/ERPs, neurophysiological measures, EFRP, and a combination of the above tools.

Among the articles retrieved and shown in **Figure 5**, eye-tracking was the most frequently used tool, used in 38 papers (38.4%). In these studies, several main topics were discussed. For example, using eye-tracking, Djamasbi et al. (2011) found that baby boomers gazed more than Generation Yers on web browsing and online viewing, and their range of gaze was wider. Therefore, if the page did not present key information using a limited number of clear focuses at the top of the fold, Generation Yers were more likely to miss the key information than baby boomers. In subsequent studies, Wang et al. (2014) found that when users performed simple tasks, the fixation count and task completion time were at the highest level on highly complex websites. However, the fixation duration did not show a significant difference among websites with different complexities. This study explains this conclusion from a cognitive-load perspective. In addition, Willems et al. (2019) also used eye-tracking to analyze the effectiveness of online platforms using star ratings to show reputation and product or service quality. They found that reputation star ratings provided more supplementary information than alternative information. Moreover, users' attention to different stars was asymmetric, which means that they paid more attention to situations with fewer stars. Reviewing previous research in the NeuroIS field, it was found that research on eye-tracking focused on online marketing and web search tasks.

The second most commonly used tool was fMRI, used in 13 studies (13.1%). Among these articles, Riedl et al. (2014) used fMRI to explore the differences and similarities between humans and avatars and between humans and humans based on multi-round trust games. They found that humans were better able to judge the credibility of humans and had less medial frontal cortex when judging avatar credibility. This brain region is crucial for predicting other people's thoughts and intentions, and the trustworthiness learning rate is similar in both human and avatar interactions. It was found that when the product sold signaled a high reputation, consumers paid a higher premium for the product. Using fMRI, it was found that the seller's high reputation signal triggered significantly stronger neural activity in brain regions associated with emotions in the prefrontal cortex. In these studies, fMRI analysis has mainly focused on exploring the neural basis of human information processing and decision-making.

The third was EEG/ERPs used in 12.1% of the papers. Specifically, Kuan et al. (2014) examined the role of two types of inducement information on group-buying sites: the number of people who have purchased a product and Facebook friends who like the product. It was found that both positive and negative information about the number of people who purchased had an asymmetrical effect on purchase intention. EEG observations revealed that information about the number of people who purchased was more associated with negative emotions, whereas information about Facebook friends' likes was associated with positive emotions. Moravec et al. (2019) used the behaviors and EEG data of social media users in their study. They found most users could not distinguish between real and fake news and were more likely to believe news consistent with their political views, even if they were flagged as fake news, while titles that challenged their views rarely elicited cognitive activity (ignored). Only 17% of the users could detect fake news. Li et al. (2014) observed user attention and immersion in games using EEG data. Specifically, cortical activity on the left side of the DLPFC is associated with participation in games. Most studies using EEGs/ERPs have focused on the influence of emotion on decision-making.

Fourth is a neurophysiological measure. In addition to traditional neuroscientific methods, some researchers have adopted neurophysiological measures (10 studies). For example, Astor et al. (2013) designed a tool that can continuously display users' emotional states through biofeedback, and adjust the difficulty of the decision-making environment according to users' emotional states when they participate in decision-making

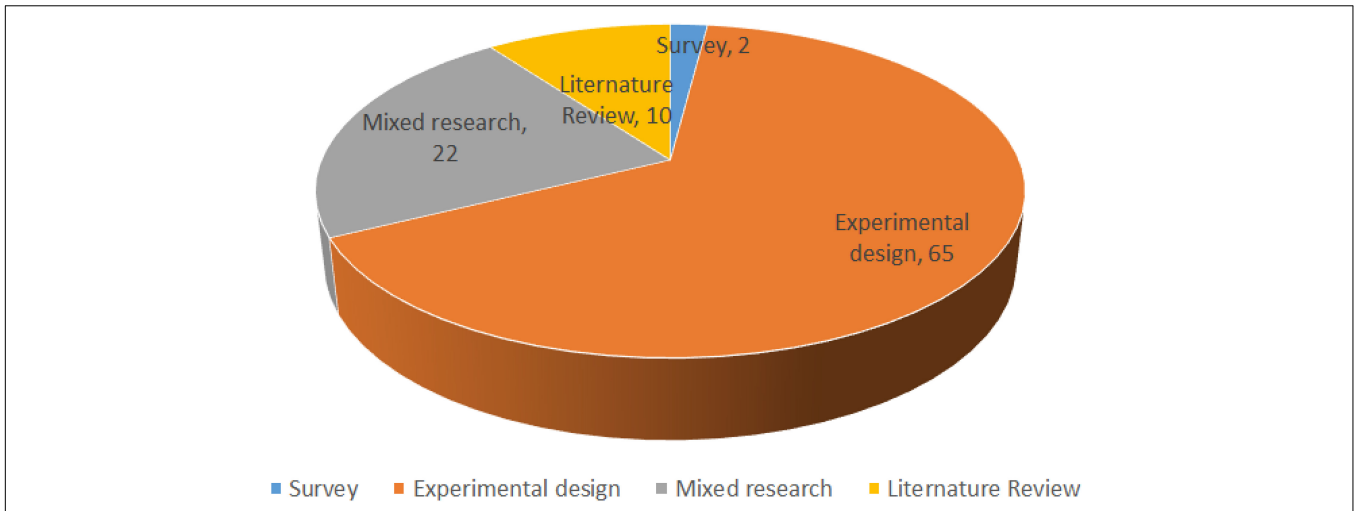

FIGURE 6 | Analysis of research method from 2010 to 2021.

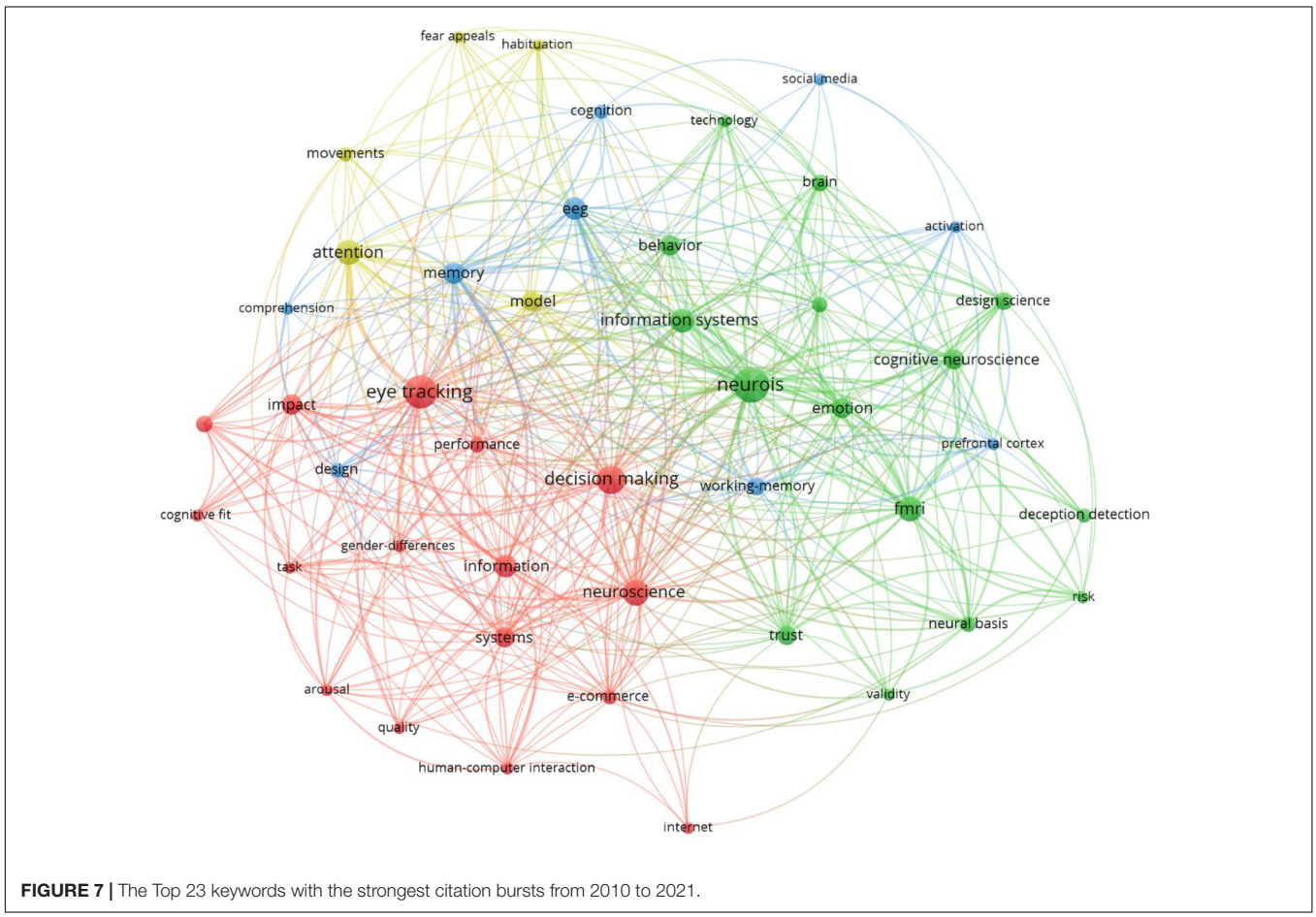

FIGURE 7 | The Top 23 keywords with the strongest citation bursts from 2010 to 2021.

games. EFRP was also used in the other four studies. Leger et al. (2014) introduced this method in their research on Information Systems. Adopting this method, researchers can use EEG and eye-tracking simultaneously to accurately capture users' neural activity at the exact time they start to cognitively process a stimulus. In this paper, an example was given to show that EFRP could detect the attention response when the email notification popped up, the cognition and processing of the pop-up notification, and the motor planning activity designed to decide whether to open the email.

Finally, it is worth noting that six papers in the NeuroIS field adopted mixed tools. For example, Twyman et al. (2014a) built autonomous scientifically controlled screening systems (ASCSS). This system is used to detect whether individuals intentionally withhold information during a criminal investigation. Minas et al. (2014) used EEG, electrodermal activity, and facial electromyography to explore how team members process information received from text-based collaboration during group decision making. This provides neurological evidence for the underlying process of confirmation bias in information processing during online team discussions. These studies mainly focused on mixed research and effectively explored changes in consumer decision-making behaviors through measurements using multiple tools.

Furthermore, based on the previously excavated relevant literature (99 papers in total), the research methods were classified and summarized in **Figure 6**. With regard to research methods, the majority of papers (65 papers) obtained in this study used an experimental design, just two studies used surveys (Moody and Galletta, 2015; Turel and Qahri-Saremi, 2016), and 22 papers applied mixed research. In the mixed study, Schultheiss and Lewandowski (2021) adopted a mixed-research method, including pre-study interviews, an eye-tracking experiment, and a post-experiment questionnaire, to explore the effects of knowledge level and device screen size on users' ability to distinguish between search results and advertisements when using search engines. Zhang and Zhang (2021) first used eye-tracking to obtain the time spent on reading words and subsequently used a neural network model to integrate the time spent on reading words into keyphrase extraction models. Ellison et al. (2020) adopted eye-tracking, survey, and interview methods to confirm that there was no difference in viewing duration between clicking in and not clicking on Facebook content. It can be seen that papers based on mixed research are relatively new, which means that mixed research may be a new trend in the NeuroIS field. In addition, 10 literature review-based studies were conducted for this study. Specifically, Riedl et al. (2014), Tams et al. (2014), and vom Brocke and Liang (2014) published papers on the special issues of JAIS and JMIS in 2014. The remaining literature reviews were distributed evenly between 2010 and 2021. These literature reviews are highly cited and influential and, to some extent, represent the trend that NeuroIS has begun to pay attention to the development and future integration of such research methods in this field in recent years.

Co-occurrence Analysis: Keywords Network

Keywords are intuitive indicators of core research content and topics in a specific scientific field. Research hotspots within a scientific field can be identified through keyword co-occurrence network analysis. A keyword co-occurrence network graph for the 99 articles analyzed in this study, generated using VOSviewer, is illustrated in **Figure 7**; keywords with a frequency greater than or equal to four were visualized. The size of the nodes is proportional to the number of keyword occurrences, with large nodes reflecting research hotspots in a certain field. The thickness of the lines linking nodes represents the strength of the correlation or co-occurrence between those keywords; that is, the thicker the line, the more frequently two keywords appear in the same literature. Different colors represent different clusters (i.e., research topics). **Table 6** lists high-frequency keywords (i.e., those with a frequency greater than or equal to four).

TABLE 6 | Cluster terms.

Clusters	Keywords
1	Activation (28), Arousal (20), Attention (18), Behavior (13), Brain (11), Cognition (10), Cognitive fit (7), Cognitive neuroscience (6), Comprehension (5), Deception detection (4), Decision making (4), Design (4), Design science (4), e-commerce (4), EEG (4), Emotion (4)
2	Eye tracking (32), Fear appeals (16), fMRI (15), Gender-differences (11), Habituation (11), Human-computer interaction (10), Impact (9), Information (8), Information search (7), Information systems (6), Internet (6), Memory (5), Model (4), Movements (4), Neural basis (4)
3	NeuroIS (13), Neuroscience (12), Performance (8), Prefrontal cortex (5), Quality (5), Research Agenda (4), Risk (4), Social media (4), Systems (4)
4	Task (16), Technology (11), Trust (5), Validity (4), Working-memory (4)

Cluster 1 reflected hotspot keywords in the neuroinformatic field, namely activation, arousal, attention, behavior, brain, cognition, cognitive fit, cognitive neuroscience, comprehension, deception detection, decision-making, design, design science, e-commerce, EEG, and emotion. According to these hotspot keywords, relevant research in neuroscience has focused on cognition-induced and conciseness-induced behavioral patterns. Brain, behavior, cognitive fit, and other cognitive neuroscience concepts have served as the foundation for cognitive comprehension, deception detection, and decision-making experiments. For example, Proudfoot et al. (2016) researched how variations in oculometric behaviors evolve during interactions with a deception detection system. Anderson et al. (2016a) investigated how neurobiology affects users' habitual substantive understanding of security warnings and behaviors. Moreover, decision-making has always been a research hotspot. Twenty-seven of the 99 articles (27.84%) discussed in this study were centered on decision-making. For example, Xu et al. (2020) studied seller reputation by exploring emotions and power in online decision-making. Minas et al. (2014) investigated how team members process information received through text-based collaboration during a team decision-making process, as well as how information influences an individual's preference for prediscussion. Day (2010) explored the effectiveness of applying the Needleman–Wunsch algorithm in identifying decision-making strategies using eye movement data. Moshfeghi and Pollick (2019) analyzed consumer demand for information retrieval and discovered brain regions related to inform decision-making through brain activity-related data. This study aims to understand consumers' demand for information. Browne and Walden (2021) explored how consumers make decisions about information search and stop when making shopping behavior decisions and discovered brain activation through experiments to reveal the distributed regional network covered by the brain. These are also decision-making regions in which consumers do not participate in the search.

Browne and Walden (2021) revealed the influence of excessive information consumption on a programmer's information system design. The aforementioned research has focused on the effective use of cognitive neuroscience tools to promote behavioral pattern studies, thereby advancing the comprehensive development of various disciplines.

Cluster 2 reflected the hotspot keywords related to the research tools and basic dimensions of NeuroIS. These keywords were eye-tracking, fear appeal, functional magnetic resonance imaging (fMRI), gender differences, habituation, human-computer interaction, impact, information, information search, information systems, Internet, memory, model, movements, and neural basis. The aforementioned hotspot keywords covered research techniques, such as eye-tracking, movement, and fMRI, in addition to multiple basic research dimensions, such as fear appeal, human-computer interaction, gender differences, and habituation models (Anderson et al., 2016c; Vance et al., 2018; Bera and Poels, 2019; Kalgotra et al., 2019; Hong et al., 2021). Furthermore, much attention has been paid to information capture and comprehensive understanding in terms of research on information systems, information searches, and internalized memory. From the results of the cluster classification, the main research directions were as follows: Anderson et al. (2016b) used eye-movement tracking to learn how habituation occurs when people view security messages repeatedly, thus enabling us to design more effective security messages and reduce the security risks caused by excessive security warnings and reduced stimulus effects. Using fMRI, Warkentin et al. (2016) analyzed cognitive and emotional responses to fear appeals. They compared the arguments of fear appeal theory with the current neurological experience of internal personnel in the face of information security fear appeals. Through analysis, the effect of information system security can be better understood. Jaeger and Eckhardt (2021) used eye-tracking and surveys to analyze the security awareness of phishing emails. According to research findings, previous experiences could effectively improve the awareness of security warnings, but an effective content design could reduce the awareness of security. The results also verify that situational information can improve the awareness of threats and efficiency and the actual behavior response to phishing attacks. In these studies, basic tools and research dimensions in NeuroIS texts were comprehensively explored to broaden our understanding of human cognition, emotion, and behavior and capitalize on the potential of neuroscience knowledge and tools to further expand information systems research.

Cluster 3 reflected the hotspot keywords related to the microscopic inspection of related studies in NeuroIS research, namely NeuroIS, neuroscience, performance, prefrontal cortex, quality, research agenda, risk, social media, and systems. The high-frequency keywords of NeuroIS, neuroscience, and the research agenda, all reflected a microscopic focus on the control of the overall research and development direction of the NeuroIS field. Accordingly, when reviewing the research process, researchers must consider the future outlook, draft a blueprint for future development directions, and analyze the development potential of each research direction. Such studies have proposed views on the future NeuroIS research agenda and investigated its potentially considerable societal contributions (vom Brocke et al., 2020).

Cluster 4 reflected the hotspot keywords related to research techniques and methods and comprised task, technology, trust, validity, and working memory. Task, technology, trust, validity, and other abstract concepts represent current research directions and influences. According to the analysis of Cluster 4, these topics focused on the perspective of technology acceptance in several directions. By analyzing the technology acceptance model commonly discussed in behavioral beliefs, de Guinea et al. (2014) verified the potential implicit determinants of cognitive beliefs in traditional research through neuroscientific experiments. Their study made several contributions to the emerging field of receptive research and NeuroIS, including demonstrating the importance of emotional perception in mediating the effects of neurophysiological states on behavioral beliefs. On the other hand, some studies have used statistical methods and consumer neuroscience theories to take the perspective of technology and trust. For example, Karampournioti and Wiedmann (2021) used Parallax technology to determine how stories affect the user experience in online stores and variables related to branding and behavior. By applying parallax scrolling storytelling techniques, the online store improved the user experience of visitors at both the explicit and implicit information processing levels and enhanced the overall perceived appeal of the online store. Storytelling with parallax motion can effectively convey brand-related associations to consumers, enhance their explicit and implicit brand attitudes, and increase their willingness to pay higher prices. Therefore, according to the results of Cluster 4, this classification mainly focuses on the perspective of technology and trust, and relevant studies are also conducted from the perspective of technology adoption, purchase behaviors, and consumer intentions (Cheung et al., 2017; Mikalef et al., 2021), and then analyzed through the tools and methods of neuroscience.

Keyword Evolution Analysis

To further elucidate research changes in the field, keywords with strong citation bursts were first identified (see **Table 7**).

During the time course of keywords with strong citation bursts from 2010 to 2013, NeuroIS research articles were rare, and the general direction of research revolved around the field of cognitive neuroscience. Research directions mainly concentrated on information search (Huang and Kuo, 2011) and price premium (Dimoka, 2010; Ye et al., 2013). Although price premiums were no longer a focus after this citation burst period, information systems remain the primary topic of research.

The first research climax occurred in 2014 when extensive research into and application of related technologies (e.g., fMRI and working memory) first occurred. In particular, fMRI has been prevalent and has guided the development of research experiments in various directions on a large scale. For example, researchers have explored the problems of habituating security warnings (Vance et al., 2018), the potential to induce trust between individuals and their avatars (Riedl et al., 2014), and the potential to induce trust between individuals and their avatars (Xu et al., 2020). Behavior, decision support, and information

TABLE 7 | Keywords burst.

Keywords	Strength	Begin	End	2010–2021
Cognitive neuroscience	1.33	2010	2012	
Information search	1.06	2010	2011	
Price premium	0.98	2010	2013	
Neural basis	0.98	2010	2013	
Emotion	2.12	2011	2014	
Impact	1.42	2011	2014	
Deception detection	1.2	2011	2014	
Performance	1.54	2013	2014	
FMRI	2.76	2014	2016	
Working memory	1.91	2014	2016	
Acceptance	0.75	2014	2015	
Internet	1.29	2015	2017	
Decision support	1.04	2015	2016	
Behavior	1.55	2016	2017	
Information system	0.8	2016	2018	
Design	0.73	2016	2018	
Eye tracking	1.39	2017	2018	
Criteria	0.77	2017	2019	
Memory	2.53	2018	2019	
Neuroscience	2.25	2018	2019	
Cognitive fit	0.74	2018	2019	
Consumer	0.62	2018	2021	
Comprehension	0.52	2018	2019	

systems have become popular research topics in numerous emerging research fields.

Eye-tracking was introduced in 2017, greatly expanding the related technologies and research methods. Eye-tracking allows for experimental designs that focus on more specific and subtle dimensions in neuroscience, such as cognitive fit and memory (Walden et al., 2018; Bera and Poels, 2019) (including but not limited to working memory). Under these basic conditions, the research direction in this field has been continually extended. Many research objectives and experimental designs have been based on a comprehensive analysis of customer psychology. The promotion of neuroscience technology has also facilitated the analysis and comprehension of user psychology.

DISCUSSION AND CONCLUSION

Research Discussion

Neuroscience attracted great attention from scholars in the field of information systems (IS) a decade ago when Dimoka et al. (2009) systematically introduced the concept of NeuroIS. According to the definition by Riedl et al. (2010), NeuroIS is the application of neuroscience and neurophysiological theories and tools in order to "facilitate scientific progress in the IS discipline." Thus, the present study analyzed 99 articles on NeuroIS retrieved from the WOS database between 2010 and 2021 to provide a deeper insight into the research field. The conclusions drawn from the analysis results are as follows:

The co-author network helps to identify leading researchers and institutions. Angelika Dimoka and René Riedl are two prominent scholars based on their total citations. Both proposed a profound research agenda and outlook for NeuroIS in the early 2010s.

The number of articles published each year has increased steadily, indicating that NeuroIS has experienced preliminary exploration of research hotspots at present. Before 2014, most studies were limited to cognitive neuroscience, and the main research topics focused on information search and price premiums. In 2014, fMRI as well as other related techniques and approaches were extensively used to design and conduct experiments. Later, eye-tracking greatly expanded the methodology of NeuroIS in 2017, which focuses more on the specific and micro dimensions (e.g., cognitive fit and memory). Accordingly, numerous studies have started to apply these techniques to further analyze and comprehend consumer behavior and information processing. For instance, Hong et al. (2021) contributed to this strand of literature by identifying the role of animated banner ads in online marketing with eye-tracking. The advantages and disadvantages of these tools have also been discussed (Dimoka et al., 2012, respectively).

From the perspective of keywords, the most important three clusters are "cognition and behavior," "research methodologies and tools," and "research agenda and potential directions." In addition, many studies have examined the topics of task (e.g., Kim et al., 2015; Cheung et al., 2017; Ahn et al., 2018; Browne and Walden, 2020), trust (Dimoka, 2010; de Guinea et al., 2014; Karampournioti and Wiedmann, 2021), validity (Twyman et al., 2014a,b; Moody and Galletta, 2015), and working memory (Li et al., 2014; Berget and Sandnes, 2016; Jenkins et al., 2016), which may still be hot topics for future research.

According to the cited reference (co-citation), the articles obtained can be divided into three categories, from macro to micro, roughly consistent with the results of word clustering. Some articles cited reviews on NeuroIS or IS and discussed the research field at an aggregate level. Another type of article mainly contributes to NeuroIS by introducing and improving methodologies and techniques. These tools, such as fMRI, EEG, EFRP, and Brownie, as a platform for conducting NeuroIS experiments (Hariharan et al., 2017), to some degree, imply the research landscape of NeuroIS studies. To further understand the hot topic of the time change, keyword emergence analysis was conducted on the progress of keywords in this study. Based on the analysis results, it can be concluded that, from 2010 to 2013, there were few research fields on neural information systems, and researchers focused on the discussion of cognitive neuroscience-related issues during this period. Later, because several special journals in the field of Information Systems were

published in 2014, a large number of studies began to apply fMRI and other research tools. In 2017, NeuroIS embraced the application of technology and eye-tracking, and the research direction was continuously extended. Many experimental designs have been based on a complete analysis of consumer psychology. Compared with the initial research introduced from neuroscience to information systems, the research on NeuroIS was more focused on neurocognitive science, and subsequent research on NeuroIS was further explored by information system researchers. Through content analysis of 99 papers, this study also made several important findings. For example, in the selection and adoption of research tools, eye-tracking is currently the main core tool in the field of information systems, especially for online marketing and web search tasks, followed by tools such as fMRI and EEG/ERPs. The research results in selecting research methodology also show that mixed research was mainly applied after 2020, which also shows that Information Systems researchers attach more importance to the mixture of multiple methods in behavior measurement.

Implications for Academic Research

Research on neural information systems is mainly related to information search, human-computer interaction, e-commerce, and other issues. Such issues are related to consumer decision-making and behavior. Undoubtedly, with the development of the information systems field, this topic has become more important. Bibliometric and content analyses were used to summarize the application of neuroscience in IS research on Information Systems. The following important research prospects and directions are proposed in this study to provide more detailed research directions for researchers in the NeuroIS field.

First, from the perspective of the development of research trends, under the prospect of more and more interdisciplinary integration perspective, apart from the traditional investigation and experiment methods, the research on online purchase has become a new research channel to explore technology adoption, purchase behavior and consumer intention through the tools of neuroscience in major NeuroIS studies. It can also improve consumers' purchase intention to determine the influence of purchase behavior by studying buyers' experiences or decision-making (Xu et al., 2020; Karampournioti and Wiedmann, 2021).

Second, topics such as network security and fake news are also important research directions in the NeuroIS field, particularly in the discussion of social media user behavior (Moravec et al., 2019), information security (Twyman et al., 2014b; Anderson et al., 2016b; Warkentin et al., 2016) and phishing (Jaeger and Eckhardt, 2021). Based on the above two research directions, this study suggests that NeuroIS will remain focused on online buyer decision-making behaviors in the future, especially in the directions of Livestream e-commerce and short video streaming, through which changes in consumer behavior and purchase decision making could be further explored. With regard to information security, discussions of fake information on social media and fake advertisements on social media will continue.

Finally, future research should integrate multiple neuroscientific tools and methods. It can be found that the use of neuroscience tools is gradually diversified. In particular, mixed research methods will gradually become popular in 2020 (Ellison et al., 2020; Zhang and Zhang, 2021). Whether it is empirical research combined with neuroscience experiments, traditional experiments combined with neuroscience experiments, or the integration of multiple neuroscientific experimental tools, it can be found that mixed research is relatively new in NeuroIS. In part, this shows that mixed research is a new trend in NeuroIS. The prediction of consumer behavior can more accurately analyze the impact of consumer behavior decisions.

Research Limitation

However, research limitations cannot be avoided. Although this study used ABS 3-star journals in the field of information systems as the main data source, there are still some limitations. In particular, NeuroIS journals are not limited to 3-star journals. The Journal of Electronic Commerce, Electronic Commerce Research, Frontiers in Neuroscience, Journal of Advertising Research, European Journal of Marketing, Journal of Consumer Psychology, Journal of Interactive Marketing, Journal of Consumer Research, and other journals in the field of e-commerce or marketing have also studied NeuroIS. In addition, the Notes in Information Systems and Organization collected at the NeuroIS Retreat conferences and NeuroIS Society also has a number of NeuroIS-related issues. These studies were not included in this study and can be further analyzed and discussed in future studies.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

C-LL and ZC designed the research and provided guidance throughout the entire research process. C-LL, ZC, and XJ collected the references, did the literature analysis, and wrote the manuscript. GC helped translating and offered modification suggestions. XJ participated in the collecting, analyzing, and organizing of the literature. All authors contributed to the article and approved the submitted version.

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Choice perseverance underlies pursuing a hard-to-get target in an avatar choice task

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People sometimes persistently pursue hard-to-get targets. Why people pursue such targets is unclear. Here, we hypothesized that choice perseverance, which is the tendency to repeat the same choice independent of the obtained outcomes, leads individuals to repeatedly choose a hard-to-get target, which consequently increases their preference for the target. To investigate this hypothesis, we conducted an online experiment involving an avatar choice task in which the participants repeatedly selected one avatar, and the selected avatar expressed their valence reactions through facial expressions and voice. We defined "hard-to-get" and "easy-to-get" avatars by manipulating the outcome probability such that the hard-to-get avatars rarely provided a positive reaction when selected, while the easy-to-get avatars frequently did. We found that some participants repeatedly selected hard-to-get avatars (Pursuit group). Based on a simulation, we found that higher choice perseverance accounted for the pursuit of hard-to-get avatars and that the Pursuit group had significantly higher choice perseverance than the No-pursuit group. Model fitting to the choice data also supported that choice perseverance can account for the pursuit of hard-to-get avatars in the Pursuit group. Moreover, we found that although baseline attractiveness was comparable among all avatars used in the choice task, the attractiveness of the hard-to-get avatars was significantly increased only in the Pursuit group. Taken together, we conclude that people with high choice perseverance pursue hard-to-get targets, rendering such targets more attractive. The tolerance for negative outcomes might be an important factor for succeeding in our lives but sometimes triggers problematic behavior, such as stalking. The present findings may contribute to understanding the psychological mechanisms of passion and perseverance for one's long-term goals, which are more general than the romantic context imitated in avatar choice.

KEYWORDS

choice perseverance, pursuit behavior, avatar choice task, preference, reinforcement learning, hard-to-get

Introduction

People sometimes persistently pursue "hard-to-get" targets that do not easily provide the desired outcomes. For instance, scientists passionately pursue specific hypotheses that are difficult to prove for a long time (e.g., Singh, 1997). Even in the context of mate selection, people direct their unrequited passion to a person who does not respond positively and sometimes even pursue a specific person as a stalker (Meloy, 1999; Marazziti et al., 2015). However, it is poorly understood why people pursue hard-to-get targets.

Reinforcement learning has been widely used in a variety of areas to account for choice behavior in organisms (Doya, 2007). From a conventional reinforcement learning perspective, choice behaviors depend on previously obtained outcomes (Sutton and Barto, 1998; Daw and Tobler, 2014). According to this outcome-dependent process, an option that is never reinforced is rarely chosen. Thus, it is difficult to explain the pursuit of hard-to-get targets by reinforcement learning. From the computational perspective of reinforcement learning, previous studies have reported that asymmetric value updating leads to repetitive choices as follows: asymmetric value updating is able to facilitate the impact of positive outcomes and inhibit the impact of negative outcomes, subsequently leading individuals to repeat their previous choice (Katahira, 2018). However, hard-to-get targets rarely provide positive outcomes. On the other hand, humans and other animals have an inherent tendency to repeat their past choice independently of past outcomes (Lau and Glimcher, 2005; Schönberg et al., 2007; Akaishi et al., 2014; Alós-Ferrer et al., 2016; Erev and Haruvy, 2016). This tendency, called choice perseverance, is often incorporated into reinforcement learning models (Schönberg et al., 2007; Gershman et al., 2009; Katahira, 2015; Wilson and Collins, 2019; Sugawara and Katahira, 2021; Wang et al., 2022). We hypothesized that choice perseverance can account for the pursuit of hard-to-get targets more than asymmetric value updating.

If choice perseverance accounts for the pursuit of hard-to-get targets, are scientists and stalkers coasting on unattractive targets? Many studies have reported that choice *per se* increases the preference for a chosen target (Brehm, 1956; Ariely and Norton, 2008; Sharot et al., 2009; Izuma and Murayama, 2013; Cockburn et al., 2014; Schonberg et al., 2014; Koster et al., 2015; Nakao et al., 2016; Hornsby and Love, 2020). Through this choice-induced reevaluation, the chosen target becomes more preferred, which often leads an individual to choose the same option again. Therefore, we also hypothesized that if the target is continuously chosen due to choice perseverance, the target becomes recognized as more attractive.

This study aimed to investigate the above-mentioned hypotheses that choice perseverance accounts for the pursuit of hard-to-get targets and consequently increases the attractiveness of the pursued targets based on choice-induced reevaluation. We constructed an avatar choice task that mimicked partner selection in which the participants repeatedly select one avatar, and the selected avatar expresses the valence reactions through facial expressions and voice. We defined "hard-to-get" and "easy-to-get" avatars by manipulating the outcome probability such that hard-to-get avatars rarely provide a positive reaction when selected, while easy-to-get avatars frequently do. To control the baseline attractiveness of the avatars presented in the choice task, we selected avatars based on preference ratings that the participants provided before completing the choice task. Additionally, by manipulating the outcome probabilities (see section "Materials and methods" for further information), we established hard-to-get and easy-to-get avatars. The participants rated the attractiveness of the avatars again after the choice task, allowing us to examine whether attractiveness was altered by the choice task. All participants pursued the easy-to-get avatar, which frequently responded positively, whereas some participants pursued the hard-to-get avatar, which rarely responded positively. The simulation supported the hypothesis that the pursuit of the hard-to-get avatar was caused by higher choice perseverance. Subsequently, this hypothesis was empirically confirmed by fitting models to the experimental data.

Materials and methods

Participants

One hundred fifty participants were recruited *via* CrowdWorks.[1] Due to the nature of our task, we only recruited participants who were at least 18 years old and were romantically interested in women. At the time this study was designed, there was no information regarding the effect size of the difference between participants who pursued and did not pursue the hard-to-get avatar. Therefore, the power analysis was conducted assuming that the difference between the two groups had a moderate effect size (0.25) (Cohen, 1988). The power analysis (α = 0.05 and β = 0.80) revealed that a minimum sample size of 64 participants per group was necessary. In addition, considering the possibility that the proportion of participants who pursued the hard-to-get avatar was relatively small, we decided to recruit 150 participants. The study was approved by the ethical research committee at Nagoya University and was carried out in accordance with relevant guidelines and regulations (NUPSY-200306-K-01).

Online experimental procedures

Informed consent was obtained from all participants when they clicked "I Agree" after reading information

1 https://crowdworks.jp/

regarding the aims and procedures of this study. After they completed the survey collecting basic demographic information, including gender and age, they downloaded the Inquisit player (Millisecond Software LLC, Seattle, WA, United States) and started a series of behavioral tasks (see the details below). To protect the participants' privacy, all data were anonymized. If the participants completed the entire task and survey without interruption, we paid them 550 yen (approximately $5).

To exclude the effect of inappropriate choice behavior, the following exclusion criteria were applied: (i) the participants did not respond within the time limit (3,000 ms) in more than 30% of the total trials in the choice task, (ii) the participants' choice reaction time was too short (less than 300 ms) in more than 30% of trials in the task, and (iii) the participants demonstrated a task-irrelevant choice pattern, such as alternating between left and right or always selecting only one side (even though each avatar randomly appeared on both sides). Only two participants were excluded from the subsequent analyses based on criterion (i). No participants met criterion (ii) or (iii). Thus, the data of 148 participants (129 males and 19 females; age: range = 18–65 years, mean ± SD = 38.07 ± 11.03) were analyzed.

Behavioral task

Avatar evaluation task

In the online experiment, the participants performed the following two tasks: an avatar evaluation task and an avatar choice task. We created 48 avatars by using VRoid Studio (Pixiv Inc.[2]). First, the participants performed an avatar evaluation task in which they investigated the baseline attractiveness of 48 avatars. In this task (**Figure 1A**), the same avatar with different facial expressions (positive, neutral, and negative expressions) was displayed on the computer screen in a horizontal arrangement. For all avatars, the positive stimulus was a smiling facial expression, while the negative stimulus was a disappointed facial expression. The stimuli used in this task were identical across all participants. The participants were asked to rate the subjective attractiveness of the presented avatar on a 9-point scale (1: not at all attractive, 9: very attractive) by pushing numeric keys on their PCs. Such a point scale has also been used in previous studies investigating facial attractiveness (Shibata et al., 2016; Sakano et al., 2021). In this study, the initial evaluation task aimed to select avatars rated as more attractive than the middle point. Additionally, the second evaluation task aimed to assess the change in attractiveness compared to the initial evaluation task. We considered a 9-point scale a sufficient range to achieve these aims. The order of the presentation of the avatars was randomized across the participants. The full text of the instructions for the avatar evaluation task is shown in the **Supplementary Material**.

2 https://vroid.com/en

After the avatar evaluation task was completed, the participants performed the avatar choice task. To minimize the difference in the baseline attractiveness of the avatars used in the avatar choice task as much as possible, eight avatars were selected based on their attractiveness rating by the participants in the preceding avatar evaluation task. Avatars were selected following three steps.

- Step 1: Because it was important that the avatar used in this task was attractive to the participant (i.e., score of more than 6 points) and had the potential to become more attractive (i.e., did not score too high), avatars rated 6 or 7 points were selected.
- Step 2: If fewer than eight avatars were rated 6 or 7 points, among the avatars that rated less than 5 points, the avatar with the highest rating was selected.
- Step 3: If the total number of selected avatars was still less than eight, among the avatars rated more than 8 points, the avatar with the lowest rating selected. If there was more than one avatar with the highest rating among the avatars rated less than 5 points in Step 2 or with the lowest rating among the avatars rated more than 8 points in Step 3, an avatar was randomly selected from the avatars that fit the criteria. Then, Steps 2 and 3 were repeated in sequence until eight avatars were selected.

The participants again rated the attractiveness of the 48 avatars presented in the initial evaluation task after they completed the avatar choice task, allowing us to investigate whether the attractiveness of the avatars was altered after the choice task.

Avatar choice task

The avatar choice task consisted of two sessions. Based on the avatar evaluation task, we selected eight avatars that rated similar in attractiveness by each participant. Four pairs of avatars were randomly created from the eight selected avatars. Two pairs were used in the first session, and the remaining avatars were used in the second session. In each session, the participants completed 80 trials (40 trials/pair). The trials of both pairs were presented in a random order for each participant and session. That is, in each session, pairs A and B were presented in a mixed manner. In each trial (**Figure 1B**), the participants were required to choose one of two avatars with a neutral facial expression presented simultaneously on the screen for 3,000 ms. The presented position of the avatars was randomized across trials. After the participant selected an avatar, the selected avatar was highlighted with a red frame until 3,000 ms elapsed. In our previous study (Sugawara and Katahira, 2021), which investigated choice behaviors using non-meaning abstract images, the subjects were asked to choose one option for 2,000 ms. Some subjects did not complete their choice within this duration. Based on this experience, we extended the

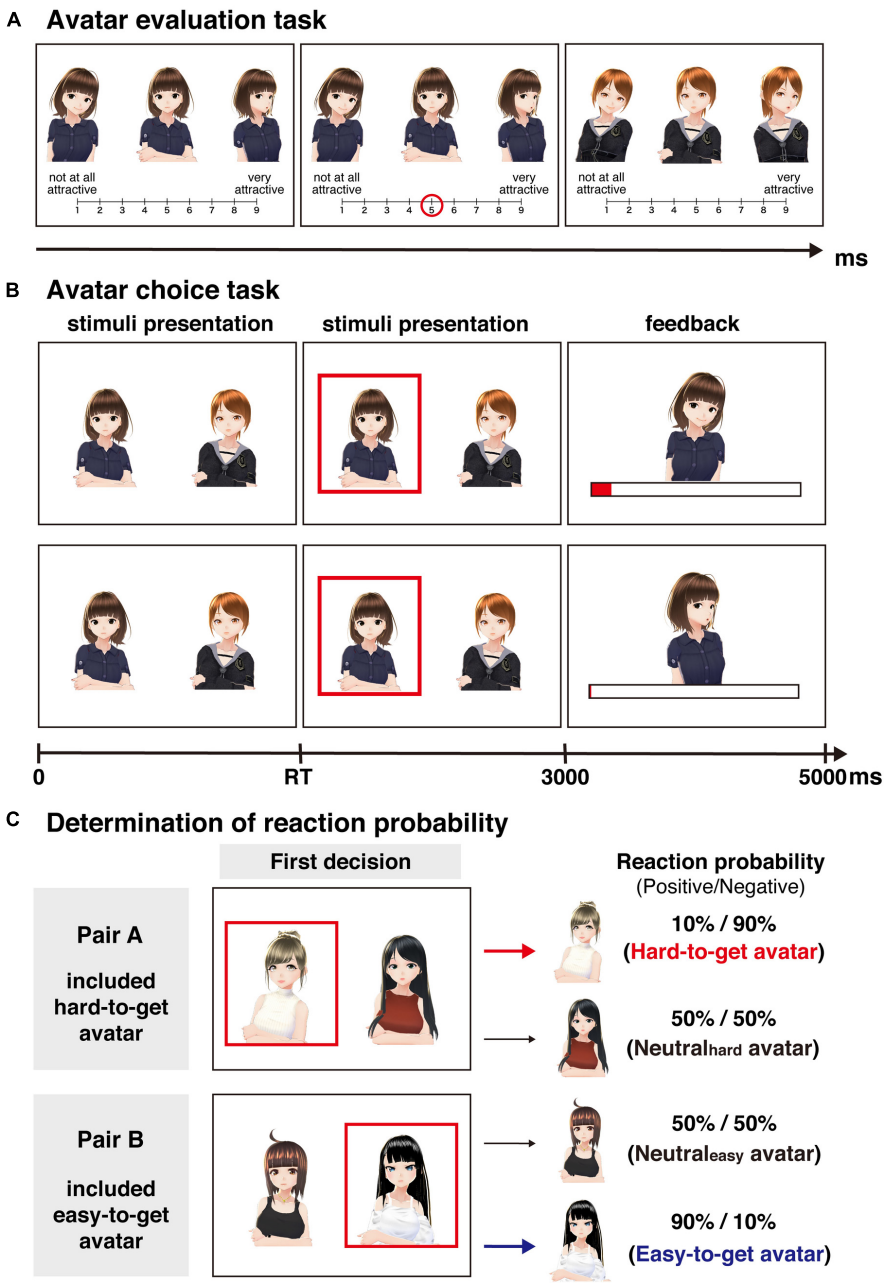

FIGURE 1
Behavioral tasks. **(A)** Avatar evaluation task. Participants were asked to rate the attractiveness of 48 avatars on a 9-point scale. **(B)** Avatar choice task. This task required participants to choose one of the two avatars displayed on the screen and to maximize the extent to which the avatar liked them, represented as a length of red bar. After they chose an avatar (RT is response time), the reaction from the chosen avatar was displayed. The upper line represents the flow of the task with a positive avatar reaction, while the lower line represents the flow of the task with a negative avatar reaction. Positive reactions increase likeability, while negative reactions do not alter likeability. **(C)** The outcome probability for each avatar was determined based on the first choice in the avatar choice task. In pair A, the initially chosen avatar was rarely associated with positive reactions in subsequent trials (positive/negative = 0.1/0.9; i.e., hard-to-get avatar). On the other hand, the initially chosen avatar in pair B was frequently associated with positive reactions in subsequent trials (positive/negative = 0.9/0.1; i.e., easy-to-get avatar). Avatar images reproduced with permission from Pixiv Inc.

duration of choice to 3,000 ms in the present study. Then, the visual and auditory stimuli associated with the reaction of the selected avatar were presented for 2,000 ms. Specifically, the positive reaction was a smiling facial expression and a happy voice, while the negative reaction was a disappointed facial expression and a bored voice. When the reaction was displayed,

a horizontal bar representing the accumulated liking from the avatar for the participant was presented below the avatar. At the beginning of the session, the width of this bar was zero for all avatars. Since the display size depended on the participant, the bar increased by 2% of the screen width when the avatar expressed a positive reaction, while the bar did not change when the avatar expressed a negative reaction. The participants were asked to maximize the extent to which the avatars liked them throughout the task. In the first trial of each avatar pair, the reaction of the selected avatar was always negative. In the following trials, the ratio of positive and negative reactions was determined by the first choice to minimize the influence of first impressions (Shteingart et al., 2013). For pairs A and B, the reaction probability (positive/negative) of the initially chosen avatar was set at 0.1/0.9 and 0.9/0.1, respectively. Based on this probability, we referred to the initially chosen avatar in pair A as the "hard-to-get" avatar and the initially chosen avatar in pair B as the "easy-to-get" avatar. For the unchosen avatars of both pairs (called "$\text{neutral}_{\text{hard}}$" and "$\text{neutral}_{\text{easy}}$") in the first trial, the reaction probability was set at 0.5/0.5. These probabilities were fixed across the task. The participants were not informed in advance of the response probability of each avatar. Therefore, the participants were required to learn the response probability of each avatar (**Figure 1C**). The full text of the instructions for the avatar choice task is shown in the **Supplementary Material**.

Behavioral analyses

We calculated the choice probability (hereafter CP) of avatars presented in the avatar choice task by dividing the number of choices by the number of trials (40 per avatar). Based on the CP of the hard-to-get avatar (CP_{hard}), the participants were divided into the following two groups: the Pursuit group (CP_{hard} was more than 0.5) and the No-pursuit group (CP_{hard} was less than 0.5). Since there was no previous evidence regarding the pursuit of hard-to-get targets, the criteria for grouping were based on the chance level (i.e., 0.5). To confirm the difference in the CP of the hard-to-get and easy-to-get avatars between groups, two-way mixed-design analysis of variance (ANOVA) with group (Pursuit vs. No-pursuit) and avatar (hard-to-get vs. easy-to-get) was conducted.

To examine whether the baseline attractiveness differed among the avatars, including hard-to-get, easy-to-get, $\text{neutral}_{\text{hard}}$, $\text{neutral}_{\text{easy}}$, and unused avatars that were not presented in the choice task in the two groups, two-way mixed-design ANOVA with group (Pursuit vs. No-pursuit) and avatar (hard-to-get, easy-to-get, $\text{neutral}_{\text{hard}}$, $\text{neutral}_{\text{easy}}$, and unused) was performed. Additionally, to investigate whether attractiveness changed after the avatar choice task, we calculated the difference in the avatars' attractiveness before and after the participants completed the avatar choice task. Then, two-way mixed-design ANOVA with group (Pursuit vs. No-pursuit) and avatar (hard-to-get, easy-to-get, $\text{neutral}_{\text{hard}}$, $\text{neutral}_{\text{easy}}$, and unused) was performed. To examine whether the attractiveness of each avatar changed, the degree of change in attractiveness was compared with zero using one-sample *t*-tests. The issue of multiple comparisons for one-sample *t*-tests was corrected with Bonferroni's method. Moreover, to examine whether the choice *per se* increased the attractiveness of the chosen avatar, a general linear model analysis was performed. In this model, the change in attractiveness was a dependent variable. The changes in the attractiveness of the avatars used in the choice task were pooled across all participants. The number of choices, the number of positive reactions, and an interaction were independent variables.

All analyses were executed using R version 4.0.2 statistical software.[3] Mendoza's multisample sphericity test was used to check the validity of the sphericity assumption in all ANOVAs. To correct for violation of the sphericity assumption, Greenhouse–Geisser's adjustment of the degrees of freedom was used in all ANOVAs when appropriate. *Post hoc* pairwise comparisons for significant effects were conducted based on Shaffer's correction for multiple comparisons. The statistical threshold for significance was set at 0.05 for all behavioral analyses.

Computational models

To investigate whether asymmetric value updating or choice perseveration better explains the pursuit of hard-to-get targets, we fit (i) asymmetric and (ii) perseveration models to the choice data. In addition, we previously demonstrated that a hybrid model including both asymmetric value updating and choice perseverance allows us to separately evaluate the contribution of these two cognitive processes to actual choice behavior (Sugawara and Katahira, 2021). Thus, we also fit (iii) a hybrid model. All models were modified based on a typical Q-learning model (called the "RL model"):

$$\delta(t) = R(t) - Q_i(t), \tag{1}$$

$$Q_i(t+1) = Q_i(t) + \alpha\delta(t). \tag{2}$$

Throughout this article, we usually consider cases with only two options ($i = 1$ or 2). The model assigns each option i an expected outcome $Q_i(t)$, where t is the index of the trial. The initial Q-values are set to zero [i.e., $Q_1(1) = Q_2(1) = 0$]. The model updates the Q-values depending on the outcome of the choice

3 http://cran.us.r-project.org

(i.e., the reaction of the chosen avatar). The actual outcome at trial t is denoted by $R(t)$. We typically consider a binary outcome case whereby we set $R(t) = 1$ if a positive reaction is given and $R(t) = 0$ if a negative reaction is given. Learning rate α determines how much the model updates the action value depending on the reward prediction error, $\delta(t)$. Here, we denote the option that is chosen at trial t by $act(t)$ (= 1 or 2). Based on the set of Q-values, the model assigns the probability of choosing option 1 using the softmax function:

$$P(act(t) = 1) = \frac{1}{1 + \exp\left(-\beta\left[Q_1(t) - Q_2(t)\right]\right)}, \quad (3)$$

where β is called the inverse temperature parameter, which determines the sensitivity of the choice probabilities to differences in Q-values.

Based on the RL model, the asymmetric model assumes two independent learning rates:

$$Q_i(t+1) = \begin{cases} Q_i(t) + \alpha^+\delta(t) & \text{if } \delta(t) \geq 0 \\ Q_i(t) + \alpha^-\delta(t) & \text{if } \delta(t) < 0, \end{cases} \quad (4)$$

where α^+ adjusts the amplitude of value changes from one trial to the next when prediction errors are positive (when the actual reward $R(t)$ is better than the expected outcome $Q(t)$); the changes with α^- are vice versa (Frank et al., 2007; Gershman, 2015; Palminteri and Lebreton, 2022).

The perseveration model is also based on the RL model and adds the computational process of choice history independent of the outcome-based learning process (Schönberg et al., 2007; Gershman et al., 2009; Akaishi et al., 2014):

$$C_i(t+1) = C_i(t) + \tau\left(I(act(t) = i) - C_i(t)\right). \quad (5)$$

Choice trace $C_i(t)$ is defined to introduce the effect of past choice into the CP. The initial values of $C_i(t)$ are set to zero [i.e., $C_1(1) = C_2(1) = 0$]. Indicator function $I(\cdot)$ takes a value of 1 if the statement is true and 0 if the statement is false. Decay rate τ is a free parameter that determines the number of preceding choices in the choice history influencing the current choice. When the choice is binary, the probability of choosing option 1 is implemented by the following:

$$P(act(t) = 1) = \frac{1}{1 + \exp\left(-\beta\left[Q_1(t) - Q_2(t)\right] - \varphi\left[C_1(t) - C_2(t)\right]\right)}, \quad (6)$$

where the weight of choice history (φ) is a parameter that controls the tendency to repeat previous choices or avoid previously chosen options. A high positive value of this parameter indicates that the agent frequently repeats the previous choice.

Finally, the hybrid model has features of both asymmetric and perseveration models. This model incorporates not only asymmetric learning rates but also choice traces (equations 4–6). A previous study demonstrated that this hybrid model allows separate evaluation of asymmetric learning rates and choice perseverance (Katahira, 2018; Sugawara and Katahira, 2021).

Simulation

To investigate what computational process contributes to the pursuit of the hard-to-get avatar, we simulated agents' choices with the hybrid model. In particular, we systematically varied the free parameters of the hybrid model and evaluated CP_{hard} and CP_{easy} based on the simulated choice data. The task structure used in the simulation was identical to that in the online experiment.

The hybrid model had five parameters: learning rates for positive and negative reward prediction error (α^+, α^-), inverse temperature (β), decay rate (τ), and weight of choice history (φ). Because we were interested in the degree of asymmetric learning rates, the difference in learning rates ($\alpha_{bias} = \alpha^+ - \alpha^-$) was calculated as the learning rate bias. In case 1, to examine the parameters related to the impact of past outcomes, the learning rate bias ($-1 \leq \alpha_{bias} \leq 1$, interval = 0.1) and inverse temperature ($0 \leq \beta \leq 10$, interval = 1) were varied, but the decay rate ($\tau = 0.5$) and the weight of choice history ($\varphi = 1$) were fixed. In case 2, to examine the parameters related to the impact of past choice, the decay rate ($0 \leq \tau \leq 1$, interval = 0.1) and the weight of choice history ($0 \leq \varphi \leq 10$, interval = 1) were varied, but the learning rate bias ($\alpha_{bias} = 0$) and inverse temperature ($\beta = 2$) were fixed. We hypothesized that the increased CP_{hard} would be accounted for by the higher choice perseverance, which was represented as the greater weight of choice history. Thus, we further examined the interaction between the weight of choice history and parameters related to the impact of past outcomes on the CP. In case 3, the learning rate bias ($-1 \leq \alpha_{bias} \leq 1$, interval = 0.1) and the weight of choice history ($0 \leq \varphi \leq 10$, interval = 1) were varied, while the inverse temperature ($\beta = 2$) and the decay rate ($\tau = 0.5$) were fixed. In case 4, the inverse temperature ($0 \leq \beta \leq 10$, interval = 1) and the weight of choice history ($0 \leq \varphi \leq 10$, interval = 1) were varied, while the learning rate bias ($\alpha_{bias} = 0$) and the decay rate ($\tau = 0.5$) was fixed. In the simulation, 100 virtual datasets were simulated for each parameter setting.

Parameter estimation and model selection procedures

We fit the four models mentioned above (i.e., asymmetric, perseveration, and hybrid models) to the choice data derived from the avatar choice task. The standard RL model was also included as a benchmark for model fitting. Using the R function "solnp" in the Rsolnp package (Ghalanos and Theussl, 2015), we fit the parameters of each model with the maximum a

posteriori estimation and calculated the log marginal likelihood for each model using the Laplace approximation (Daw, 2011). If all models have equal prior probability, because the marginal likelihood is proportional to the posterior probability of the model, the model resulting in the highest marginal likelihood is the most likely one given a dataset. Note that this study used the negative log marginal likelihood (i.e., lower values indicate a better fit). The prior distributions and constraints were set following previous studies (Palminteri et al., 2017; Sugawara and Katahira, 2021). All learning rates were constrained to the range of $0 \leq \alpha \leq 1$ with a *beta* (1.1, 1.1) prior distribution. The inverse temperature was constrained to the range of $\beta \geq 0$ with a *gamma* (shape = 1.2, scale = 5.0) distribution. In the perseverance model, the decay rate was constrained to the range of $0 \leq \tau \leq 1$ with a *beta* (1, 1) distribution (i.e., a uniform distribution), and the choice trace weight was constrained to the range of $-10 \leq \varphi \leq 10$ with a *norm* ($\mu = 0$, $\sigma^2 = 5$) distribution.

For the model comparisons, two-way mixed-design ANOVA with group (Pursuit and No-pursuit) and model (RL, asymmetric, perseveration, and hybrid) was conducted to compare the log marginal likelihoods. Additionally, we compared the estimated model parameters. For the learning rates (α_c^+, α_c^+), two-way mixed-design ANOVA with group and valence was performed. To correct for the violation of the sphericity assumption, Greenhouse–Geisser's adjustment of the degrees of freedom was used for the within-subject factor when appropriate. *Post hoc* pairwise comparisons were performed based on Shaffer's correction for multiple comparisons. For the bias of learning rates, inverse temperature, decay rate, and weight of choice history, the group difference was evaluated using a two-sample *t*-test. All analyses were executed using R version 4.0.2 statistical software (see text footnote 3). The statistical threshold for significance was set at 0.05 for all comparisons of model fit and estimated model parameters.

Results

The data of 148 participants (129 males and 19 females; age: range = 18–65 years, mean ± SD = 38.07 ± 11.03) were analyzed in the following steps. First, by calculating the CP in the avatar choice task, we investigated whether some participants pursued the hard-to-get avatars. Second, based on the subjective ratings of the attractiveness of the avatars, we tested the hypothesis that the pursuit of a specific avatar consequently increased the attractiveness of the pursued avatar. Third, to determine which cognitive processes (i.e., asymmetric value updating or choice perseverance) accounted for the pursuit of the hard-to-get avatar, we simulated hypothetical choice rates by varying the parameters of the hybrid model including the two cognitive processes (Sugawara and Katahira, 2021). Finally, to empirically confirm the prediction from the simulation, we fitted some variants of the reinforcement learning models to the actual choice data collected in the online experiment.

Behavioral and subjective evaluation results

Choice probability in the avatar choice task

To characterize the participants who pursued the hard-to-get avatar despite frequent negative reactions, we focused on the choice probability of the hard-to-get avatar (CP_{hard}) in the avatar choice task. For 68 of 148 participants, CP_{hard} was greater than 0.5 (i.e., they chose the hard-to-get avatar in more than half of the trials). Thus, we divided the participants into two different groups based on CP_{hard}. The participants with a CP_{hard} value greater than 0.5 were assigned to the Pursuit group (n = 68; range = 0.50–1.00, mean ± SD = 0.80 ± 0.20), while the participants with a CP_{hard} value lower than 0.5 were assigned to the No-pursuit group (n = 80; range = 0.063–0.49, mean ± SD = 0.28 ± 0.12). The CP exhibited significant group differences between the hard-to-get and easy-to-get avatars [**Figure 2**; two-way mixed-design ANOVA; group × avatar interaction: $F(1,146) = 144.29$, $p < 0.001$, $\eta^2_G = 0.31$]. CP_{hard} in the Pursuit group was significantly higher than that in the No-pursuit group [simple main effect of group; $F(1,146) = 385.66$, $p < 0.001$, $\eta^2_G = 0.73$], confirming that the participants were grouped as intended. Meanwhile, CP_{easy} was comparable between groups [Pursuit group: range = 0.44–1.00, mean ± SD = 0.90 ± 0.17; No-pursuit group: range = 0.14–1.00, mean ± SD = 0.84 ± 0.20; simple main effect of group: $F(1,146) = 3.87$, $p = 0.051$, $\eta^2_G = 0.026$]. These results confirmed that the participants in the Pursuit group behaved differently only toward the hard-to-get avatar, whereas the participants in both groups repeatedly chose the easy-to-get avatar.

Attractiveness of avatars before and after the avatar choice task

If the baseline attractiveness of the initially chosen avatar was higher than that of the unchosen avatar, this difference in baseline attractiveness might have affected whether the participant pursued the hard-to-get avatar. However, our results indicated that the attractiveness of the avatars used in the choice task was not different between groups and that the paired avatars were rated at the same level of attractiveness in both groups. We compared the attractiveness rated before the choice task between avatars and groups. The baseline attractiveness for any type of avatar (i.e., hard-to-get, easy-to-get, $neutral_{hard}$, $neutral_{easy}$, and unused avatars) was not significantly different between groups [**Supplementary Figure 1**; two-way mixed-design ANOVA; main effect of group: $F(1,146) = 0.28$, $p = 0.60$, $\eta^2_G < 0.001$; group × avatar interaction: $F(1.4,204.05) = 0.32$,

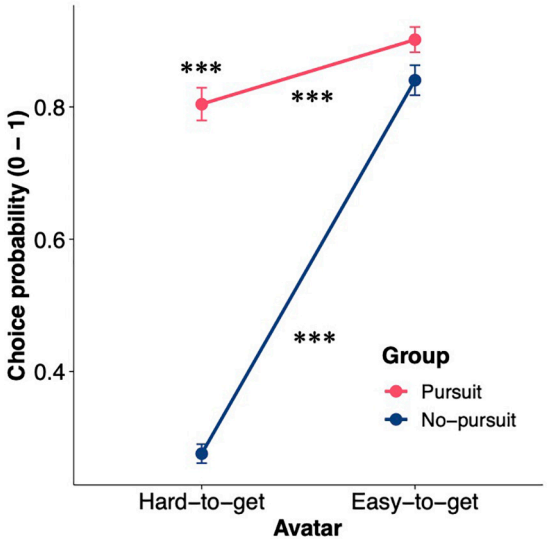

FIGURE 2
Choice probability for the hard-to-get and easy-to-get avatars in the two groups. The figure shows the choice probability for the hard-to-get and easy-to-get avatars in the two groups. The error bars represent the standard error of the mean. Asterisks above points denote whether the difference in choice probability between two groups for the avatar was significant, while asterisks above or below lines denote whether the difference in choice probability between two avatars was significant in each group: $^{***}p < 0.001$.

$p = 0.64$, $\eta^2_G = 0.001$]. On the other hand, baseline attractiveness was significantly different among avatars [main effect of avatar: $F(1.4,204.05) = 82.20$, $p < 0.001$, $\eta^2_G = 0.223$]. The avatars used in the choice task were rated as more attractive than the unused avatars [*post hoc* pairwise comparisons; vs. hard-to-get avatar: $t(146) = 9.15$, $p < 0.001$, $d = 0.76$; vs. easy-to-get avatar: $t(146) = 10.07$, $p < 0.001$, $d = 0.84$; vs. $\text{neutral}_{\text{hard}}$ avatar: $t(146) = 9.56$, $p < 0.001$, $d = 0.80$; vs. $\text{neutral}_{\text{easy}}$ avatar: $t(146) = 9.98$, $p < 0.001$, $d = 0.83$; Shaffer corrected]. In addition, the avatars in pair B, including easy-to-get and $\text{neutral}_{\text{easy}}$ avatars, had significantly higher attractiveness scores than the avatars in pair A, including hard-to-get and $\text{neutral}_{\text{hard}}$ avatars [*post hoc* pairwise comparisons; easy-to-get vs. $\text{neutral}_{\text{hard}}$ avatars: $t(146) = 4.77$, $p < 0.001$, $d = -0.39$; hard-to-get vs. easy-to-get avatars: $t(146) = 3.80$, $p < 0.001$, $d = -0.32$; $\text{neutral}_{\text{hard}}$ vs. $\text{neutral}_{\text{easy}}$ avatars: $t(146) = 2.81$, $p < 0.05$, $d = -0.23$; Shaffer corrected], with the exception of the comparison between hard-to-get and $\text{neutral}_{\text{easy}}$ avatars [*post hoc* pairwise comparisons; $t(146) = 0.46$, $p = 0.65$, $d = 0.04$; Shaffer corrected]. However, the paired avatars had comparable attractiveness in the two groups [*post hoc* pairwise comparisons; hard-to-get vs. $\text{neutral}_{\text{hard}}$ avatars: $t(146) = 1.57$, $p = 0.24$, $d = -0.13$; easy-to-get vs. $\text{neutral}_{\text{easy}}$ avatars: $t(146) = 2.12$, $p = 0.11$, $d = -0.17$; Shaffer corrected].

We investigated how the attractiveness of the avatars changed through the choice task. The change in avatar attractiveness was calculated by subtracting the score before the choice task from the score after the choice task (**Figure 3**). The interaction between groups and the types of avatar was significant [group × avatar interaction: $F(3.52,513.71) = 14.61$, $p < 0.001$, $\eta^2_G = 0.058$]. The attractiveness of the unused avatars was not changed after the choice task in either group [one-sample *t*-test; Pursuit: $t(67) = -0.50$, $p > 0.99$, $d = -0.06$, No-pursuit: $t(79) = 0.48$, $p > 0.99$, $d = 0.05$; simple main effect of group: $F(1,146) = 0.44$, $p = 0.51$, $\eta^2_G = 0.003$]. The change in the attractiveness of the easy-to-get and $\text{neutral}_{\text{easy}}$ avatars did not differ between groups [simple main effect of group; easy-to-get: $F(1,146) = 0.016$, $p = 0.90$, $\eta^2_G < 0.001$, $\text{neutral}_{\text{easy}}$: $F(1,146) = 0.71$, $p = 0.40$, $\eta^2_G = 0.004$]. In both groups, the easy-to-get avatar was rated as more attractive [one-sample *t*-test, Pursuit: $t(67) = 5.35$, $p < 0.001$, $d = 0.65$; No-pursuit: $t(79) = 5.31$, $p < 0.001$, $d = 0.59$], while the $\text{neutral}_{\text{easy}}$ avatar was rated as less attractive after the choice task [one-sample *t*-test, Pursuit: $t(67) = -4.03$, $p < 0.01$, $d = -0.50$; No-pursuit: $t(79) = -4.08$, $p < 0.01$, $d = -0.46$]. On the other hand, the attractiveness of the hard-to-get avatar increased in the Pursuit group [one-sample *t*-test, $t(67) = 3.02$, $p = 0.036$, $d = 0.37$], while it did not change in the No-pursuit group [one-sample *t*-test, $t(79) = -1.82$, $p = 0.72$, $d = -0.20$; simple main effect of group; $F(1,146) = 12.33$, $p < 0.001$, $\eta^2_G = 0.078$]. In contrast, the attractiveness of the $\text{neutral}_{\text{hard}}$ avatar, which was paired with the hard-to-get avatar, decreased in the Pursuit group [one-sample *t*-test, $t(67) = -4.65$, $p < 0.001$, $d = -0.56$] but did not change in the No-pursuit group [one-sample *t*-test, $t(79) = 2.35$, $p = 0.21$, $d = 0.26$; simple main effect of group; $F(1,146) = 27.55$, $p < 0.001$, $\eta^2_G = 0.159$]. These results indicated that both hard-to-get and easy-to-get avatars were more attractive after the choice task in the Pursuit group, while only easy-to-get avatars were more attractive in the No-pursuit group.

The increased attractiveness of the hard-to-get and easy-to-get avatars in the Pursuit group raised the question of what events occurred in the choice task to increase the attractiveness of avatars. To answer this question, we conducted a general linear model analysis with the number of choices, the number of positive reactions, and an interaction with these numbers as independent variables and the changes in attractiveness as the dependent variable (see section "Materials and methods"). The number of choices had a significant effect only on the change in attractiveness observed after the choice task ($\beta = 0.28$, $p < 0.001$, $d = 0.021$). The main effect of the number of positive reactions ($\beta = 0.063$, $p = 0.69$, $d = -0.018$) and the interaction between the number of positive reactions and the number of choices were not significant ($\beta = 0.005$, $p = 0.96$, $d < 0.001$). Thus, the changes in attractiveness depended on the choice *per se* rather than reactions in the choice task.

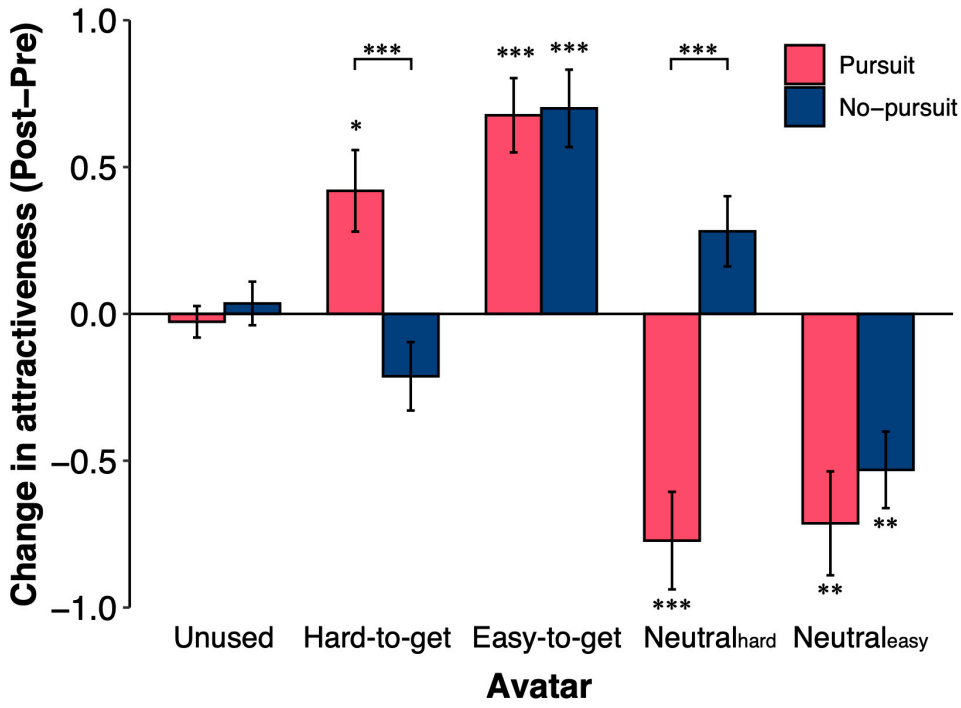

FIGURE 3
Changes in attractiveness ratings after the avatar choice task. The figure shows the changes in the attractiveness ratings of the five types of avatars in the two groups. Changes in attractiveness ratings were calculated by subtracting the score at the pre-choice rating from that at the post-choice rating. The unused avatars were not used in the avatar choice task (i.e., 40 avatars). The other types of avatars (i.e., hard-to-get, easy-to-get, $\text{neutral}_{\text{hard}}$, and $\text{neutral}_{\text{easy}}$) were used in the avatar choice task. The error bars represent the standard error of the mean. Asterisks denote whether the difference in attractiveness from before to after the avatar choice task was significant: $^{***}p < 0.001$, $^{**}p < 0.01$, and $^{*}p < 0.05$.

Simulation

We found that some participants (i.e., the Pursuit group) pursued the hard-to-get avatar despite receiving very few positive reactions. This behavioral phenomenon raised the question of which cognitive process led these participants to pursue the hard-to-get avatar. To answer this question, we used several variants of reinforcement learning models to determine what accounted for this choice behavior. As mentioned in the Introduction, asymmetric value updating (Lefebvre et al., 2017; Palminteri et al., 2017) and choice perseverance (Akaishi et al., 2014) can lead to repetitive choices of a previously selected option (Katahira, 2018). Thus, we conducted a simulation to investigate what parameters implemented in the hybrid model could account for the behavioral pattern shown in the Pursuit group. In particular, the hybrid model has five free parameters: learning rates for positive and negative reward prediction errors (α^+ and α^-), inverse temperature (β), decay rate of choice history (τ), and choice trace weight (φ) (see section "Materials and methods"). The degree of asymmetric value updating is denoted by the difference in the two learning rates (i.e., $\alpha_{\text{bias}} = \alpha^+ - \alpha^-$). Thus, we simulated an agent's choice behavior by manipulating these four parameters (α_{bias}, β, τ, and φ) under the same task structure as the online experiment (see section "Materials and methods").

In case 1, α_{bias} and β were varied, while τ (= 0.5) and φ (= 1.0) were fixed. The asymmetric learning rates quadratically decreased CP_{hard} (Figure 4A) but quadratically increased CP_{easy} (Figure 4B). Moderate positivity bias ($\alpha_{\text{bias}} = 0.4$) induced the smallest CP_{hard}, while moderate negativity ($\alpha_{\text{bias}} = -0.6$) bias induced the largest CP_{easy}. The inverse temperature produced a linear decrease in CP_{hard} and a linear increase in CP_{easy}. In any combination, CP_{hard} was less than 0.5, indicating that these parameters did not account for the behavioral pattern observed in the Pursuit group ($\text{CP}_{\text{hard}} > 0.5$).

In case 2, τ and φ were varied, while α_{bias} (= 0) and β (= 2.0) were fixed. For the hard-to-get avatar, CP_{hard} values in the condition with a moderate decay rate ($\tau > 0.2$) and higher perseverance factor ($\varphi > 6.0$) reached over 0.7 (Figure 4C). Meanwhile, CP_{easy} did not depend on these parameters and was always over 0.7 (Figure 4D). Under the higher perseverance condition, the behavioral pattern was similar to that in the Pursuit group in the experiment.

To further examine whether the effect of perseverance trades off with the effect of the value-related parameters (i.e., α_{bias} and

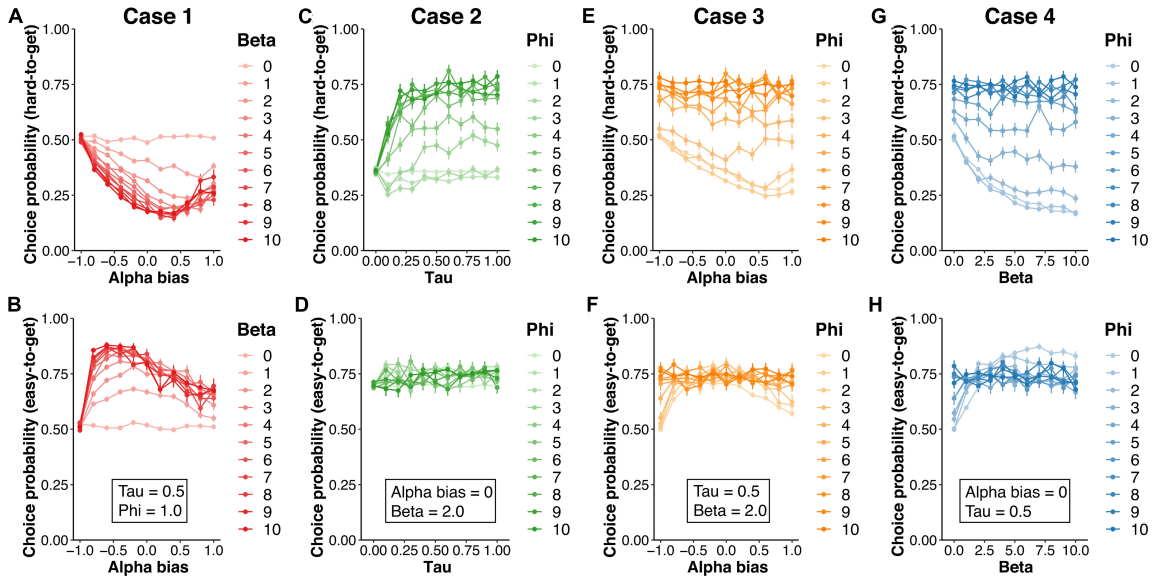

FIGURE 4
The results of the simulation in the hybrid model. The simulation of the agent's choice behavior was generated by manipulating four parameters (α_{bias}, β, τ, and φ) included in the hybrid model. The upper and lower rows show the choice probability for hard-to-get and easy-to-get avatars, respectively. In case 1, the bias of learning rates ($\alpha_{bias} = \alpha^{+} - \alpha^{-}$) and the inverse temperature (β) were varied, while the decay rate (τ = 0.5) and the weight of choice history (φ = 1.0) were fixed **(A,B)**. In case 2, τ and φ were varied, while α_{bias} (= 0) and β (= 2.0) were fixed **(C,D)**. In case 3, α_{bias} and φ were varied, while φ (= 1.0) and β (= 2.0) were fixed **(E,F)**. In case 4, β and φ were varied, while α_{bias} (= 0) and τ (= 0.5) were fixed **(G,H)**.

β), we covaried either α_{bias} (case 3) or β (case 4) with φ. In case 3, although CP_{hard} was modulated by the asymmetric learning rates (α_{bias}) in the condition with lower perseverance ($\varphi < 6.0$), the condition with higher perseverance ($\varphi > 6.0$) showed higher CP_{hard} (**Figure 4E**) and CP_{easy} (**Figure 4F**). Likewise, in case 4, in the condition with higher perseverance ($\varphi > 6.0$), CP_{hard} (**Figure 4G**) and CP_{easy} (**Figure 4H**) were not affected by inverse temperature and showed higher probability (CP > 0.7). Therefore, these results suggested that higher perseverance was consistent with the behavior pattern shown in the Pursuit group.

Model selection

To further investigate the mechanisms driving the pursuit of the hard-to-get avatar, we fit computational models to the choice data derived from the experiment. We used four variants of RL models to examine the benchmark of model fit: (1) a standard Q-learning model (hereafter, the RL model), (2) the asymmetric model, (3) the perseveration model, and (4) the hybrid model (see section "Materials and methods"). The results revealed that the perseveration model was the best for the Pursuit group, while the asymmetric model was the best for the No-pursuit group (**Table 1**). Mixed-design ANOVA showed a significant interaction between group and model [$F(1.29,187.70) = 52.39$, $p < 0.001$, $\eta^2_G = 0.011$]. There were no significant differences among the models in the No-pursuit group [simple main effect of model, $F(1.05,83.28) = 0.12$, $p = 0.75$, $\eta^2_G < 0.001$], but there were differences in the Pursuit group [simple main effect of model, $F(1.57,105.27) = 91.00$, $p < 0.001$, $\eta^2_G = 0.036$]. For the Pursuit group, there was no significant difference between the perseveration and hybrid models [*post hoc* comparison; $t(67) = 0.47$, $p = 0.64$, $d = -0.06$; Shaffer corrected]. However, the RL and asymmetric models, which did not include the choice history process, were much worse than the perseveration and hybrid models, which did include the choice history process [*post hoc* pairwise comparisons; RL vs. perseverance: $t(67) = 11.83$, $p < 0.001$, $d = 1.44$; RL vs. hybrid: $t(67) = 10.42$, $p < 0.001$, $d = 1.26$; RL vs. asymmetric: $t(67) = 9.53$, $p < 0.001$, $d = 1.16$; asymmetric vs. perseverance: $t(67) = 9.52$, $p < 0.001$, $d = -1.15$; asymmetric vs. hybrid: $t(67) = 7.38$, $p < 0.001$, $d = -0.90$].

Furthermore, to examine whether the group difference in the underlying cognitive process was manifested in both pair A (including the hard-to-get avatar) and pair B (including the easy-to-get avatar), we separated the choice data of pairs A and B and then fit four models into the separated datasets (**Table 2**). The results showed a significant interaction between group and model in pair A [$F(1.58,230.41) = 41.58$, $p < 0.001$, $\eta^2_G = 0.037$] but not in pair B [$F(1.51,220.14) = 1.19$, $p = 0.30$, $\eta^2_G < 0.001$]. Although the simple main effect of model in pair A was significant in both groups [Pursuit: $F(1.42,94.92) = 44.90$, $p < 0.001$, $\eta^2_G = 0.076$; No-pursuit group: $F(1.61,127.04) = 4.12$, $p = 0.026$, $\eta^2_G = 0.008$], *post hoc* pairwise comparisons did not

TABLE 1 Models and model selection results.

Model	Learning rate (s)	Inverse temperature	Perseveration	No. of free parameters	Pursuit group LML (SD)	No-pursuit group LML (SD)
RL	α ($\alpha^+ = \alpha^-$)	β	–	2	−51.94 (27.52)	−53.83 (27.50)
Asymmetric	α^+, α^-	β	–	3	−47.09 (29.21)	−53.71 (27.47)
Perseveration	α ($\alpha^+ = \alpha^-$)	β	τ, φ	4	−37.89 (33.87)	−54.17 (27.23)
Hybrid	α^+, α^-	β	τ, φ	5	−38.23 (34.33)	−54.14 (27.29)

TABLE 2 Models and model selection results in each pair.

Condition	Model	Learning rate (s)	Inverse temperature	Perseveration	No. of free parameters	Pursuit group LML (SD)	No-pursuit group LML (SD)
Pair A includes	RL	α ($\alpha^+ = \alpha^-$)	β	–	2	−35.21 (12.23)	−34.37 (13.64)
hard-to-get	Asymmetric	α^+, α^-	β	–	3	−30.30 (15.06)	−34.19 (14.00)
avatar	Perseveration	α ($\alpha^+ = \alpha^-$)	β	τ, φ	4	−22.30 (21.06)	−37.14 (15.91)
	Hybrid	α^+, α^-	β	τ, φ	5	−23.51 (23.17)	−36.56 (15.16)
Pair B includes	RL	α ($\alpha^+ = \alpha^-$)	β	–	2	−16.57 (16.54)	−19.96 (15.95)
easy-to-get	Asymmetric	α^+, α^-	β	–	3	−15.74 (16.80)	−19.54 (16.36)
avatar	Perseveration	α ($\alpha^+ = \alpha^-$)	β	τ, φ	4	−17.33 (19.56)	−19.35 (16.48)
	Hybrid	α^+, α^-	β	τ, φ	5	−15.75 (19.61)	−19.50 (17.66)

show any differences among models in the No-pursuit group (all $t < 2.31$, all $p > 0.14$, all $d < 0.26$). In contrast, there was a significant difference between all models in the Pursuit group [RL vs. asymmetric: $t(67) = 11.30$, $p < 0.001$, $d = 1.37$; RL vs. perseverance: $t(67) = 9.09$, $p < 0.001$, $d = 1.10$; RL vs. hybrid: $t(67) = 6.80$, $p < 0.001$, $d = 0.83$; asymmetric vs. perseverance: $t(67) = 6.73$, $p < 0.001$, $d = -0.08$; asymmetric vs. hybrid: $t(67) = 4.42$, $p < 0.001$, $d = -0.54$] with the exception of the comparison between the perseveration and hybrid models [$t(67) = 1.32$, $p = 0.19$, $d = -0.16$].

These results indicate that the choice behaviors in the Pursuit group depended on the choice history, while the choice behaviors in the No-pursuit group did not show such a clear difference in history dependence. Furthermore, this group difference in the impact of choice history was observed only in the specific context involving avatars with relatively few positive reactions.

Parameter estimation

To directly examine what computational process elicited the difference in choice behavior between the two groups, we compared the model parameters estimated from the hybrid model between groups. Although the hybrid model was not the best for the Pursuit and No-pursuit groups (Table 1), our previous study demonstrated that the hybrid model allows us to distinguish the effects of asymmetric value updating and choice perseverance (Sugawara and Katahira, 2021).

The Pursuit group had higher learning rates (α^+, α^-) than the No-pursuit group [Figure 5A; $F(1,146) = 16.46$, $p < 0.001$, $\eta^2_G = 0.051$]. Positive learning rates were higher than negative learning rates in both groups [$F(1,146) = 42.85$, $p < 0.001$, $\eta^2_G = 0.133$]. The interaction was not significant [$F(1,146) = 1.67$, $p = 0.20$, $\eta^2_G = 0.006$]. Furthermore, the difference between the positive learning rate minus the negative learning rate was calculated as the learning rate bias. There was no significant difference in the learning rate bias between groups [Figure 5B; $t(146) = -1.29$, $p = 0.20$, $d = -0.21$]. The inverse temperature (β) was significantly lower in the Pursuit group than in the No-pursuit group [Figure 5C; $t(146) = 7.45$, $p < 0.001$, $d = 1.25$]. While the decay rate (τ) was not significantly different between groups [Figure 5D; $t(146) = 1.28$, $p = 0.20$, $d = 0.21$], the choice trace weight (φ) was significantly higher in the Pursuit group than in the No-pursuit group [Figure 5E; $t(146) = -8.48$, $p < 0.001$, $d = -1.40$]. These results indicated that the Pursuit group placed greater weight on past choices than the No-pursuit group, while past outcomes had a greater influence on choice in the No-pursuit group than in the Pursuit group.

To examine whether this group difference in choice perseverance was observed in a specific context, we compared the model parameters in each separate dataset. Regarding the learning rates with both pair A (Figure 6A) and pair B (Figure 6B), the main effect of valence was significant [pair A: $F(1,146) = 78.36$, $p < 0.001$, $\eta^2_G = 0.222$; pair B: $F(1,146) = 42.88$, $p < 0.001$, $\eta^2_G = 0.128$], whereas the interaction was not significant [pair A: $F(1,146) = 0.06$, $p = 0.81$, $\eta^2_G < 0.001$; pair

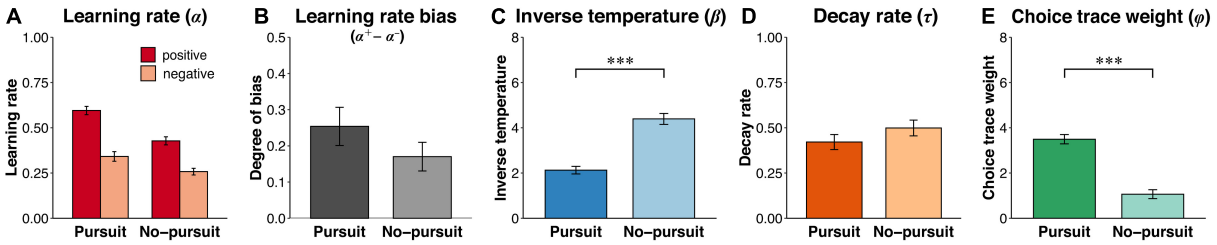

FIGURE 5
Estimated parameters with the hybrid model. The figure shows the estimated parameters by fitting the hybrid model to the choice data derived from the online experiment. **(A)** The learning rates for the positive and negative reward prediction errors (α^+ and α^-). **(B)** The learning rate bias calculated by subtracting the negative learning rate from the positive learning rate ($\alpha^+ - \alpha^-$), indicating the degree of asymmetric value updating. **(C)** The inverse temperature (β) representing the sensitivity to value differences in decision-making. **(D)** The decay rate (τ) indicating how far past choices are incorporated into the next choice. **(E)** The weight of choice history (φ) representing the sensitivity to differences in the choice history in decision-making. Error bars represent the standard error of the mean. Asterisks denote significant group differences: $^{***}p < 0.001$ and $^{**}p < 0.01$.

B: $F(1,146) = 2.10$, $p = 0.15$, $\eta^2_G = 0.007$]. While the Pursuit group had a higher learning rate than the No-pursuit group with pair A [$F(1,146) = 8.84$, $p < 0.01$, $\eta^2_G = 0.028$], no significant difference was shown with pair B [$F(1,146) = 2.93$, $p = 0.09$, $\eta^2_G = 0.010$]. The learning rate bias was not significantly different with either pair [Figure 6C; pair A: $t(146) = 0.24$, $p = 0.81$, $d = 0.40$; Figure 6D; pair B: $t(146) = -1.45$, $p = 0.15$, $d = -0.24$]. The inverse temperature was significantly lower in the Pursuit group than in the No-pursuit group with both pairs [Figure 6E; pair A: $t(146) = 7.64$, $p < 0.001$, $d = 1.28$, Figure 6F; pair B: $t(146) = 3.05$, $p < 0.01$, $d = 0.51$]. The decay rate was not significantly different between groups [Figure 6G; pair A: $t(146) = -0.37$, $p = 0.71$, $d = -0.06$; Figure 6H; pair B: $t(146) = -1.85$, $p = 0.07$, $d = -0.31$] with both pairs. Importantly, while the choice trace weight was significantly higher in the Pursuit group than in the No-pursuit group with pair A [Figure 6I; $t(146) = -8.41$, $p < 0.001$, $d = -1.39$], there was no significant difference with pair B [Figure 6J; $t(146) = -1.30$, $p = 0.20$, $d = -0.22$]. The increased weighting for past choices shown in the Pursuit group was noticeable only in the context that included the hard-to-get avatar. The results suggested that an increased weight of past choices (i.e., higher choice perseverance) may lead to the pursuit of the hard-to-get avatar.

Discussion

The present study investigated why people pursue hard-to-get targets. We hypothesized that choice perseverance, which is the tendency to repeat past choices, accounts for the pursuit of hard-to-get targets and consequently increases the attractiveness of the pursued targets. In the online experiment, the participants performed an avatar choice task to clarify the pursuit of hard-to-get targets. By manipulating outcome probabilities, we established the hard-to-get avatar as one that rarely had positive reactions and the easy-to-get avatar as one that frequently had positive reactions. For most participants, the easy-to-get avatars, which usually had positive reactions, were more frequently chosen than the paired avatars, which had positive and negative reactions at the same frequency. Nevertheless, some participants (i.e., the Pursuit group) frequently chose hard-to-get avatars that seldom had positive reactions and easy-to-get avatars. Thus, we confirmed that some people pursue hard-to-get targets. The participants also performed an avatar evaluation task to investigate increased attractiveness dependent on the choice *per se*. The attractiveness of the avatars after the choice task changed in accordance with the number of choices. Subsequently, following the choice task, the Pursuit group rated the hard-to-get avatar as more attractive, while the No-pursuit group rated this avatar as less attractive. Then, we used a computational modeling approach to reveal the cognitive process mediating the pursuit of the hard-to-get avatar. In a simulation, we demonstrated that a higher weight for choice history (i.e., choice perseverance) led to repetitive selection of not only the easy-to-get avatar but also the hard-to-get avatar. To confirm this finding in the empirical data, we fitted the hybrid model proposed in a previous study (Sugawara and Katahira, 2021) to the choice data derived from the online experiment. Consistent with the simulation results, the weight placed on choice history was significantly higher in the Pursuit group than in the No-pursuit group. According to these findings, we concluded that higher choice perseverance leads to repetitive choice of hard-to-get targets, consequently increasing the attractiveness of the selected target.

The primary finding of this study is that a part of participants pursued the hard-to-get avatar, which rarely provided positive outcomes. The pursuit of hard-to-get avatars in the Pursuit group was not explained by traditional reinforcement learning theory, which argues that the action probability is increased if the action is associated with positive outcomes (Thorndike, 1898; Sutton and Barto, 1998),

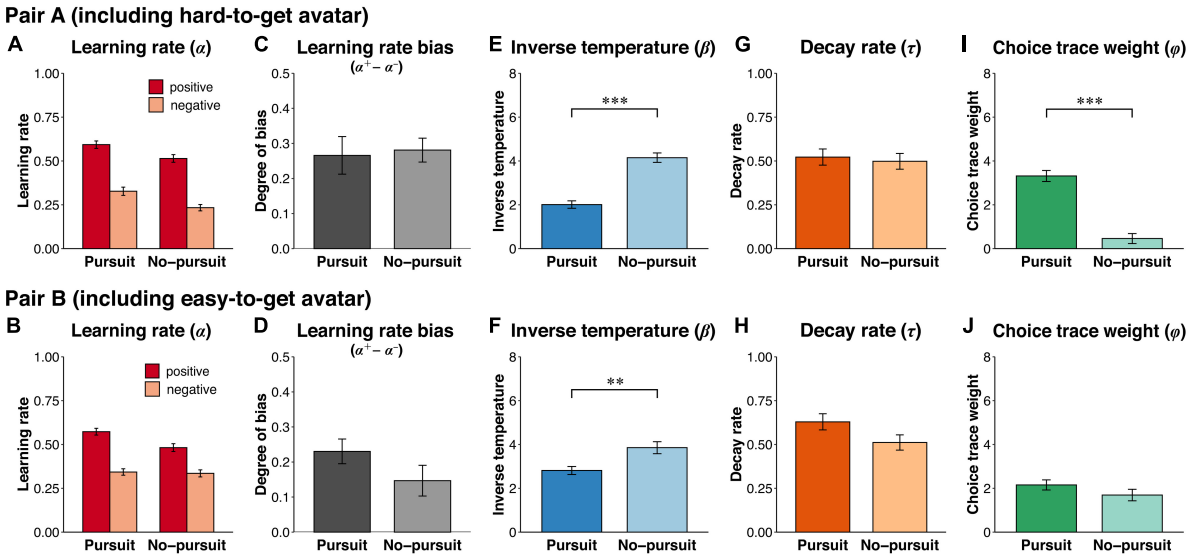

FIGURE 6
Estimated parameters with the hybrid model in each pair. The figure shows estimated parameters by fitting the hybrid model to the choice datasets separated by avatar pair. Upper and lower rows indicate estimated parameters for pair A (including the hard-to-get avatar) and pair B (including the easy-to-get avatar), respectively. **(A,B)** The learning rates for the positive and negative reward prediction errors (α^+ and α^-). **(C,D)** The learning rate bias calculated by subtracting the negative learning rate from the positive learning rate ($\alpha^+ - \alpha^-$), indicating the degree of asymmetric value updating. **(E,F)** The inverse temperature (β) representing the sensitivity to value differences in decision-making. **(G,H)** The decay rate (τ) indicating how far past choices are incorporated into the next choice. **(I,J)** The weight of choice history (φ) representing the sensitivity to differences in the choice history in decision-making. Error bars represent the standard error of the mean. Asterisks denote significant group differences: $^{***}p < 0.001$ and $^{**}p < 0.01$.

even though the participants in the current experiment had to maximize the extent to which the avatar liked them. Another possible explanation is that the Pursuit group preferred the hard-to-get avatar over the alternative avatar because the baseline preference influenced their decision-making (Glimcher, 2009). However, in both groups, baseline attractiveness did not differ between the paired avatars used in the avatar choice task. Thus, differences in baseline attractiveness did not account for the pursuit of hard-to-get avatars. Choice perseverance reflects Thorndike's law of exercise stating that producing an action makes it more likely to be selected on future occasions (Thorndike, 1898). Although the law of exercise captures the key feature of habits in which behavioral repetition automatizes behavior (Perez and Dickinson, 2020), habituation is due to reward-based learning mechanisms (Miller et al., 2019). Because the hard-to-get avatar seldom gave positive reactions, the pursuit of the hard-to-get avatar could not be accounted for by habituation. Unlike habituation, choice perseverance and the law of exercise are independent of choice outcomes. It is reasonable that the pursuit of the hard-to-get avatar is accounted for by choice perseverance.

Another important finding is that the increase in attractiveness depended on the number of choices rather than the number of positive reactions. This choice-dependent reevaluation has been reported (Brehm, 1956; Lieberman et al., 2001; Egan et al., 2007). Brehm (1956) reported that after a choice was made between two similarly valued options, the selected option was evaluated as better than the unchosen option. Choice-dependent reevaluation is usually accounted for by cognitive dissonance theory (Festinger, 1957). In this theory, when people choose one of two similarly desirable options, the conflict resulting from the desirability of the rejected option induces psychological distress. The reevaluation of the desirability of the chosen option occurs after choices are made to reduce such distress. One possibility is that the post-choice increases in avatar attractiveness found in this study might be accounted for by cognitive dissonance theory. However, previous studies observed choice-induced reevaluation even in amnesic patients who did not remember the option they chose (Lieberman et al., 2001), younger children, and capuchin monkeys (Egan et al., 2007). According to this evidence, it is reasonable that choice-induced reevaluation is mediated by a relatively simple and automatic process rather than complex cognitive reasoning. Sharot et al. (2009) showed that hedonic-related neural activity in the caudate nucleus in response to a selected option was enhanced after a decision was made in a free-choice task in which the participants freely choose between two options. This neuroimaging study suggests that imagination during the decision process activates hedonic-related brain regions and conveys pleasure expected from the simulated event. This choice-induced reevaluation

modifies the hedonic response to the selected option. From the view of imagination-related pleasure, participants feel two types of pleasure in the avatar choice task used in this study: one induced by the imagination during the decision process and another induced by the obtained outcome. Participants with higher choice perseverance focus on the decision process rather than the obtained outcome. Thus, it is possible that their preferences are more strongly affected by the pleasure from imagination during the decision process, which consequently increases the attractiveness of the hard-to-get avatar.

Notably, some participants pursued hard-to-get targets, but others did not in the present study. Given that choice perseverance accounted for this group difference in pursuing hard-to-get targets, a critical question is how choice perseverance emerges. Although this important question remains unanswered, the present results could provide some insight into the context-dependency of choice perseverance. The computational modeling showed that the group difference in the weight of choice history (φ) was observed only in the choice context including hard-to-get avatars but not in the context including easy-to-get avatars. This finding suggests that the choice context modulated choice perseverance even among the participants who pursued hard-to-get avatars. The choice-dependent reevaluation mentioned above could be a potential source of choice perseverance. As discussed above, the choice-induced increase in the attractiveness of the chosen avatar might be mediated by value updating based on the pleasure derived from imagination during the decision process (Sharot et al., 2009). It is plausible that such imagination-based learning is emphasized by the lack of pleasure from the chosen outcomes (i.e., in the context including the hard-to-get target), leading to context-dependent choice perseverance. Future studies should investigate the fruitful hypothesis that imagination-based pleasure emphasizes choice perseverance, resulting in the pursuit of hard-to-get targets and the increased attractiveness of the pursued target.

Another important question is whether the pursuit of hard-to-get targets is specific to a social context or general in a broader decision-making paradigm. In this study, we adopted an avatar choice task to mimic the selection of romantic partners in real-life situations. It is possible that the specific effect of the social context, such as partner selection, leads to unexpected strategies and behaviors of a participant (e.g., perseverance to maintain self-image and not being directly upset by negative feedback). On the other hand, our previous study used an instrumental learning task with non-meaning simple symbols (Sugawara and Katahira, 2021). Even in a task with simple symbols, the degree of choice perseverance differed largely among individuals. According to our previous findings and the aforementioned evidence (Ghalanos and Theussl, 2015), some participants might pursue hard-to-get targets in a choice task with simple symbols. Furthermore, the avatar choice task used in this study was designed as a conventional two-armed bandit task. The participants must learn the outcome probability based on choice outcomes and maximize the outcomes obtained throughout the task. Thus, it was necessary to make the participants aware of the differences in the choice outcomes depending on the avatar's response. To emphasize the difference between positive and negative outcomes, voice and facial expressions were also changed. If such a gamified nature of the avatar choice task contributes to pursuing hard-to-get targets, such pursuing behaviors might occur in a nonsocial choice task with gamified natures. Whether the degree of choice perseverance differs between social and nonsocial contexts even in the same participant remains largely unknown. To understand the effect of social contexts on cognitive processes underlying decision making, future studies should investigate whether choice perseverance differs between social and nonsocial contexts, or between with and without a gamified nature of the choice task.

We are able to evaluate the attractiveness of targets in various aspects such as physical, sexual, emotional, or aesthetic. Participants in this study were not instructed to rate attractiveness in terms of a specific aspect. It is possible that the aspects from which they rated attractiveness differed among participants. Nevertheless, the choice-dependent reevaluation of the avatar's attractiveness was consistently found in both Pursuit and No-pursuit groups. We believe that individual differences in the aspect from which the attractiveness was rated did not have a significant effect on the present findings. Furthermore, in the present study, the apparent features such as hair and eyes were varied across avatars. Although the avatars used in the avatar choice task were selected based on the participant's ratings preceding the choice task, it is possible that the differences in the apparent features between avatars might affect the choices if there was a bias in the apparent features. Indeed, numerous evidences show that avatars' apparent features such as age, face shape, ethnicity, and eye/hair colors affect our perceptual responses (Messinger et al., 2008; Andrade et al., 2010; Turkay, 2012; Watson et al., 2012; Allison and Kendrick, 2013). The impact of these avatar's apparent features on the choice behaviors remains an issue for future studies.

The present study has at least three limitations. The first issue is that statistical bias resulting from the free-choice paradigm might affect the choice-dependent attractiveness change observed in this study (Chen and Risen, 2010). Although the participants were repeatedly asked to choose one of the same paired avatars and received outcomes in the avatar choice task, the present experimental design is similar to a typical free-choice paradigm in which items are classified by preceding freely determined choices. The multiple regression analysis in the present study showed that the degree of attractiveness change depended on the number of choices of the avatar, which cannot be accounted for solely by statistical bias. Furthermore, a meta-analysis of the unbiased results (Izuma and Murayama, 2013) concluded that choice-induced preference

change exists. However, to control for statistical bias resulting from a free-choice paradigm, forced-choice trials should be included in the avatar choice task. The second issue is that the amount of experienced positive outcome differed between the participants. As the avatar choice task was designed based on an instrumental learning framework in which the participants learn the outcome probability in a trial-and-error manner to maximize the obtained outcome, it is possible that the amount of experienced positive outcome depends on the chosen pattern and greatly varies among participants. To randomly choose two avatars at the beginning of each session, we introduced several tricks in the avatar choice task as follows: (1) avatars with a similar attractiveness were used, and (2) the initial reaction was always negative (see section "Materials and methods" for further information). Nevertheless, if the participant chose the hard-to-get avatar in all trials, the amount of experienced positive outcome from the hard-to-get avatar was more than that from another avatar that had never been chosen (Don et al., 2019; Don and Worthy, 2021). To solve this issue, the avatar choice task should be designed with an aligned number of reinforcements (Don and Worthy, 2021) or forced-choice trials should be incorporated (Niv et al., 2012). Future studies should confirm the present findings in more sophisticated task designs. The third issue is that most participants were male. Because of the abundance of avatar materials, we created avatars only with a female appearance. Thus, this study recruited subjects who were romantically interested in women. It remains unclear whether the present findings would be fully replicated even if the participants were female and the avatars were male in appearance. Future research needs to clarify whether the findings apply to female's choice behavior.

The present study demonstrates that persons with higher choice perseverance pursued a target that rarely responded positively and consequently rated the selected target as more attractive *via* the choice-induced reevaluation mechanism. The tendency to pursue hard-to-get targets can be interpreted as tolerance for negative outcomes, contributing to grit (Duckworth et al., 2019). Tolerance for negative outcomes might be essential for success in our lives but sometimes triggers problematic behavior, such as stalking. The present findings shed light on the cognitive computational mechanisms underlying the pursuit of hard-to-get targets and may contribute to understanding the psychological substrates of grit constituted from passion and perseverance for one's long-term goals, which are more general than the romantic context imitated in avatar choice (Duckworth et al., 2019).

Data availability statement

The data supporting the findings of this study and the codes used for the simulation and model fits of the computational models are available in Figshare at https://figshare.com/articles/dataset/Pursuing_behavior_in_humans/13048478.

Ethics statement

The studies involving human participants were reviewed and approved by the Ethical Research Committee at Nagoya University (NUPSY-200306-K-01). The patients/participants provided their written informed consent to participate in this study.

Author contributions

MS conceived the study, performed the experiment, analyzed the data, and wrote the manuscript. MS and KK designed the experiment and interpreted the results. KK revised the manuscript. Both authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2022.924578/full#supplementary-material

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Visual Attention to Novel Products – Cross-Cultural Insights From Physiological Data

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The study aims to investigate visual attention and perceived attractiveness to known versus unknown (novel) products above and beyond self-report applying physiological methods. A cross-cultural exploratory approach allows for comparing results gathered in the United States and China. We collected field data on physiological parameters accompanied by behavioral data. Mobile eye-tracking was employed to capture attention by measuring gaze parameters and electrodermal activity serves as indicator for arousal at an unconscious level. A traditional scale approach measuring perceived attractiveness of known versus novel products provide insights at a conscious level. US-American and Chinese consumers in our sample indeed process novel products differently. This can be observed at an unconscious and conscious level. Different gaze movements and arousal levels are observed at an unconscious level. Regarding behavioral data, the level of vertical orientation shapes the perceived attractiveness of novel products at a conscious level. The study showcases how physiological methods complement behavioral ones when investigating visual attention to products. It underlines varying conscious as well as unconscious visual attention and attractiveness ratings comparing known versus novel products, driven by cultural differences. Data from a field setting further enrich the implications derived for new product development and applied marketing.

Keywords: visual attention, attractiveness of novel products, mobile eye-tracking, electrodermal activity, cross-cultural comparison, consumer neuroscience

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INTRODUCTION

Launching novel products often cuts both ways, it either paves the path for further economic growth or it ends in loss and troubles. Hence, for companies engaging in new product development, it is vital to understand which factors contribute to a new product's success. In a meta-analysis, Evanschitzky et al. (2012) report product-, strategy-, process-, market- place-, or organizational characteristics to have an effect on new product success. Being innovative positively affects specific economic performance values, like firm value (i.e., market to book ratio), market position (i.e., sales, market share), or financial positions (i.e., return on investment) (Rubera and Kirca, 2012). In turn, this effect can be mainly attributed to the success of novel products. However, products are only

successful if they are bought by consumers. Hence, it is all about understanding the consumers' perceptions and attractiveness ratings which serve as key to new product success.

A substantial percentage of newly developed products fail because consumers do not understand them or do not accept them (Feiereisen et al., 2008; Evanschitzky et al., 2012). Especially the decision-making process of consumers to buy novel products is often characterized by a high degree of complexity (Broniarczyk and Alba, 1994; Mukherjee and Hoyer, 2001). Visual attention plays a crucial role in this context. It serves as gatekeeper for further information processing (Hoyer et al., 2018). Proper processing of information is especially vital when it comes to the understanding and acceptance of novel products. Perceived risk and uncertainty further play a crucial role in this context (Mitchell and Boustani, 1993). In turn, cultural aspects shape the levels of perceived risk and associated levels of arousal (Gierlach et al., 2010). The increased speed at which companies develop novel products has led to a rise in studies on visual attention, associated perceived risk and arousal as well as information processing of consumers regarding novel products (Bettman et al., 1998; Mukherjee and Hoyer, 2001; Arts et al., 2011; Kardes and Wyer, 2013; Hubert et al., 2017). Moreover, in today's globalized world and with regard to strategies in international marketing, the perception and production of new products needs to be discussed in a multicultural setting (Evanschitzky et al., 2012; Rubera and Kirca, 2012). Having a more comprehensive knowledge of how novel products are perceived by consumers in cross-cultural settings is crucial. Previous studies have already shown that cultural differences drive the perception of products and objects in general (e.g., Ishii et al., 2003; Strombach et al., 2014). As the processes of visual attention and perception are often related to complex unconscious automatic processes (Messner and Wänke, 2011) it is difficult to measure these concepts using self-report data only. Physiological as well as gaze parameters allow for a more comprehensive understanding in this regard (Shimojo et al., 2003). Prior intercultural studies (e.g., Bao et al., 2003; Shavitt et al., 2006) did also not account for socioeconomic changes such as Chinese increasingly focusing on Western behavior (Davis, 2013).

Against this background, the present exploratory study focuses on a cross-cultural comparison of visual attention and attractiveness ratings of already known versus novel products. In particular, the study investigates the visual information processes regarding cars that consumers already are familiar with as well as prototypes of cars that are new to them (novel products). With respect to unconscious processes, eye-tracking was applied to measure consumers' visual attention and electrodermal activity (EDA) measures were included for investigating their arousal levels, which are according to literature related to psychological correlates such as positive/negative emotion, mental effort, task difficulty, risk perception/uncertainty, and anxiety (Holper et al., 2014). The field setting applied in the United States and China allows for a cross-cultural comparison and increases external validity (Kopton and Kenning, 2014; Gneezy, 2017). With regard to the conscious evaluation of the products under scrutiny, a traditional scale approach featuring measures for attractiveness (Brakus et al., 2014) was employed.

The paper contributes to the understanding of cross-cultural differences in visual information processing of products in general and novel products in particular. It, potentially, provides insights into product evaluation in terms of attractiveness ratings at both, conscious and unconscious levels. This approach enables to understand consumer behavior in a cross-cultural setting above and beyond mere survey data. Implications within the context of new product development can be derived on a more comprehensive level, as physiological data of gaze parameters as well as electrodermal activity provide insights into the unconscious drivers of stated product ratings. Adding this kind of data enables to draw a more holistic picture of what is really going on inside the consumers' in terms of cognitive and affective information processing and therefore it might help to come up with ideas to enhance the customer experience and consumers' value perceptions.

THEORETICAL FRAME AND HYPOTHESES

In the following, we provide the conceptual frame for the hypotheses tested along the relevant theoretical concepts investigated in the present study. The study provides insights mainly into the areas of visual attention and perceived attractiveness of novel products. Theoretical underpinnings of how uncertainty and culture relate to those key areas are outlined.

Visual Attention

For human beings vision has been seen as the most dominant sense (Hutmacher, 2019). When it comes to new product evaluation from a consumers' perspective, visual attention therefore plays a vital role. For the understanding of visual attention and attentional deployment, different antecedents like (1) surrounding context, (2) salience mapping, (3) inhibition of return, (4) eye movement, or (5) scene understanding and object recognition are crucial (Itti and Koch, 2001). Regarding the design aspects in new product development, prior studies have stated that especially visual attention plays an important role in the way that consumers process novel product designs (Johnston et al., 1990; Folkes and Matta, 2004). From a physiological perspective, gaze parameters serve as an indicator for visual inspection (Shimojo et al., 2003). When it comes to the investigation of visual perception of novel products among consumers from different cultures, it is important to note that prior research has shown different gaze parameters comparing Asian and Western cultures. Consumers from Asian nations tend to screen stimuli for short durations, whereas people from Western nations tend to fix their vision on objects for longer durations (Chua et al., 2005; Goh et al., 2009; Peng-Li et al., 2020). Therefore, the following hypothesis is derived:

H1: Chinese consumers in our sample pay shorter visual attention to products than US-American consumers in our sample.

The Role of Arousal in Visual Attention and in Different Cultural Settings

The novelty of products can create uncertainty in decision-making and is related to perceived risk (Cox and Rich, 1964; Bauer, 1967; Taylor, 1974; Shoemaker and Shoaf, 1975). Prior findings showed that the facets of perceived risk are context-dependent (Campbell and Goodstein, 2001; Featherman and Pavlou, 2003). Perceived risk and uncertainty are accompanied by higher EDA levels and activation in the anterior cingulate cortex of the brain, indicating a higher level of arousal (Critchley, 2002). Psychophysiological arousal covary with risk-sensitive decision-making processes (Studer and Clark, 2011). Furthermore, with respect to the interaction of risk-aversion and culture, it has been shown that Asians tend to be more risk-averse than US-Americans (Bao et al., 2003; Sorrentino et al., 2013). Therefore, it is hypothesized that:

H2: While observing novel products, Chinese consumers in our sample show higher levels of arousal (indicating a potentially higher level of perceived risk) than US-American consumers in our sample.

Moreover, prior research has shown that risk-averse consumers tend to delay the adoption of new products (Aggarwal et al., 1998) and relate them to losses (Bao et al., 2003). This connotation of experiencing a loss might in turn have a negative impact on the consumers' evaluation of the new product. Therefore, it is assumed that:

H3: Perceived attractiveness of the novel car is lower for Chinese consumers compared to US-American consumers in our sample.

The Role of Culture in Visual Attention

The theory of individualism versus collectivism has aimed at explaining cross-cultural differences in consumption (Singelis et al., 1995; Shavitt et al., 2006). Closely related to the theory of individualism/collectivism is the approach of vertical versus horizontal orientation. Vertical orientation emphasizes hierarchy versus horizontal orientation focuses more on equality (Triandis and Gelfand, 1998; Rahman and Luomala, 2020). Early consumer research stated that the Chinese were more vertically oriented and collectivistic than US-Americans (e.g., Bao et al., 2003). However, some studies demonstrate that Chinese society (more specifically, people with high income) are increasingly focusing more on individualistic factors than on collectivistic factors (Yan, 2010). Personal wellbeing is one such individualistic factor (Steele and Lynch, 2013). Recent studies also show acculturation to global consumer culture (Czarnecka et al., 2020) as well as a person's social value orientation playing a role in this context (Moon et al., 2018). Besides those recent developments, it is assumed that power distance and hierarchy is generally still ranked higher in Asian cultures compared to the US (Li et al., 2014; Goa and Zhang, 2022). The following is hypothesized:

H4a: Chinese and US-American consumers in our sample differ in terms of individualism/collectivism.

H4b: Chinese and US-American consumers in our sample differ in terms of vertical versus horizontal orientation.

More specifically, vertically oriented consumers, such as the Chinese, have a high focus on hierarchy, power distance and structure. These consumers rely less on equality in power/status (higher "power distance"; Hofstede, 1984) and focus more on hierarchical structures. Furthermore, consumers from high power distance cultures show lower impulsive buying tendencies, higher self-control, and more deliberate processing (Zhang and Mittal, 2008; Zhang et al., 2012). The greater degree of deliberate processing and the higher self-control are aligned with higher risk-aversion. The subsequent hypothesis is based on these findings and on the conceptual underpinnings regarding the level of arousal:

H5: The vertical orientation of consumers has a significant effect on their attractiveness ratings of the novel car. This effect is moderated by the level of arousal.

METHODOLOGY

Experimental Setting

The present physiological field studies were conducted in the United States (Los Angeles) and China (Beijing). The 42 participants (US: N = 22, Mage = 46.50, SD = 11.97, 14 males; China: N = 20, Mage = 35.95, SD = 9.64, 13 males)[1] were randomly recruited from a base of the targeted segment of potential premium car consumers (e.g., participants with high income, generally well-educated). Different cars were chosen from five well-known car brands in the premium class–subsequently referred to as brands C1, C2, C3, C4, and P. The car brands were neither US-American nor Chinese. Thus, "country-of-origin" effects (Michaelis et al., 2008) can be excluded. While, previous studies on novel product designs lack the use of real prototypes (e.g., Kreuzbauer and Malter, 2005), one of the cars with the presented study was a "real" prototype (P). The prototype showed substantial design changes (compared to the existing model) and had been developed exclusively by a well-known automobile company and was not yet available on the market. In consequence, the use of a real prototype offers the advantages of increasing the external validity of the experiment and of ensuring that the unknown car is not processed differently by participants as a result of being perceived as unrealistic or even artificial.

In both cultural groups (China and the United States), a study supervisor led participants through the entire experiment, and for the Chinese group the supervisor was a native speaker of Mandarin. The first sequence of the experiment involved the participants observing all cars from a distant position (capturing their very first impression after opening their eyes from an approximately 5 m distance) (see **Figure 1**), and the second

[1]Age differences between samples are due to the possible pool of participants in the targeted consumer segment. We assume no bias here, because studies on age differences and visual attention are mainly focused on performance and age ranges are much higher between young (around 20 years) and older (around 60 years) participants (see for example Madden et al., 2007).

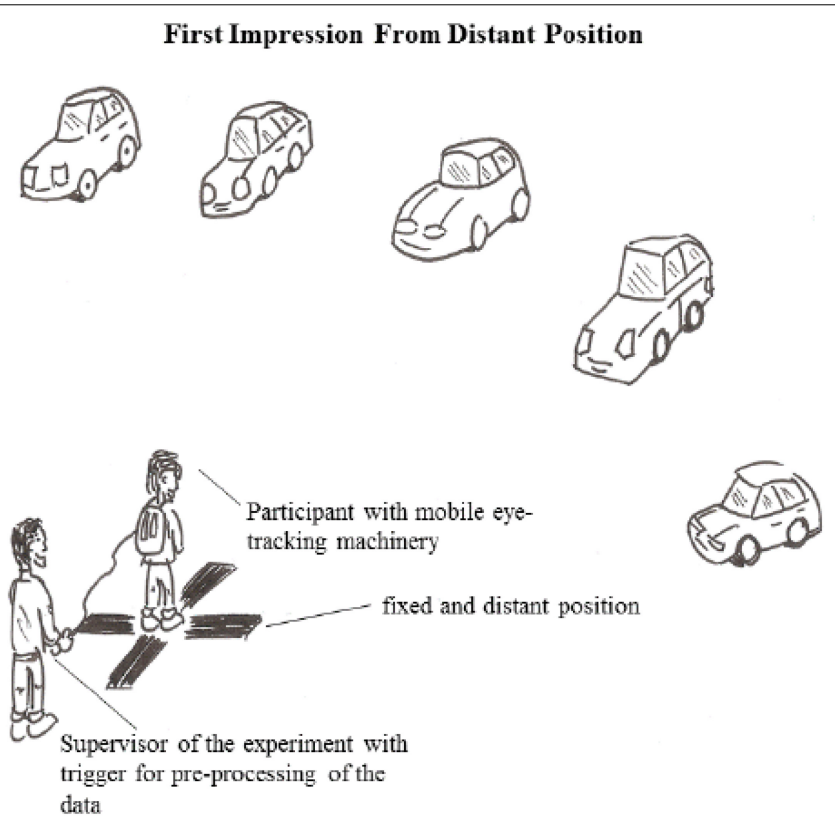

FIGURE 1 | First phase of the experimental setup (own illustration).

sequence involved the participants observing each car separately, and from a close-up position (see **Figure 2**). Each participant was equipped with the mobile neurophysiological technology and ran through the experiment individually. Each participant was instructed by a single experimental supervisor.

Measurements

For capturing the physiological data a mobile eye-tracking tool (SensoMotoric Instruments, Teltow, Germany) and a mobile EDA tool (edaMove by movisens, with Ag/AgCl electrodes) was used. These tools measure, respectively, visual attention (stationary: Rosbergen et al., 1997; Brasel and Gips, 2008; mobile: Clement et al., 2013; Suher et al., 2014) and arousal (stationary: Kopton et al., 2013; mobile: Kuijpers et al., 2012). They were used during the phases of visual information processing and attractiveness ratings of actual novel cars, in an exhibition hall. For eye-tracking data, the dwell times (ms) were measured associated with visual information processing of each car. The participants looked from a fixed place from which the automobiles were positioned in a way so that the participants could observe the front-side perspective of each car (see **Figures 1**, **2**). In contrast to classical computer lab experiments, the field approach featured different time-durations for each participant's experimental run. Therefore, each EDA integral (μ) was normalized for each stimulus condition concerning time-duration and was furthermore log-transformed (Bach et al., 2010). As relative values (individual baselines) were used for each participant, it is possible to compare the responses of the Chinese and the Americans without any potential bias due to differences in body temperature or respiration levels.

To determine cultural differences, a traditional rating scales approach was applied. The Horizontal (H)/Vertical (V)–Individualism (I)/Collectivism (C) scale (e.g., Triandis and Gelfand, 1998) (with a nine-point Likert scale range from 1 = "strongly disagree" to 9 = "strongly agree"; HI: $\alpha = 0.81$; HC: $\alpha = 0.89$; VI: $\alpha = 0.72$; and VC: $\alpha = 0.76$) was used. Attractiveness ratings of the cars served as key behavioral dependent variables. Participants were asked to indicate their general liking for the cars' exterior designs according to a five-point Likert scale (1 = "extremely attractive" and 5 = "not attractive at all") similar to Brakus et al. (2014). In order to avoid any language induced bias, scales were translated to Mandarin and American English by a native speaker.

Results

Manipulation Check

Responses from all participants measuring attractiveness were generally high for all cars [Median (Mdn)_C1 = 2; Mdn_C2 = 2; Mdn_C3 = 2; Mdn_P = 1.5] with one exception (Mdn C4 = 3). Friedman's ANOVA for comparison of all cars was significant, $\chi 2(4) = 37.56$, $p < 0.001$. However, Bonferroni-corrected pairwise follow-up tests showed significant differences only for

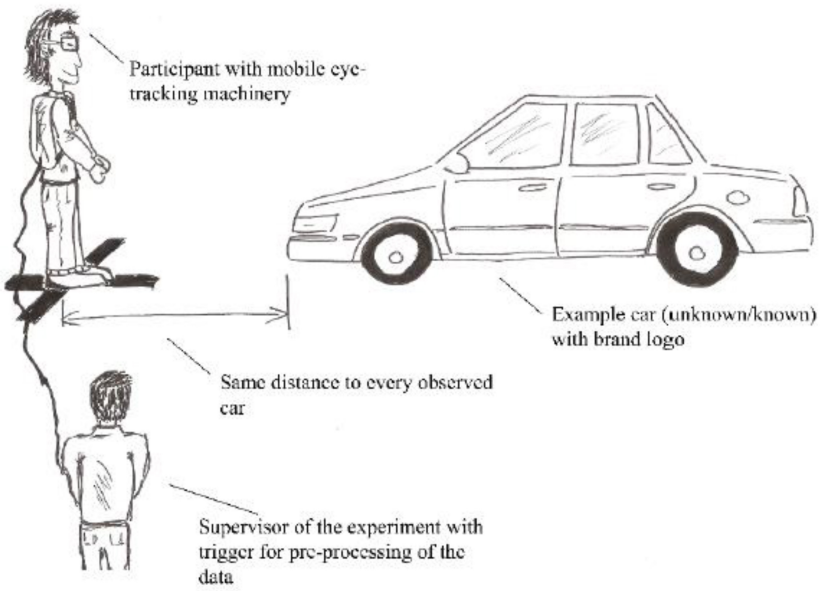

FIGURE 2 | Second phase of the experimental setup (own illustration).

brand C4 (P-C4: $T = -1.91$, adj. $p < 0.001$; C1-C4: $T = -1.06$, adj. $p = 0.021$; C2-C4: $T = -1.16$, adj. $p = 0.008$; C3-C4: $T = -1.18$, adj. $p = 0.006$) (see **Table 1**). The other comparisons were insignificant. Thus, C4 was excluded from analysis.

Results of Eye-Tracking Measures

Eye-tracking results from independent *t*-tests (for C2) and from Mann–Whitney tests for non-normally distributed variables (C1, C3, P)[2] showed that during the first phase of visual processing of the cars, Chinese consumers significantly showed shorter dwell times for all known cars [car C1: Mdn_US = 1499.50, Mdn_China = 166.40, $U = 85.00$, $z = -2.00$, $p = 0.024$; car C2: M_US = 3685.97, SD = 2359.66; M_China = 1622.05, SD = 1538.38, $T(32) = 2.93$, $p = 0.002$; car C3: Mdn_US = 2728.10, Mdn_China = 1131.30; $U = 88.00$, $z = -1.89$, $p = 0.003$] (see **Table 2**), affirming H1. For the prototype (P), it was found only a marginally significant difference (Mdn_US = 4151.30; Mdn_China = 2446.50, $U = 96.00$, $z = -1.61$, $p = 0.056$).

Results of Electrodermal Activity Measures

For data pre-processing prior to the main EDA analyses, each participant's overall mean arousal level was computed for all cars (with the mean arousal level for each car's front, sides, and rear considered).[3] This allowed to capture the consumers' complex overall impressions of each car and to account for differences between the front of the car and the other sides of it (see **Table 3**).

[2]It needs to be mentioned that three US-American and four Chinese participants had to be excluded due to inaccurate eye tracking after re-calibration.

[3]It needs to be mentioned that one US-American and one Chinese participants had to be excluded due to inaccurate EDA measurements.

TABLE 1 | Manipulation check: Paired comparisons for Friedman's ANOVA.

Comparisons	Test statistic	Stand. test statistic	*p*	Adj. *p*
Car P–Car C1	−0.85	−2.45	0.014	0.014
Car P–Car C2	−0.75	−2.17	0.030	0.030
Car P–Car C3	−0.73	−2.11	0.035	0.035
Car P–Car C4	−1.91	−5.52	0.000	<0.001
Car C1–Car C4	−1.06	−3.07	0.002	0.002
Car C2–Car C4	−1.16	−3.35	0.001	0.008
Car C3–Car C4	−1.18	−3.42	0.001	0.006
Car C2–Car C1	0.10	0.28	0.783	1.00
Car C3–Car C1	0.12	0.35	0.730	1.00
Car C3–Car C2	0.02	0.35	0.069	1.00

TABLE 2 | Statistics of dwell time.

	Americans (*N* = 19)		Chinese (*N* = 15)		Comparisons	
	M (SD)	Mdn	M (SD)	Mdn	Mann–Whitney *U* (z)/*T*-test	*p*
Car C1*	2522.926 (3028.342)	1499.50	1136.25 (1583.53)	166.40	$U = 85.00$ $z = -2.00$	0.024
Car C2	3685.974 (2359.661)	3892.70	1622.05 (1538.38)	1365.80	$T = 2.927$ ($df = 32$)	0.002
Car C3*	3432.000 (2892.018)	2728.10	2236.37 (2538.39)	1131.30	$U = 88.00$ $z = -1.89$	0.003
Car P*	5076.168 (3867.421)	4151.30	3572.25 (4169.86)	2446.50	$U = 96.00$ $z = -1.61$	0.056

**Non-parametric (based on Kolmogorov–Smirnov tests).*

TABLE 3 | Statistics of arousal levels.

Stimulus	Americans (N = 21)		Chinese (N = 19)		Comparisons	
	M (SD)	Mdn	M (SD)	Mdn	Mann–Whitney U (z)/T-test	P
Car C1	0.2417 (0.169)	0.20	0.33 (0.18)	0.34	$T = -1.67$ (df = 38)	0.052
Car C2*	0.21 (0.15)	0.15	0.30 (0.18)	0.30	U = 130.00 $z = -1.88$	0.031
Car C3*	0.19 (0.11)	0.15	0.30 (0.18)	0.33	U = 118.00 $z = -2.02$	0.022
Car P	0.22 (0.13)	0.18	0.36 (0.21)	0.33	$T = -2.60$ (df = 38)	0.007
Car Front C1	0.25 (0.15)	0.15	0.32 (0.19)	0.32	$T = -1.31$ (df = 38)	0.099
Car Front C2*	0.25 (0.16)	0.19	0.34 (0.24)	0.32	U = 155.00 $z = -1.21$	0.114
Car Front C3**	0.22 (0.13)	0.16	0.36 (0.27)	0.30	U = 135.00 $z = -1.55$	0.061
Car Front P*	0.24 (0.16)	0.17	0.42 (0.29)	0.39	U = 137.00 $z = -1.69$	0.047

*Non-parametric (based on Kolmogorov–Smirnov tests).
**Highly significant Shapiro–Wilk Test, so that non-parametric test was implemented.

The independent t-tests (C1, P) and Mann–Whitney tests (C2, C3) indicated significant differences between American and Chinese participants [car C1: M_US = 0.24, M_China = 0.33, $t(38) = -1.67$, $p = 0.052$; car C2: Mdn_US = 0.15, Mdn_China = 0.29, $U = 130.00$, $z = -1.88$, $p = 0.031$; car C3: Mdn_US = 0.15, Mdn_China = 0.33, $U = 118.00$, $z = -2.02$, $p = 0.022$]. Car P showed the highest significant difference [M_US = 0.22, M_China = 0.36, $t(38) = -2.60$, $p = 0.007$]. Furthermore, only the arousal levels corresponding to the car fronts, each of which is described as the "car's face" and which characterize the car's design (Keaveney et al., 2012), are processed further. These results show no significant differences for the known cars. However, they show significant differences for the front of the prototype P (Mdn_US = 0.17, Mdn_China = 0.39, $U = 137.00$, $z = -1.69$, $p = 0.047$), affirming H2.

Regarding H3, focusing on the conscious level of visual information processing *via* asking for the attractiveness ratings, it was found that Chinese participants (Mdn_China = 2.00) indicated significantly lower ratings for the prototype than US-American participants (Mdn_US = 1.00, $U = 156.00$, $z = -1.76$, $p = 0.039$), affirming H3. For the three known cars, the differences between Americans and Chinese were not significant (car C1: Mdn_US = 2, Mdn_China = 2.50, $U = 185.00$, $z = -0.92$, $p = 0.179$; car C2: Mdn_US = 2, Mdn_China = 2, $U = 193.00$, $z = -0.72$, $p = 0.24$; car C3: Mdn_US = 2, Mdn_China = 2, $U = 206.50$, $z = -0.36$, $p = 0.361$).

Culture and Arousal as Moderators

Individual cultural differences were captured by using traditional self-report scales for the cultural differences of individualism (vertical/horizontal orientation), collectivism (vertical/horizontal orientation), horizontal orientation (individualism/collectivism), and vertical orientation (individualism/collectivism). There was no significant difference between Chinese and American participants with regard to "individualism" [M_US = 5.97, SD = 1.01, M_China = 6.07, SD = 1.37; $t(40) = -0.28$, $p = 0.391$] and "collectivism" [M_US = 6.97, SD = 1.11, M_China = 6.62, SD = 1.44; $t(4) = 0.90$, $p = 0.186$]. Therefore, H4a had to be rejected. However, results showed differences between the Chinese and American participants concerning horizontal orientation (Mdn_US = 7.56, Mdn_China = 6.94, $U = 132.50$, $z = -2.21$, $p = 0.014$) and vertical orientation [M_US = 5.36, SD = 1.31, M_China = 6.02, SD = 1.34; $t(40) = -1.60$, $p = 0.059$], affirming H4b (see **Table 4**).

Finally, to test H5, stating that the individual vertical orientation has an effect on the attractiveness rating of the novel car, a factorial ANOVA (bootstrapping, within-subject design) with attractiveness of P being the dependent variable (z-transformed) was computed. Moreover, we tested a potential moderating effect of arousal. The independent variables of vertical orientation (mean of factor sum) and arousal relating to prototype P were binary coded by a median split [Mdn (vertical orientation) = 5.78; Mdn (overall arousal level) = 0.28]. The results demonstrate a marginally significant main effect of consumers' vertical orientation on the attractiveness ratings for the novel car (prototype P) [$F(1,15) = 3.09$, $p = 0.099$,

TABLE 4 | Statistics of cultural differences: Combined factors.

Cultural differences	Americans (N = 22)		Chinese (N = 20)		Comparisons	
	Means (SD)	Mdn	Means (SD)	Mdn	Mann–Whitney U (z)/T-test	p
Individualism (V and H orientation)	5.97 (1.01)	5.94	6.07 (1.37)	5.80	$T = -0.28$	0.391
Collectivism (V and H orientation)	6.97 (1.11)	7.19	6.62 (1.44)	6.72	$T = 0.90$	0.186
Vertical orientation (I and C)	5.36 (1.31)	5.23	6.02 (1.34)	6.00	$T = -1.60$	0.059
Horizontal orientation (I and C)*	7.56 (0.83)	7.56	6.67 (1.46)	6.94	U = 132.50 $z = -2.21$	0.014

*Non-parametric (based on Kolmogorov–Smirnov tests).

TABLE 5 | Statistics of bootstrapped factorial ANOVA: Cultural differences and arousal level for novel product.

Dependent variable: Attractiveness rating for novel product P (z-transformed)

Independent variables	Sum of squares	F	p	η_p^2
Arousal level (P)	0.26	0.49	0.495	0.03
Vertical orientation	1.61	3.09	0.099	0.17
Interaction(Arousal level × Vertical orientation) [$R^2 = 0.556$.]	9.75	18.74	0.001	0.56

Levene's test showed non-significant results.

η_p^2 = 0.171]. The arousal relating to car P showed no main effect. However, the interaction effect turned out to be highly significant [$F(1,15) = 18.74$, $p = 0.001$, η_p^2 = 0.55]. Follow-up tests with confidence intervals based on 1000 bootstrap samples indicated marginally significant differences between consumers with low versus high vertical orientation regarding their attractiveness ratings (M_diff = 0.65, 95% CI [−0.54, 1.22], $p = 0.081$). However, there is no significant difference regarding the arousal of the novel car (prototype P) (M_diff = 0.26, 95% CI [−1.13, 0.86], $p = 0.251$) (see **Table 5**).

CONCLUSION, LIMITATIONS, AND FURTHER RESEARCH

Overall, the present small-scale study contributes to a range of areas in consumer research. First, it presents new exploratory findings in the area of cultural differences in consumers' visual attention of novel products, by providing physiological data from a field study enhancing external validity of the contribution.

Second, the study demonstrates that Chinese and American consumers included in our sample differ in their way, how to visually engage with products. This finding is crucial for any new product development aiming to be launched across different cultures. The cultural differences in visual attention are specifically based on unconscious processes (such as differences in gaze parameters as well as in arousal levels). These findings underline the relevance of investigating cultural differences with physiological measures in addition to behavioral ones.

Third, the analyses reveal that Chinese and US-American consumers included in our sample approach novel products differently. Vertical orientation in particular seems to shape the perceived attractiveness of the novel product. The level of arousal (measured at an implicit level), turns out to be the driving force in this context. Although these findings are already intriguing, further studies would be valuable to test the robustness of the differences found. Further analyses could also focus on a potentially moderating role of perceived uncertainty, thereby strengthening the findings with regard to the differences in arousal levels. Moreover, prior studies have revealed that Chinese participants show lower impulsive buying tendencies due to triggered self-control (Zhang et al., 2012). Because uncertainty could also be managed with higher self-control, it would be useful to observe whether the reaction to uncertainty resulting from novel product changes over time (for instance, after self-control exhaustion for the different cultures). Additionally, the findings provide an indication that Chinese consumers who are targeted for premium products like cars also tend to be more individualistic, like Western consumers. This cultural finding, potentially, demonstrates that socioeconomic change in China is shaping new cultural approaches, which is an area of inquiry that should deserve substantial attention from researchers in the near future. The present study shows that among present-day consumers, US-Americans and Chinese differ predominantly on the basis of divergent horizontal and vertical approaches.

Due to the small sample size, which is often the case in psychophysiological studies (Riedl et al., 2020), the results of the present study are exploratory in nature. Future research should build upon our findings and test whether the effects found also hold for a broader sample.

Moreover, we also suggest including a more diverse set of stimuli as well as further features of the cars tested. Regarding a potential psychological explanation, further research in this context should also account for further socio-demographic variables of the respondents, including individual personality characteristics beyond variables focusing on cultural difference. Doing so would enable to get a more comprehensive picture on different market segments. Focusing not only on evaluations on an attitude-level but also on intentions or actual purchase behavior would further enhance the practical implications of the topic.

Further research could include studies manipulating particular features and element of the cars as well as to include overall evaluations of those features beyond mere visual aspects or where subject asked to mentally compare the cars. This could include qualitative investigations focusing on the mental representations of the features of the cars.

A valuable extension of this research would result from measuring not only the arousal level as such but also including other methods, which are capable of capturing the associated valence component. In this regard, methods like startle reflex modulation (e.g., Koller and Walla, 2012) or fMRI would support the further exploration of the valence changes in EDA levels of consumers with low or high vertical orientations. This would also allow gaining a better understanding of the role of arousal within the context of novel products in a qualitative manner. It would help to develop further insights into the role of positively toned (e.g., excitement or curiosity) or rather negatively toned (e.g., risk and uncertainty) facets within the evaluation and decision-making processes of novel products. Furthermore, moving into the area of brain activation research offers potential for providing information about underlying brain mechanisms that can reveal important insights into the influence that cultural patterns and ongoing cultural changes impose on consumer decision-making. The significance of this line of research extends beyond Chinese and US-American cultures, and beyond the valuable knowledge of responses to novel products. In this way, the present research has potentially opened an avenue of investigation that both needs and deserves an energetic research response.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the first and corresponding author upon request, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by IRB, Zeppelin University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

IR was the leading author responsible for data collection, data analysis, and the first draft of the manuscript. This manuscript was one part of her Ph.D. thesis "Beiträge zur Integration neurophysiologischer Methoden in das Innovationsmanagement." MH, MK, and PK contributed equally to the manuscript, revisions, and writing on the provided draft. All authors contributed to the article and approved the submitted version.

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Customer's Channel Selection Behavior on Purchasing Standardized and Customized Products: Optimized Prices and Channel Performances

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Nowadays, the traditional production is unable to meet the new diverse needs of target customers. In the current customization era, more and more companies are required by customers to provide more desirable customized products. However, research on customization and standardization based on quantitative analysis has drawn little attention in the literature of dual channel supply chain. In this paper, we study the effect of adopting a dual channel supply chain on the performance of a two-level system (manufacturer-retailer) by using a novelty quantitative approach. We try to analyze the system to get optimal prices and maximize profits, where manufactures offer both standardized and customized products via their traditional and customized channels, respectively. We build a Stackelberg game mode to construct a centralized and a decentralized dual channel scenarios. Furthermore, we study the effects of the different channel structures on price, degree of customization, degree of standardization, and supply chain profitability. We also analyze the effects of both standardized and customized demand sensitivities on their prices and profits. Eventually, we introduce a cost-sharing coordinating contract to optimize the channel's performance. We find that the potential market demand for customization affects the price of customized products and the profits of customized channels. Compared with the decentralized dual channel case, the cost-sharing contract can achieve higher total channel profits. In the cost-coordination case, there is an optimal range for the proportion of standardized costs borne by manufacturers.

Keywords: customer behavior, channel selection, standardized product, customized product, dual channel

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1. INTRODUCTION

In recent years, with the rapid development of internet technology and many advanced technologies, consumers' desire for customized products has received unprecedented attention. Many companies are willing to understand the real needs of consumers and provide them with excellent service experience of customized products. On the other hand, consumers are also prefer

to pay the corresponding premium for customized products. What's even more incredible is that, consumers are looking forward to actively participate in the product design and production process. The result of this is, the manufacturing process of products is increasingly directly driven by the individual needs of consumers.

Meanwhile, advances in manufacturing and information technology make it possible to efficiently produce customized product. Throughout the history of production, the Industrial production modes have evolved from the craft production mode to the mass production mode during the Industrial Revolution, then developed to the mass customization mode, and eventually to the customized production mode. In the customized production mode, companies will pay more attention to collect consumers' preferences and analyze their potential needs. They would like to fit consumers' demand with their customer-oriented, multi-variety, small batch production mode. The transformation of production mode is not only the production strategy of some companies, but the industrialization strategy of many countries. Many countries have published their re-industrialization strategies in the past years. For instance, Germany published the Industry 4.0 strategy in 2013 while China announced the Made-in-China 2025 (a 10-year national plan) in 2015, see Li (2018). Meanwhile, the United States, United Kingdom, France and other developed countries also have their re-industrialization strategies. The Made-in-China 2025 plan lays down China's approach to move up on the value chain and transform itself from a world manufacturing production workshop into a world-class industrialized giant. It focuses on binding the new generation of information technology, such as big data and cloud computing, with the modern manufacturing industry, and making continuous transformations and upgrades.

Product customization is increasingly becoming an important feature of the coordinated development of manufacturing industry and information technology. It's obvious to see that information technology is a powerful tool for the development of customer service. It does not only reconstruct the design process and improve the efficiency of production, but also push the digital and customized development of product design. In the industries of clothing, furniture, household appliances, automobiles, among others, design-based customization on information technology becomes an essential method for companies to achieve transformation. For instance, we can design a customized watch with our favorite frames and dial color, we can choose the straps with metal or leather under different colors at the website timissimo.com. Besides, customized slogans can even be engraved on the back of the watch. Therefore, customization is a multi-variety, small-batch-production mode which follows the personalized needs of customers, and reflects the people-oriented business philosophy of the companies. Additionally, it is an important manifestation of the core competitiveness of companies under the Industry 4.0 scheme. There are many advantages in customization. First, to improve the customer loyalty. Customers can make good use of the convenient information channel to timely communicate with product providers or design departments before purchase (greatly reducing the time to select products). Moreover, customers can also examine the production process through the network system. In the production process, any problem can be solved directly. Therefore, the customized business mode could improve customer satisfactions with their finished products. Then the customers' loyalty to the company will be greatly enhanced. Uniqlo's UT custom area allows customers to create their own designs, print and embroider. In addition, uniqlo relies on LBS positioning service to enable users to find nearby stores and to place orders online and pick up goods in stores, which makes the relationship between consumers and company closer. However, in the traditional channel, consumers can only buy high-rating clothes, and the company will not provide other services. Second, to reduce the inventory cost. In the past, companies have to produced products and sold them later, and the products may even remain unsold. The unsold products generate inventory cost heavily. With the development of information technology, companies can allocate their production lines according to their customer needs. Therefore, it can reduce their inventory, improve their inventory turnover, and greatly improve the efficiency of capital use. Third, to reduce the cost of sales. Customization enables manufacturers to communicate with their end-consumers directly, which eliminating the cost of intermediary distributors. In addition, the goods are produced according to the customers demand or design. If the quality is guaranteed and the price is reasonable, these products will reach the customers' expectations naturally. Thus, customization can basically avoid the cost of sales and promotion. Companies can introduce customization platforms and design various customer interaction tasks. Accordingly, the customers can participate in the products' customization process. West Lake No.1, a customized silk scarf design and retail platform for consumers based on artificial intelligence technology, has been officially launched in retail stores in Hangzhou. This platform can realize the real-time communication between AI designers and consumers, and conduct one-to-one customized design and production of silk scarves according to consumers' own characteristics, which greatly reduces the operating cost of manufacturing and retail enterprises.

The innovation mode of customization driven by customers is derived from the new era characters. There are more openness, interconnections, sharing, and experience-oriented. It is a reverse-customization production mode, known as C2B (Customer to Business) mode, that subverting B2C (Business to Customer) mode. The concept of C2B originally started in the e-commerce area, which means that the customers gather together and bargain with the sellers collectively to transfer price advantage from the manufacturers to themselves, see Thirumalai and Senthilkumar (2017). The C2B mode connect with the mass customization, which is defined as C2B2M-MC (Customer to Business to Manufactory-Mass Customization) mode. Customer drive is not only reflected in the purchase, sale of goods, operation and management, but also in the manufacturing process of products, see Salvador et al. (2009). Mass customization is a basic mode of production that generates highly customized products with the costs close to the mass production ones, see Kotha and Pine (1994). The essence of mass customization is to discover the personalized demand of

customers and provide targeted solutions. Mass customization is not a complete customization, but a limited one based on the selection of a number of products and services. Furthermore, C2B is connected with mass personalization, which is defined as C2B2M-MP (Customer to Business to Manufactory-Mass Personalization) mode. The original customized mode was dominated by companies, with customers choosing only a limited mix of existing product modules. Therefore, C2B should extend from the mass customization to the mass personalization, that is, the transition from product modular customization (MC) to product fully customization (MP), see Zhang et al. (2019). Product differentiation focuses on the individual customer, rather than the whole market segments. C2B2M-MP can coordinate the needs of a single customer and produce customized products within the capacity of the factory to meet the consumers' needs. C2B developed into a C2M (Customer to Manufactory) mode. C2M is also called short circuiting economy, see Skold (2010). C2M directly connects factories and customers, that eliminates the intermediate circulation of products, realizes the zero inventory of customer orders, and meets the personalized needs of customers. Red Collar Group is an early adopter of this C2M customized business mode. Red collar is a large-scale garment manufacturer producing fine suits and other products. In the process of integration of industrialization and information, Red Collar built a clothing database system with independent intellectual property rights. It has developed a set of customization system based on the collected information and big data. Red Collar has been taking orders for customized clothes since 2003. There are more than 100 trillion pieces of data in its big database system. Customer customized requirements are submitted through a C2M platform, and the system automatically generates their orders instantaneously. This method of production breaks through the bottleneck of manual production. In this mode, customers participate in almost all of their processes such as design, manufacturing, logistics, sales and others, see Jia et al. (2016).

In practice, manufacturers in a variety of industries have developed their customized channels, while keep their distributor relationships and retail channels intact. Companies such as Dell, IBM, Nike, Hewlett-Packard, Apple, and Pioneer Electronics demonstrate the use of the dual channel mode, see Tsay and Agrawal (2009). While Nike maintains its traditional retail model, customers can purchase customized products at www.nike.com. These business transformation practices motivate us to generate the following research questions.

1. How do different channel structures affect the pricing mechanism, customization decisions, channel selection, and the overall supply chain performance?
2. What are the effects of different degree of customization and standardization on the dual channels?
3. How to coordinate the dual channel supply chains of standardized and customized products?

To address these questions, we considers three typical channel structures, the centralized dual channel (Scenario *C*) case, the decentralized dual channel (Scenario *E*) case and the cost-sharing dual channel (Scenario *O*) case. We investigate the impacts of channel structures on price, customized decision, and supply chain performance. Moreover, we demonstrate that the increasing speed of the decentralized scenario is greater than that of the centralized one. Because the decentralized channel price is more affected by both standardized and customized elasticity of demand. Comparing the overall supply chain performance under the centralized case and the decentralized case, our work shows that the overall supply chain performance can be increased with the introduction of the customized channel as well as the degree of customization. In practice, channel managers should strive to introduce and increase R&D investment in the customized channel and improve the level of product customization.

Additionally, we consider the impact of inconsistencies between the standardized elasticity of demand and the customized elasticity of demand on the supply chain decision making. Our results show that, in the centralized case, with the increase of the customized elasticity of demand, the prices of customized products keep rising, while the prices of standardized products remain relatively stable. Demand for the customized products grows faster than that for the standardized one. Then the overall supply chain performance increases. However, in the decentralized case, the channel profit does not increase significantly with the increase of the degree of customization. This result occurs because of the channel conflict between the customized channel and the standardized channel.

In the cost-sharing contract, the sales price is lower than that in the centralized case. The selling price under the coordination case is close to that under the decentralized one. Additionally, compared with the overall profit under the decentralized case, the overall profit under the cost-sharing contract achieves better. We consider that in the coordinated case, the manufacturer helps the retailer by covering part of the cost in the standardized channel. Therefore, the retailers have more incentives to invest in the construction of the standardized channel. When manufacturers absorbs the standardization costs of retailers within a moderate range, the total profit of the system is stable. When the value of the cost is too high, then the total profit of the system declines exponentially. Therefore, manufacturers can induce retailers to try harder to sell standardized products by setting a reasonable cost-sharing ratio theme.

The remainder of the paper is organized as follows. In section 2, we review the related literature. In section 3, we develop our mode including demand and profit functions, and the related assumptions. We also obtain the optimal and equilibrium outcomes of the centralized and decentralized supply chains, respectively. Moreover, we describe the impact of channel structure, the degree of standardization, the degree of customization, the customized elasticity of demand, and the standardized elasticity of demand on the supply chain decision making. In section 4, we analyze the mechanism of the cost-sharing contract to coordinate these two channels. Concluding remarks are presented in section 5.

2. RELATED LITERATURE

Customized channels can create more profits for the manufacturers. However, the existence of customized channels affects the interests of retailers, which may lead to retailers' resistance to the customized channel. Such effect has a negative impact on the manufacturers' total profits. As a result, how to effectively coordinate the customized channel and the standardized channel is an important issue in the field of customized supply chain management. Many scholars have already analyzed this issue. At present, researches on customized supply chain mainly focus on,

1. Customization research from the perspective of consumers.
2. Pricing mechanisms of product substitution effect.
3. Conflict coordination mechanisms of dual channel supply chain.

In terms of customized research from the consumer's perspective, Bardakci and Whitelock (2004) discussed the attitudes of British consumers toward customized products and the influencing factors of mass customization, pointing out that the biggest influencing factor of customized products for consumers was the rise in prices. Yan et al. (2021) reviewed the literatures of additive manufacturing and 3D printing to reveal the state-of-art technologies on the production of customized products. Kumar and Ruan (2006) showed that the degree of brand loyalty and channel loyalty may influence the wholesale price, the retail price and the manufacturer's decision of introducing customized channels. Kurniawan et al. (2006) analyzed consumer decisions in product selection and customization tasks and found that consumers who participated in product customization were more satisfied with the product itself and the customization process. Li et al. (2020) study the perceived value and product involvement for customers to purchase customized garments in the fashion textile and apparel industry. Franke and Schreier (2008) found that customized products could increase consumers' willingness to consume among them. They found that the uniqueness of customized products played a major role and it could also affect consumers' positive experience and willingness to participate in product customization.

With regard to the research on pricing mechanisms for product substitution effects, Kuyumcu and Popescu (2006) studied the inventory management for the certainty of price of alternative products. The research showed that the problem of deterministic joint price inventory control with alternative products could be reduced to a pure pricing problem under the standardized regularization assumption of demand. If demand was uncertain and/or the product showed complementary effects, demand rationing could be profitable. Karakul et al. (2008) studied joint pricing and purchase volume modes for new and existing products with product alternatives. Liu et al. (2012) found that mass customization (MC) was a targeted industry practice. MC products returns were generally prohibited, therefore, MC retailers could gain a significant competitive advantage by providing consumer return policies. Through the establishment of a demand and revenue uncertainty analysis mode, they studied the optimal mechanism under the mean square error formula pricing, consumer returns and modularization three dimensions. Gupta et al. (2020) built a supply chain system with two suppliers and one retailer. Using the settings of Nash and Stackelberg games, they analyzed the impact of disruptions in supply capacity on pricing decisions for alternative products. Chen et al. (2013) consideres the pricing policy of a manufacturer in the supply chain. The manufacturer sold products to an independent retailer and also directly to consumers through Internet channels. In addition to the manufacturer's products, the retailer sold alternative products made by another manufacturer. They derived the existence and uniqueness conditions of the corresponding equilibrium solution for the Nash and Stackelberg games. Xiao et al. (2014) uses a Stackelberg pricing mode to investigate channel structure and in which the retail channel sold standardized products and the online channel offered customized products. They found that the unit wholesale and the retail prices of a standardized product sold through a retail channel were increased due to the addition of the direct channel for customized product. Savaskan and Van Wassenhove (2006) studied the problems of joint pricing and product technology selection faced by manufacturers when introducing remanufactured products into differentiated product markets.

Eventually we review the literature on dual channel supply chain conflict coordination. Boyaci (2005) analyzed the dual channel conflict based on Nash game, and explored the channel inefficiencies induced by the presence of simultaneous vertical competition (double-marginalization) and horizontal competition (substitutability). Boyaci suggested that combined contracts could better coordinate dual channel systems. Tsay and Agrawal (2009) argued that both online direct channels and traditional distribution channel had externalities in promotion, but retail channel promotion had a cost advantage. They proposed that the combination of the buyback price and the total wholesale price contracts could coordinate the supply chain. Chiang (2010) also designed a combination contract of inventory cost and network channel revenue sharing to solve the coordination problem of the dual channel. He further verified that the combined contract could enable the coordinated operation of the network channel and the traditional channel. Kurata et al. (2007) studied dual channel operation under different pricing mechanisms and made comparative analysis with numerical simulation. He pointed out that a single wholesale price mechanism could not coordinate it, but the combination of wholesale price mechanism with price reduction or price increase compensation could effectively coordinate the dual channel system. Li et al. (2015) found that the price of standardized products offered by retailers did not necessarily fall due to the online offering of customized products. He also found that under certain conditions, both manufacturers and retailers saw increased profits when manufacturers offered customized products online.

The findings above provide a strong foundation for our research. Bardakci and Whitelock (2004), Kumar and Ruan (2006), Kurniawan et al. (2006), and Franke and Schreier (2008) mainly study the customization effects from the perspective of consumers. In this paper, we also discuss these effects when

presenting our results. Moreover, our focus is not only on the relationship between consumer demand and products' prices, but also on the influence of different degrees of customization and standardization on demand and price. Kuyumcu and Popescu (2006), Savaskan and Van Wassenhove (2006), Karakul et al. (2008), Liu et al. (2012), Chen et al. (2013), and Gupta et al. (2020) mainly study the pricing mechanisms related to product substitution effects. Our work differs from this research stream in several respects. First, we do not only employ an inverse demand function to analyze the quantity decisions in a context of dual channel supply chains. Instead, we introduce the customized channel and the standardized channel scenarios. We analyzed the influence of different degree of customization and degree of standardization on the overall channel performance and obtain a more comprehensive outcome. Finally, we also consider both customized and standardized elasticity of demand. Boyaci (2005), Tsay and Agrawal (2009), Chiang (2010), and Kurata et al. (2007) study dual channel supply chain conflict coordination mechanisms. However, the relationship between the price, the degree of customization and the degree of standardization are not considered. Nevertheless, quite a number of researchers have focused on the study of dual channel coordination from the perspective of homogeneous products, but seldom make quantitative analysis on the internal mechanism of dual channel conflict. On this basis, less research is carried out on dual channel conflict coordination mechanisms based on customization and standardization. In the context of competition between the customized channel and the standardized channel, we establish a decision modes of price, degree of customization and degree of standardization. First, we analyze the impact of different channel structures on pricing, degree of customization, degree of standardization and supply chain profitability. Then we analyze the influence of different degree of customization and standardization on the optimal results. Finally, we design a cost-sharing contract to solve the imbalance problem between customized and standardized products.

3. PROBLEM FORMULATION

We consider a supply chain system with customized and standardized channels, that consisting of two independent entities, a manufacturer and a retailer. To meet customers' demand and their preferences, the manufacturer adopts a dual channel strategy in which the manufacturer has a regular retailing channel and an online channel. The standardized products are sold by the retailer while the customized products are sold by the manufacturer. The manufacturer pays for the customized product cost and the retailer pays for the standardized product cost. We discuss the centralized case (Scenario *C*), the decentralized case (Scenario *E*), and the coordinated case (Scenario *O*) with the manufacturer as the leader and the retailer as the follower. Then we study the behavior of this system, analyze the optimal values of the decision variables under different conditions and measure the performance by using the total profit of the supply chain. Further, we examine the effects of different pricing and coordination mechanisms. m represents the degree of customization. From standardized products to modular customization to full customization, the larger m is, the higher degree of customization is. e represents the degree of standardization. The higher the degree of standardization, the clearer the product classification is and the more selective customers can be. We use the terms D_e, D_m to indicate the demand of the standardized product and the demand of the customized products, respectively. The sale price of customized products is denoted as p_m and the sale price of standardized products is represented by p_e. θ $(0 \leq \theta < 1)$ denotes channel substitutability. The channels are demand interdependent (unless θ=0), although α_e and α_m appeal to different market segments. $\alpha_i > 0$ $(i = m, e)$ represents the base demand of customized product and standardized product, respectively. λ_i $(i = m, e)$ denotes the effect of an increase in the product's customization and standardization on each channel's demand. In **Table 1** we listed all the necessary notations.

TABLE 1 | Summary of notations.

Notation	Description
U	The utility for representative consumer
p_e	Price of the standardized product
p_m	Price of the customized product
e	Degree of standardization
m	Degree of customization
w	Wholesale price, $w \leq p_e$ $w \leq p_m$
D_e	Demand for standardized products
D_m	Demand for standardized products
α_e	Base demand of the standardized product
α_m	Base demand of the customized product
θ	Channel substitutability, $0 \leq \theta < 1$
τ	Percentage of standardization costs borne by the manufacturer, $0 \leq \tau < 1$
λ_e	Standardized elasticity of demand
λ_m	Customized elasticity of demand
K_e	Unit standardized product investment
K_m	Unit customized product investment

We adopt the framework established by Ingene and Parry (2004), which has been applied extensively in the field of operations and marketing management, see Cai (2010), Cai et al. (2015), Chen et al. (2017), and Snyder and Shen (2019), and we employ a similar utility function for the representative consumer as follows.

$$\begin{aligned} U(D_m, D_e) =& \alpha_m D_m + \alpha_e D_e - p_m D_m - p_e D_e - \frac{1}{2} D_m^2 - \frac{1}{2} D_e^2 \\ & - \theta D_m D_e \\ & + \lambda_m m D_m + \lambda_e e D_e \end{aligned} \tag{1}$$

Equation (1) implies that the representative consumer utility function is linearly dependent on price, degree of standardization and degree of customization. It also indicates that utility decreases in price while increases in the degree of standardization and the degree of customization. Moreover, the utility decreases

in channel substitution θ and increases in the customized elasticity of demand λ_i.

Therefore, we estimate consumers' demand functions by maximizing U with respect to D_m and D_e, respectively.

$$\begin{cases} \frac{\partial U}{\partial D_m} & = \alpha_m - p_m - D_m - \theta D_e + \lambda_m m = 0 \\ \frac{\partial U}{\partial D_e} & = \alpha_e - p_e - D_e - \theta D_m + \lambda_e e = 0 \end{cases} \quad (2)$$

In the following, the demand of the standardized channel is

$$D_e = \frac{1}{1-\theta^2}[(\alpha_e - \theta\alpha_m) - (p_e - \theta p_m) + (\lambda_e e - \theta\lambda_m m)] \quad (3)$$

and the demand of the customized channel is

$$D_m = \frac{1}{1-\theta^2}[(\alpha_m - \theta\alpha_e) - (p_m - \theta p_e) + (\lambda_m m - \theta\lambda_e e)] \quad (4)$$

We find that the requirements function for standardized and customized products is linear, as in Zhang et al. (2015) and Chen et al. (2017).

With the above demand functions, we formulate the individual profits in the supply chain. The manufacture's profit function is

$$\Pi_M(p_m, m) = (w - c_e)D_e + (p_m - c_m)D_m - \frac{K_m}{2}m^2 \quad (5)$$

where the first term is the manufacturer's revenue of the standardized channels, the second term is the manufacturer's revenue of customized channels, and the third term is the manufacturer's customized cost. The retailer's profit function is

$$\Pi_R(p_e, e) = (p_e - w)D_e - \frac{K_e}{2}e^2 \quad (6)$$

where the first term is the retailer's revenue of the standardized channels and the second term is the retailer's standardized cost. In Equations (5) and (6), w is the wholesale price which has been given. We define c_m as the unit cost of customized channel and c_e as the unit cost of the standardized channel. We mode costs of the customization and standardization as a quadratic function, which explains why increasing the degree of customization or the degree of standardization at a high level increases costs, and reduces returns, see Tsay and Agrawal (2009). The total profit of the dual channel supply chain π_T is given by the sum of Equations (5) and (6), as follows

$$\Pi_T = \Pi_R + \Pi_M \quad (7)$$

We have the following assumes,

Assumption 1. *All of the channel members are risk-neutral and completely rational. In other words, the manufacturer and the retailer make choices to pursue their maximize expected profits.*

Assumption 2. *The products selling through standardized channel and customized channel are different. The manufacturer determines the wholesale price per unit w and the price of customized products p_m, while the retailer determines the channel retail price p_e of standardized products. The price of customized products should not lower than that of standardized products in the retail channel.*

Assumption 3. *The demands of consumers in both channels are positive, $D_e > 0$ and $D_m > 0$.*

Assumption 4. *All input parameters are positive.*

Assumption 5. *θ ($0 \leq \theta < 1$) measures channel substitution. When θ approaches 1, the channel become perfect substitutes. The demand for each channel become independent when $\theta = 0$.*

Assumption 6. *In the centralized customization and standardization channels, the following assumptions are established, $4k_e k_m(1-\theta^2) - 2k_e\lambda_m{}^2 - 2k_m\lambda_e{}^2 + \lambda_e{}^2\lambda_m{}^2 > 0$.*

Assumption 7. *In the decentralized customization and standardization channels, the following assumptions are established, $2(1-\theta^2)k_e - \lambda_e{}^2 > 0$ and $\frac{2Qk_m((1-\theta^2)(2-M\lambda_e))-(Q\lambda_m)^2}{(1-\theta^2)^2(2-M\lambda_e)^2} > 0$.*

Assumption 8. *In the cost-sharing customization and standardization channels, the following assumptions are established, $2(1-\tau)(1-\theta^2)k_e - \lambda_e{}^2 > 0$.*

3.1. The Centralized Dual Channel Supply Chain

We first consider the case of centralized decision. Both players in the supply chain act as a single system to maximize the whole supply chain profit. The manufacturer produces two products, a standardized product, sold through the retailer' channel and a customized product, sold through the customized channel. The decision variables are the price of customized products p_m, the price of standardized products p_e, the degree of customization m and the degree of standardization e. The total profit of the centralized dual channel supply chain is

$$\Pi_T(p_e, p_m, e, m) = (p_e - c_e)D_e + (p_m - c_m)D_m - \frac{K_m}{2}m^2 - \frac{K_e}{2}e^2 \quad (8)$$

According to the above total profit function, we solve the first order partial derivatives with respect to p_e, p_m, e and m, respectively, and then we solve all of those equations simultaneously.

$$\begin{cases} \frac{\partial \Pi_T(p_e,p_m,e,m)}{\partial p_e} & = 0 \\ \frac{\partial \Pi_T(p_e,p_m,e,m)}{\partial p_m} & = 0 \\ \frac{\partial \Pi_T(p_e,p_m,e,m)}{\partial e} & = 0 \\ \frac{\partial \Pi_T(p_e,p_m,e,m)}{\partial m} & = 0 \end{cases} \quad (9)$$

We can get the optimal degree of standardization is

$$e_C^* = \frac{-\theta\lambda_e\left(2k_m\right)(\alpha_m - c_m) + \lambda_e\left(2k_m - \lambda_m^2\right)(\alpha_e - c_e)}{4k_m k_e\left(1-\theta^2\right) - 2k_e\lambda_m^2 - 2k_m\lambda_e^2 + \lambda_e^2\lambda_m^2} \quad (10)$$

The optimal degree of customization is

$$m_C^* = \frac{-\theta\lambda_m\left(2k_e\right)(\alpha_e - c_e) + \lambda_m\left(2k_e - \lambda_e^2\right)(\alpha_m - c_m)}{4k_m k_e\left(1-\theta^2\right) - 2k_e\lambda_m^2 - 2k_m\lambda_e^2 + \lambda_e^2\lambda_m^2} \quad (11)$$

The optimal price of the standardized products is

$$p_{e-C}^{*}=\frac{-\theta\lambda_e^2\left(2k_m\right)\left(\alpha_m-c_m\right)+\left(4k_mk_e\left(1-\theta^2\right)-2k_e\lambda_m^2\right)\alpha_e}{2}+\frac{\left(4k_mk_e\left(1-\theta^2\right)-2k_e\lambda_m^2-4k_m\lambda_e^2+2\lambda_e^2\lambda_m^2\right)c_e}{2} \tag{12}$$

The optimal price of the customized products is

$$p_{m-C}^{*}=\frac{-\theta\lambda_m^2\left(2k_e\right)\left(\alpha_e-c_e\right)+\left(4k_mk_e\left(1-\theta^2\right)-2k_m\lambda_e^2\right)\alpha_m}{2}+\frac{\left(4k_mk_e\left(1-\theta^2\right)-4k_e\lambda_m^2-2k_m\lambda_e^2+2\lambda_e^2\lambda_m^2\right)c_m}{2} \tag{13}$$

We substitute (Equations 8, 10–13). We can get the Theorem 1.

Theorem 1. *The optimal profit under the centralized case is*

$$\pi_{T-C}^{*}=\left(p_{e-C}^{*}-c_e\right)\frac{\alpha_e-\theta\alpha_m-p_{e-C}^{*}+\theta p_{m-C}^{*}+\lambda_e e_C^{*}-\theta\lambda_m m_C^{*}}{1-\theta^2}+\left(p_{m-C}^{*}-c_m\right)\frac{\alpha_m-\theta\alpha_e-p_{m-C}^{*}+\theta p_{e-C}^{*}+\lambda_m m_C^{*}-\theta\lambda_e e_C^{*}}{1-\theta^2}-\frac{k_m m_C^{*2}}{2}-\frac{k_e e_C^{*2}}{2}$$

1. The manufacturer is the leader and the retailer is the follower.
2. The manufacturer chooses the degree of customization and decides the price of the customized products.
3. The retailer determines the retail price for standardized products and the degree of standardization.

$$\begin{cases}\frac{\partial\Pi_R(p_e,e)}{\partial p_e}=\frac{\alpha_e-\theta\alpha_m-p_e+\theta p_m+\lambda_e e-\theta\lambda_m m}{1-\theta^2}+\frac{-(p_e-\omega)}{1-\theta^2}=0\\ \frac{\partial\Pi_R(p_e,e)}{\partial e}=\frac{\lambda_e(p_e-\omega)}{1-\theta^2}-k_e e=0\end{cases}$$

Therefore,

$$\begin{cases}p_{e-E}=\frac{\alpha_e-\theta\alpha_m+\theta p_m-M\lambda_e\omega-\theta\lambda_m m+\omega}{2-M\lambda_e}\\ e_E=M\left(\frac{\alpha_e-\theta\alpha_m+\theta p_m-M\lambda_e\omega-\theta\lambda_m m+\omega}{2-M\lambda_e}-\omega\right)\end{cases} \tag{16}$$

We extend the functions of D_e and D_m as follows.

$$D_{e-E}=\frac{\left\{\begin{array}{c}\alpha_e-\theta\alpha_m-\frac{\alpha_e-\theta\alpha_m+\theta p_m-M\lambda_e\omega-\theta\lambda_m m+\omega}{2-M\lambda_e}+\theta p_m\\ +\lambda_e M\left(\frac{\alpha_e-\theta\alpha_m+\theta p_m-M\lambda_e\omega-\theta\lambda_m m+\omega}{2-M\lambda_e}-\omega\right)-\theta\lambda_m m\end{array}\right\}}{1-\theta^2} \tag{17}$$

$$D_{m-E}=\frac{\left\{\begin{array}{c}\alpha_m-\theta\alpha_e-p_m+\theta\frac{\alpha_e-\theta\alpha_m+\theta p_m-M\lambda_e\omega-\theta\lambda_m m+\omega}{2-M\lambda_e}+\lambda_m m\\ -\theta\lambda_e A\left(\frac{\alpha_e-\theta\alpha_m+\theta p_m-M\lambda_e\omega-\theta\lambda_m m+\omega}{2-M\lambda_e}-\omega\right)\end{array}\right\}}{1-\theta^2} \tag{18}$$

Equations (16)–(18) are introduced to Equation (14), we get the maximum value

$$\begin{cases}p_{m-E}^{*} &= \frac{\alpha_m}{2}+\frac{\lambda_m\left[(\omega-c_e)\frac{-2\theta\lambda_m}{2Nk_m-Q\lambda_m^2}+\left(\alpha_m+\frac{-\theta\alpha_e+(\theta+\theta M\lambda_e)\omega-\theta c_e}{Q}-c_{\mathrm{m}}\right)\frac{Q\lambda_m}{2Nk_m-Q\lambda_m^2}\right]}{2}\\ &\quad+\frac{-\theta\alpha_e+(\theta+\theta M\lambda_e)\omega-\theta c_e}{2Q}+\frac{c_{\mathrm{m}}}{2}\\ m_E^{*} &= (\omega-c_e)\frac{-2\theta\lambda_m}{2Nk_m-Q\lambda_m^2}+\left(\alpha_m+\frac{-\theta\alpha_e+(\theta+\theta M\lambda_e)\omega-\theta c_e}{Q}-c_{\mathrm{m}}\right)\frac{Q\lambda_m}{2Nk_m-Q\lambda_m^2}\end{cases} \tag{19}$$

3.2. The Decentralized Dual Channel Supply Chain

In the decentralized case, the manufacturer and the retailer take into account their own profit maximization for the decision making. The retailer has to compete with the customized channel owned by the manufacturer.

The manufacturer's profit function is

$$\Pi_M(p_m,m)=(w-c_e)D_e+(p_m-c_m)D_m-\frac{k_m}{2}m^2 \tag{14}$$

The retailer's profit function is

$$\Pi_R(p_e,e)=(p_e-w)D_e-\frac{k_e}{2}e^2 \tag{15}$$

We adopt a two-stage Stackelberg game between the manufacturer and the retailer. The following sequence of events occurs in the game.

It follows that

$$\begin{cases}p_{e-E}^{*} &= \frac{\alpha_e-\theta\alpha_m+\theta p_{m-E}^{*}-M\lambda_e\omega-\theta\lambda_m m_E^{*}+\omega}{2-M\lambda_e}\\ e_E^{*} &= M\left(\frac{\alpha_e-\theta\alpha_m+\theta p_{m-E}^{*}-\theta\lambda_m m_E^{*}-\omega}{2-M\lambda_e}\right)\\ D_{e-E}^{*} &= \frac{\alpha_e-\theta\alpha_m-p_{e-E}^{*}+\theta p_{e-E}^{*}+\lambda_e e_E^{*}-\theta\lambda_m m_E^{*}}{1-\theta^2}\\ D_{m-E}^{*} &= \frac{\alpha_m-\theta\alpha_e-p_{m-E}^{*}+\theta p_{e-E}^{*}+\lambda_m m_E^{*}-\theta\lambda_e e_E^{*}}{1-\theta^2}\end{cases} \tag{20}$$

where $M=\frac{\lambda_e}{(1-\theta^2)k_e}, N=\left(1-\theta^2\right)(2-M\lambda), Q=\left(2-M\lambda_e-\theta^2+\theta^2M\lambda_e\right)$.

We substitute (Equations 19 and 20) to the manufacturer's profit function (Equation 14) and the retailer's profit function (Equation 15). We can get the following theorem 2.

Theorem 2. *The optimal profit of the manufacturer is* $\Pi_{M-E}^{*}=(w-c_e)D_{e-E}^{*}+(p_{m-E}^{*}-c_m)D_{m-E}^{*}-\frac{k_m m_E^{*2}}{2}$ *and the optimal profit of the retailer is* $\Pi_{R-E}^{*}=(p_{e-E}^{*}-w)D_{e-E}^{*}-\frac{k_e e_E^{*2}}{2}$.

We analyze the supply chain decisions under the centralized channel and decentralized channel scenarios. To draw our results, we compare the price, the degree of standardization and the degree of customization of the supply chain under different channel structures. The default values of our input parameters are $w = 2.5$, $\alpha_e = 10$, $\theta = 0.5$, $c_m = 1.5$, $c_e = 1.5$, $K_m = 1$, $K_e = 1$, $\lambda_e = 0.25$. We set α_m as the independent variable while xing the values of other parameters. λ_m is associated to λ_e. The following propositions summarize the comparison results.

Proposition 1. *In both scenarios, the base demand of dual channel supply chain will affect the degree of customization, the degree of standardization and the overall supply chain performance*

$$\frac{\partial p^*{}_{e-C}}{\partial \alpha_e} > 0, \frac{\partial p^*{}_{e-E}}{\partial \alpha_e} > 0, \frac{\partial p^*{}_{m-C}}{\partial \alpha_m} > 0, \frac{\partial p^*{}_{m-E}}{\partial \alpha_m} > 0,$$

$$\frac{\partial e_C^*}{\partial \alpha_e} > 0, \frac{\partial e_E^*}{\partial \alpha_e} > 0, \frac{\partial m_C^*}{\partial \alpha_m} > 0, \frac{\partial m_E^*}{\partial \alpha_m} > 0$$

$$\frac{\partial e_C^*}{\partial \alpha_m} < 0, \frac{\partial e_E^*}{\partial \alpha_m} < 0, \frac{\partial m_C^*}{\partial \alpha_e} < 0, \frac{\partial m_E^*}{\partial \alpha_e} < 0$$

According to Equations (10)–(13), (19), and (20), we conclude that the optimal product pricing is related to the channel's potential market demand, whether we analyze the decentralized or the centralized case. The price of customized products will increase as the demand for customization increases, and the price of standardized products will increase as the demand for standardized products increases. The degree of customization and standardization between channels also changes according to the basic needs of the channel, for example, the degree of customization increases according to the basic needs of the customization channel. Channel managers need to work hard to explore the market potential customization needs and expand the customization market. In the field of security video surveillance, there are always some manufacturers will ignore the customer needs. In the era of network monitoring, it is essential for security companies to grasp the actual needs of customers and design appropriate customized products.

Proposition 2. *The price of standardized products rises as the degree of standardization increases. With the increased degree of standardization, the price of standardized products under the centralized scenario is higher than that of standardized products under the decentralized one. In addition, the sales price of standardized products is more affected by the degree of standardization in the decentralized case.*

Figure 1 indicates that in order to better take advantage of the standardized product channel, the retailer increase the investment in the construction of the standardized channel, which leads to an increase of the standardization price. Moreover, we find that under the decentralized case, the price of standardized products is more affected by the degree of standardization compared with the price of standardized products under the centralized case.

Proposition 3. *In a dual channel supply chain, the price of the customized products rises as the degree of customization increases. More specifically, when the degree of customization m increases, the price of customized products in the centralized scenario is higher than that of customized products in the decentralized case,* $p^*_{m-C} > p^*_{m-E}$.

Figure 2 indicates that to provide better customized products, the manufacturer increases the investment in both technical innovation and channel construction of customized products which includes the cost of building a customized platform, the cost of intelligent information production, and the cost of purchasing new equipment. As a result, the manufacturer increases the price of the customized products due to the increasing cost of customization.

Combining with **Figure 3**, it can be observed that under the decentralized scenario, the degree of customization has a significant impact on the channel profit. The profit of the manufacturer increases with the increase of the degree of customization, the profit of the retailer decreases with the increase of the degree of customization, and the manufacturer is more obviously affected by the degree of customization. In the area 1 of the figure, the manufacturer's profit is lower than the retailer's profit, and in the area 2, as the degree of customization exceeds a certain threshold, the manufacturer gradually reaps a higher level of profit than the retailer. Then we can see that, the manufacturer's profit from both the customized and standardized channels is greater than the retailer's profit from only the standardized channel. That is, $\Pi^*_{M-E} > \Pi^*_{R-E}$. According to the above analysis, it can be found that the introduction of customized channel is a good advantage for the manufacturer. By increasing the investment in customized channels, the level of channel customization can be continuously improved and a higher level of profit can be obtained. However, for the retailer, the customized channel compresses their original profit margins, which may lead to the retailer's dissatisfaction with the introduction of customized channel, which in turn leads to channel conflicts and imbalances in the system.

Proposition 4. *In the decentralized dual channel supply chain, on the one hand, manufacturers' profits rise significantly with increasing channel customization, while on the other hand, retailers' profits fall steadily. More specifically, the manufacturer's profit increase is economically greater than the decline in the retailer's profit, therefore the overall supply chain profit is still increasing.*

In **Figure 4**, we observe that the increase in customization significantly increases the manufacturer's profitability. Conversely, the existence of channel conflicts leads to a considerable impact on the retailer's profitability. In the home appliance industry, the customization has become an important direction of transformation and upgrading.With young users gradually becoming the main body of household appliances end-consumers, more and more consumers want to be able to highlight their distinctive personality, the pursuit of technology, fashion, comfort and personalized life. As a consequence, companies such as Haier, Midea, LG, Samsung,

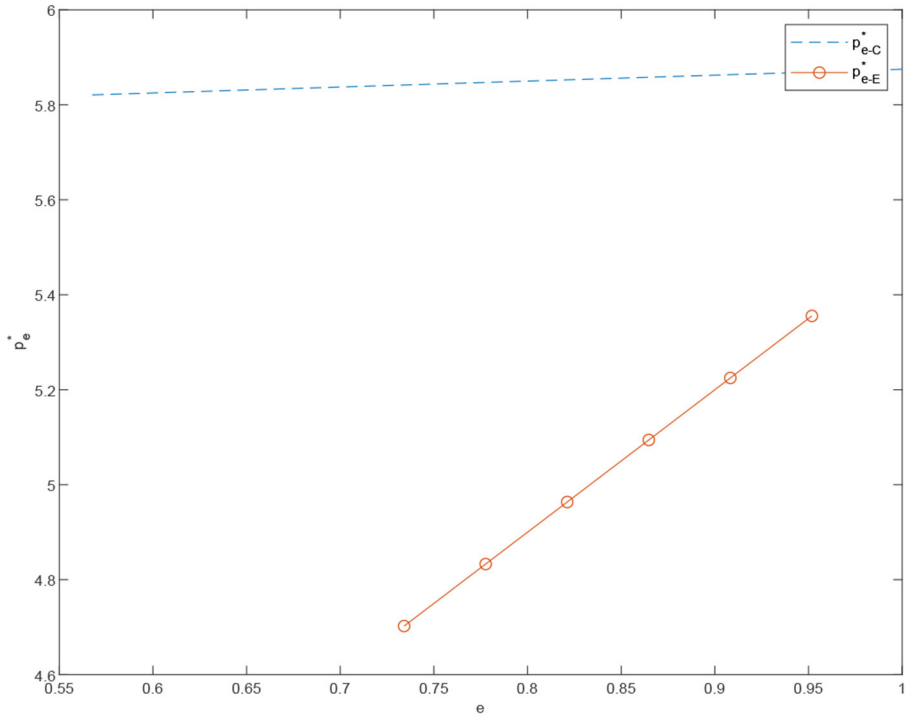

FIGURE 1 | The price of the standardized product under the centralized scenario p^*_{e-C} vs. the price of the standardized product under the decentralized scenario p^*_{e-E}.

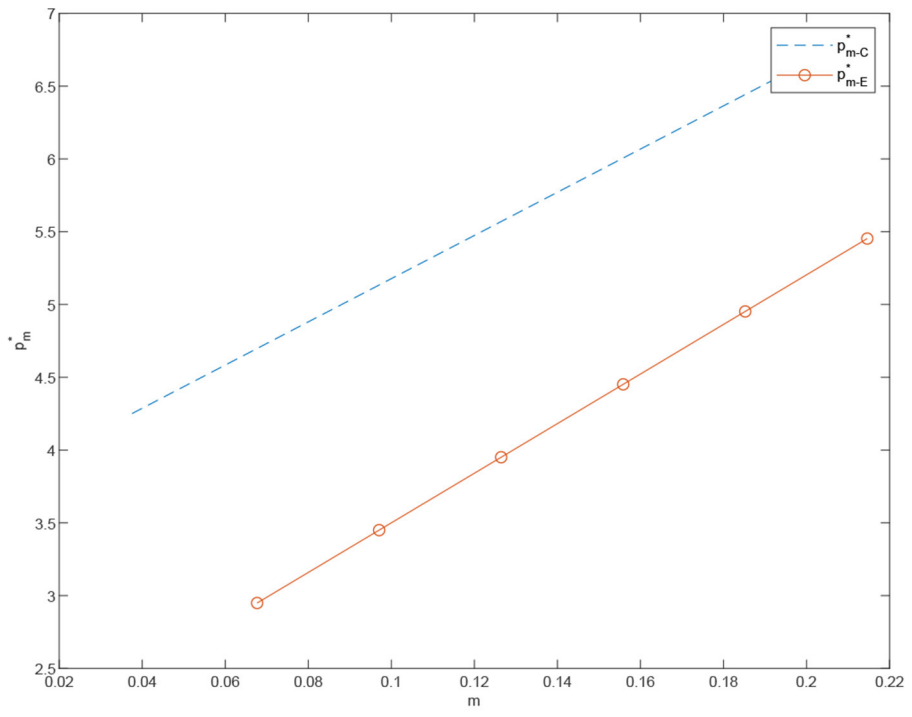

FIGURE 2 | The price of the customized product under the centralized scenario p^*_{m-C} vs. the price of the customized product under the decentralized scenario p^*_{m-E}.

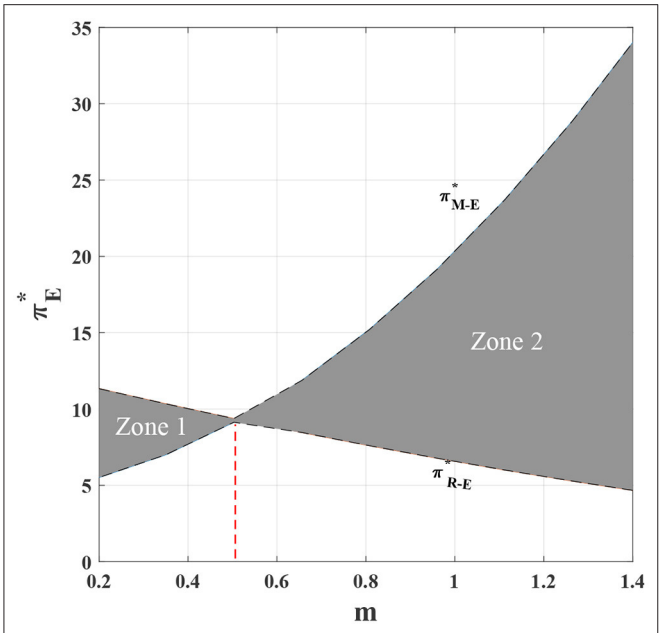

FIGURE 3 | The impact of m on the channel profits under the decentralized cases.

Bosch, Siemens and many others have launched customized services for home appliance products to meet the customized needs of their consumers. With the gradual development of the customization market, the original standardized home appliance market is bound to shrink resulting in the overall decline of the standardized market profit.

Proposition 5. *We find that the introduction of a customized channel increases the total profit of the system, especially as the market becomes more customizable.*

Figure 5 indicates that as the degree of customization m increases, the degree of standardization e decreases somewhat, but the total profit of the system increases significantly. To conclude, the channel manager should strive to introduce a customized channel or, if already existing, increase the research and development capital investments in it. Furthermore, the channel manager should do everything in the power to coordinate the supply chain and centralize the supply chain system to maximize the company's total profit. Channel managers should establish the optimal balance between the benefits of investing and increasing the customized channel, and the price increase derived by such investment. More precisely, adding a customized channel is in the manufacturer's best interest only when the customized market demand is large enough to economically justify the capital investment. For this reason, in recent years, more and more industries have chosen to add a customized channel. However, when the market demand for customization is sluggish, choosing to add a customized channel does not only directly decrease the retailer's profit and cause a channel conflict, but also fails to increase the profit of the manufacturer. This also corresponds to practice explaining why many industries do not have the option of customization, such as electric cars and hair dryers.

Because of the strong dependence of the manufacturer's choice to invest in new customized channels on the level of customized products demand, we consider the influence of the standardized elasticity of demand and the customized elasticity of demand on the supply chain decision making. Due to the incomplete substitutability between customized and standardized products, customers are heterogeneous in their preference between them. As a result, the consumers' purchase behaviors for both products lead to different channel influence coefficients between the two channels.

Equations (19) and (20) show that the degree of customization between those channels and the customized market demand, as well as the degree of standardization and the standardized market demand, also show a positive correlation. For instance, the degree of customization will increase according to the increase in the customized market demand. The same trend also applies to the standardized market. However, as shown in **Figure 6**, there is no linear growth relationship between the customized market demand and the overall profit of the system. Specifically, when the market demand for customization is large, adding a customized channel is a good choice for the system. Because even if there are higher fixed costs of production technology and higher marginal production costs, manufacturers can respond faster to customer needs by increasing customized channels, enhance channel competitiveness, and gain more profits. This also explains why in recent years, more and more industries have begun to choose to add a customized channel. However, when the market demand for customization is sluggish, choosing to add a customized channel is not only not cost-effective or flexible, but also affects the profits of the manufacturer and the retailer, and is not conducive to the long-term stability of the system.

To quantify the differences, we use the parameters λ_m to reflect the effect of an increase in the degree of customization and standardization on dual channel's demand, respectively. We use λ_r to reflect the effect of an increase in the degree of standardization on dual channel's demand. Let $\lambda_m = \varphi\lambda_r (A \geq 0)$, then φ measure the difference of coefficient between customization and standardization channel. When $0 < \varphi < 1$, the customization channel has a weaker channel advantage. When $1 < \varphi$, the customization channel has a stronger channel advantage. We use a numerical approach to study the effects of these parameters.

Proposition 6. *In the centralized case, as φ increases, the customized elasticity of demand λ_m increases. The sales price of customized products presents an upward trend, and the sales price of standardized products remains relatively stable. Additionally, the growth rate of customization demand is growing at a greater rate than that of standardization demand. As a result, the supply chain systems achieve higher profits. In the decentralized case, the system profit increases in λ_m, but the growth trend is not obvious.*

$$\frac{\partial D^*{}_{m-E}}{\partial m} > \frac{\partial D^*{}_{e-E}}{\partial e}, \frac{\partial D^*{}_{m-C}}{\partial m} > \frac{\partial D^*{}_{e-C}}{\partial e}$$

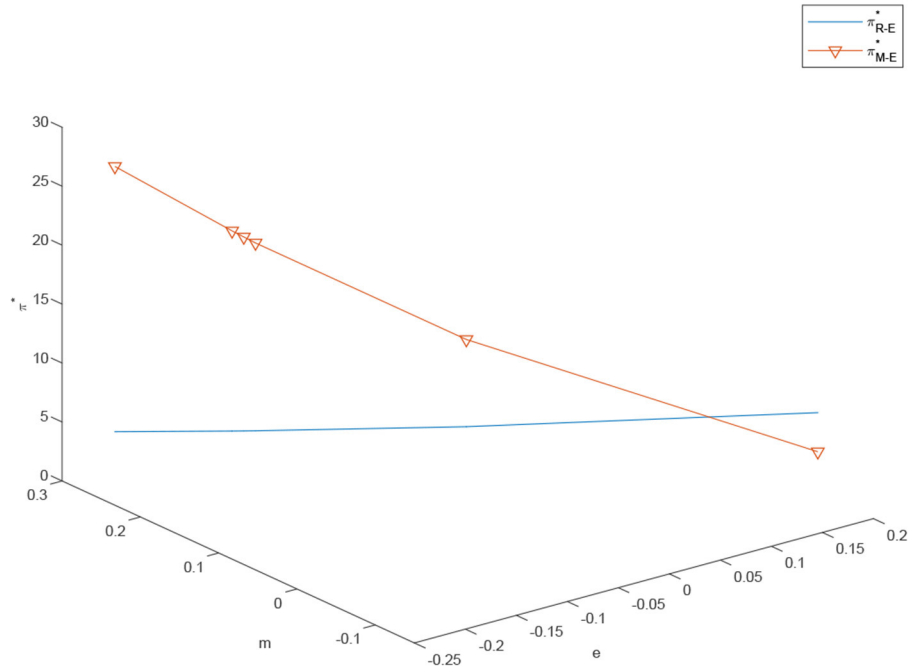

FIGURE 4 | The effects of *e* and *m* on the retailer's and manufacturer's and profits under centralized scenario, π^*_{R-E} and π^*_{M-E}.

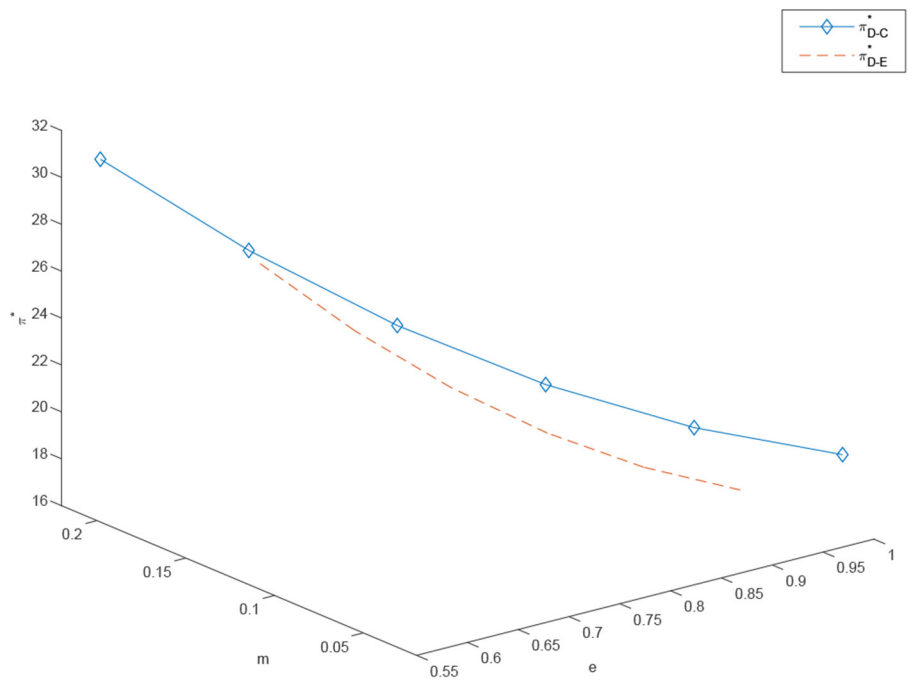

FIGURE 5 | The effects of *e* and *m* on the retailer's and manufacturer's and profits under decentralized scenario, π^*_{D-C} and π^*_{D-E}.

Figures 7, **8** show that, in the centralized case, the customized channel profit increases with λ_m. More specifically, the price of customized products continues to rise, while the price of standardized products remains relatively stable. The demand growth rate of customized products is steeper than that of standardized products and the total system profit keeps growing.

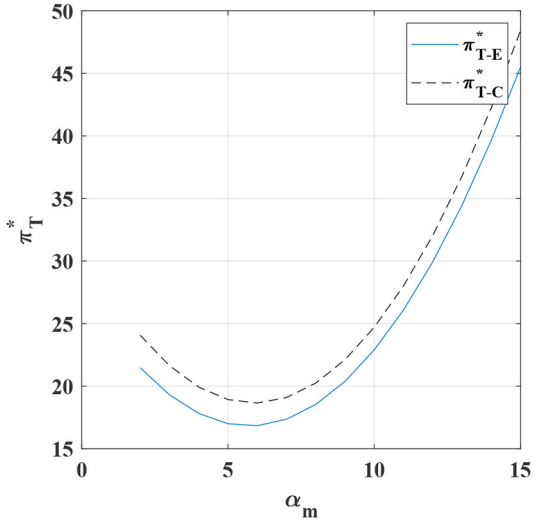

FIGURE 6 | The impact of α_m on the overall profit of the system under the different cases.

On the other hand, in the decentralized case, overall channel profit does not increase significantly in λ_m. This may be due to the channel conflict between the customized and the standardized channels.

4. COORDINATION MECHANISM

Base on the above analysis, we conclude the total profit of the centralized supply chain is greater than that of the decentralized one. To improve the overall efficiency of the supply chain and eliminate the double marginal effect, we introduce a cost-sharing contract, in which the manufacturer and the retailer share the cost of standardized production.

Our aim is to reduce the conflict between the two channels. The manufacturer absorbs the standardized cost of $\tau \frac{k_e e^2}{2}$, and the retailer is responsible for the standardized cost of $(1-\tau)\frac{k_e e^2}{2}$.

The manufacturer's profit function under the cost-sharing contract is

$$\pi_M = (\omega - c_e) D_e + (p_m - C_m) D_m - \frac{k_m m^2}{2} - \tau \frac{k_e e^2}{2} \quad (21)$$

The retailer's profit function under the cost-sharing contract is

$$\pi_R = (p_e - \omega) D_e - (1-\tau)\frac{k_e e^2}{2} \quad (22)$$

In order to ensure the supply chain achieves an optimal coordination, the fllowing condition has to hold, $\pi^*_{D-C} > \pi^*_{D-O}$,$\pi^*_{D-C} > \pi^*_{D-E}$,$\pi^*_{D-O} > \pi^*_{D-E}$.

Within the coordination case of cost-sharing, we adopt a two-stage Stackelberg game in which the following sequence of events occurs.

At the first stage, the manufacturer decides the degree of customization and the price of customized products. In the second stage, the retailer decides the retail price of standardized products and the degree of standardization of the standardized channel. The reverse solution method can be used to obtain the price of the customized products, the price of the standardized products, the degree of customization and the degree of standardization. Under the cost-sharing contract, the optimal results are as follows.

The optimal degree of customization is

$$m^*_O = (\omega - c_e)\frac{-2\theta\lambda_m}{2Ek_m - F\lambda_m^2} + \left(\alpha_m + \frac{-\theta\alpha_e + (\theta + \theta A\lambda_e)\omega - \theta c_e}{F} - c_m\right)\frac{F\lambda_m}{2Ek_m - F\lambda_m^2} \quad (23)$$

The optimal price of the customized products is

$$p^*_{m-O} = \frac{\alpha_m}{2} + \frac{\lambda_m\left[(\omega - c_e)\frac{-2\theta\lambda_m}{2Ek_m - F\lambda_m^2} + \left(\alpha_m + \frac{-\theta\alpha_e + (\theta+\theta A\lambda_e)\omega - \theta c_e}{F} - c_m\right)\frac{F\lambda_m}{2Ek_m - F\lambda_m^2}\right]}{2} + \frac{-\theta\alpha_e + (\theta + \theta A\lambda_e)\omega - \theta c_e}{2F} + \frac{c_m}{2} \quad (24)$$

The optimal degree of standardization is

$$e^*_O = \frac{\alpha_e - \theta\alpha_m + \theta p^*_{m-O} - \theta\lambda_m m^*_O - \omega}{2 - A\lambda_e} \quad (25)$$

The optimal price of the standardized products is

$$p^*_{e-O} = \frac{\alpha_e - \theta\alpha_m + \theta p^*_{m-O} - A\lambda_e\omega - \theta\lambda_m m^*_O + \omega}{2 - A\lambda_e} \quad (26)$$

where $A = \frac{\lambda_e}{(1-\theta^2)(1-\tau)k_e}, E = (1-\theta^2)(2 - A\lambda), F = (2 - A\lambda_e - \theta^2 + \theta^2 A\lambda_e)$. To verify the validity of the mode, according to the default parameter settings, we imposed, $0 \leq \tau < 1$. We substitute (Equations 23–26) to the manufacturer's profit function (Equation 21) and the retailer's profit function (Equation 22), to obtain the maximum value.

Theorem 3. *The manufacturer's optimal profit is,* $\pi^*_{M-O} = (\omega - c_e) D^*_{e-O} + (p^*_{m-O} - c_m) D^*_{m-O} - \frac{k_m m^{*2}_O}{2} - \frac{\tau k_e e^{*2}_O}{2}$. *The retailer's optimal profit is,* $\pi^*_{R-O} = (p^*_{e-O} - \omega) D^*_{e-O} - \frac{(1-\tau)k_e e^{*2}_O}{2}$.

Proposition 7. *The total profit of the coordinated dual channels is greater than that of the dual channels under the decentralized case when* $\tau = 0.4$ *and* $\alpha_m = 10$. *Moreover, as shown in* **Figure 8**, *with* φ *and* λ_m *constantly increasing, the total profit of the dual channel after coordination shows steadier growth, compared with the systematic profit under the decentralized case. This indicates that, after the coordination of cost-sharing contract, the supply chain decision making is less affected by the difference between* λ_m *and* λ_e.

Proposition 8. *Comparing the customized product prices of centralized channels and decentralized channels, standardized*

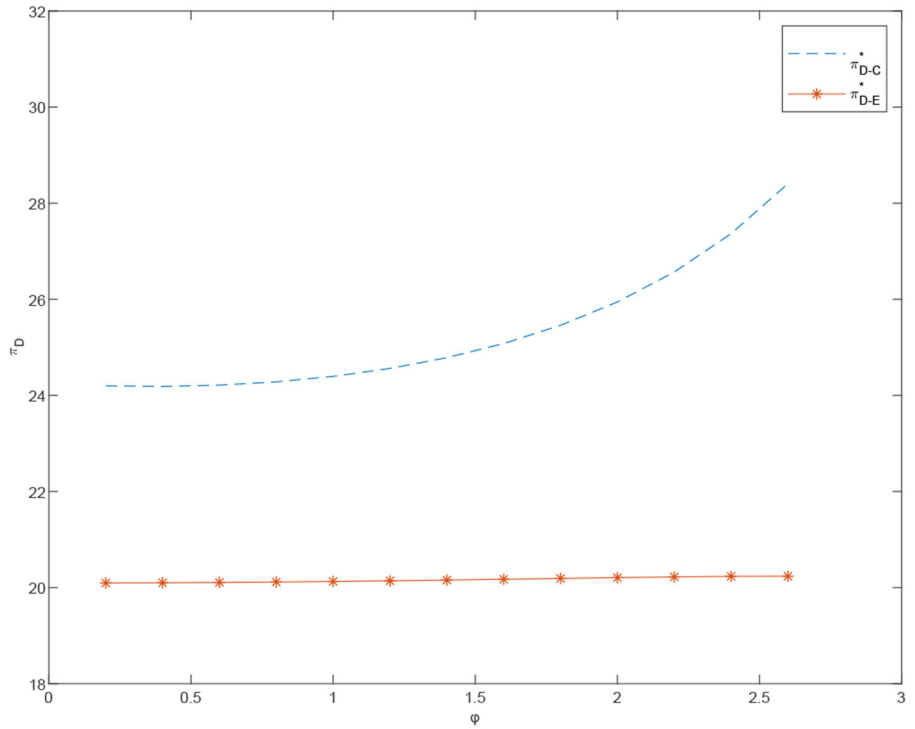

FIGURE 7 | The effects of φ on the total profits under centralized and decentralized scenarios, π^*_{T-C} and π^*_{T-E}.

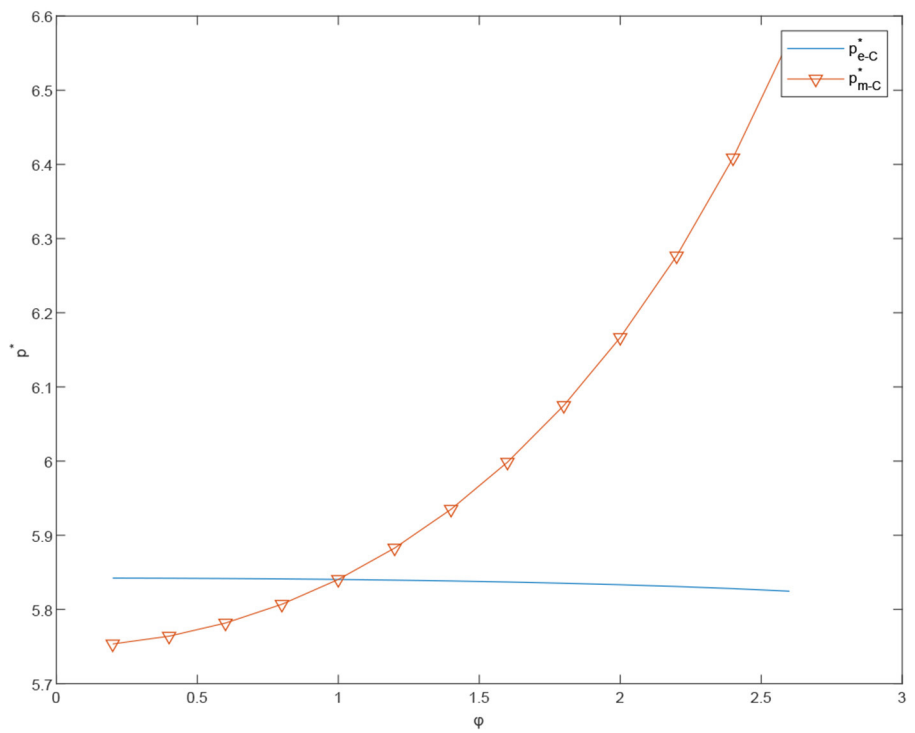

FIGURE 8 | The effects of φ on the prices under the centralized scenario, p^*_{e-C} and p^*_{m-C}.

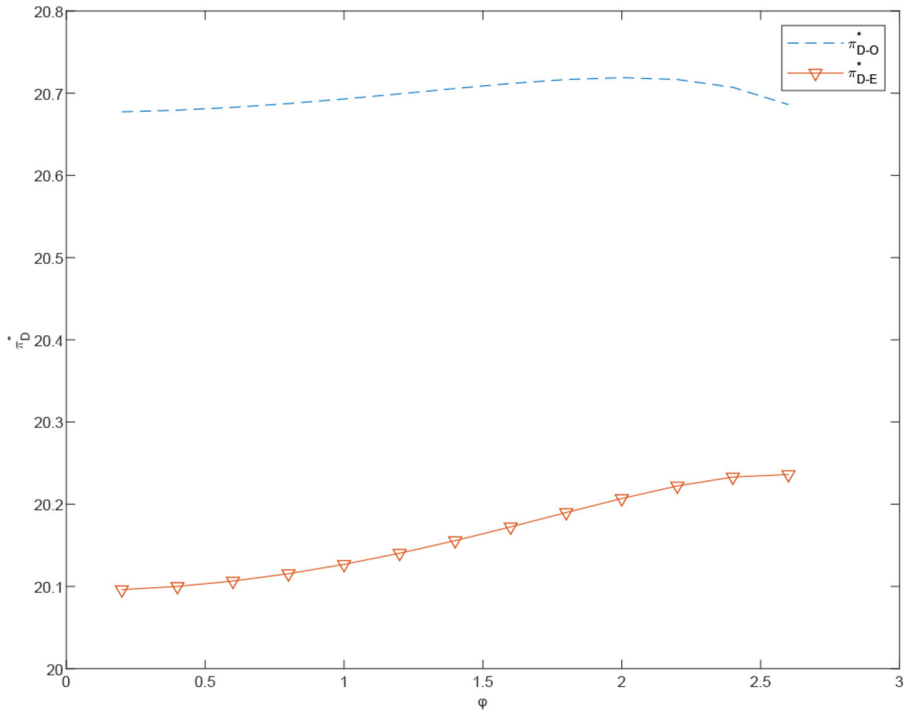

FIGURE 9 | The effects of φ on the prices under the decentralized scenario, π^*_{D-E} and π^*_{D-O}.

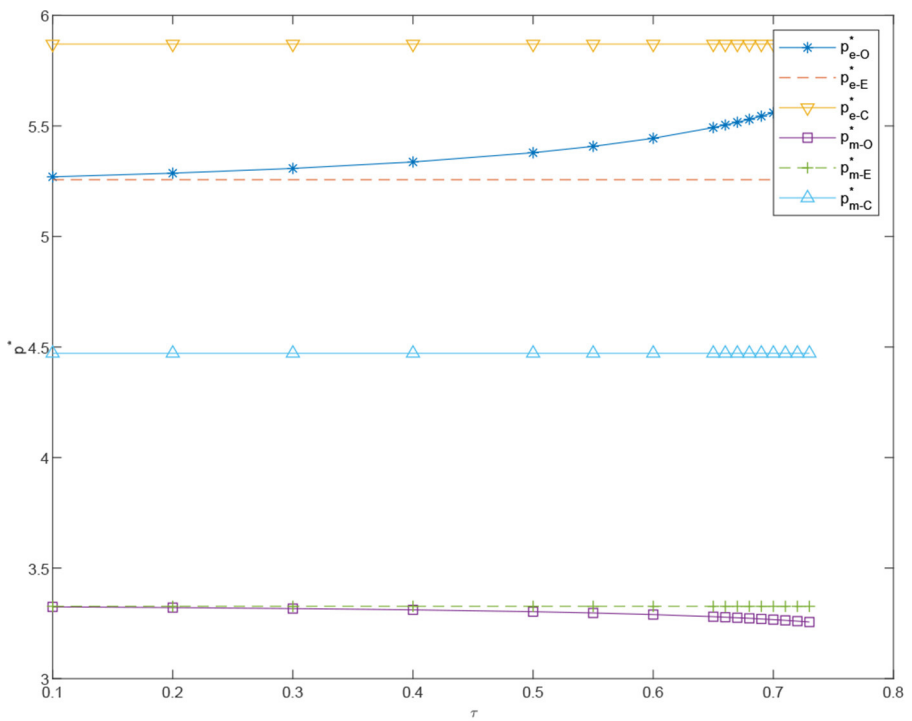

FIGURE 10 | The effect of τ on the prices, p^*_{e-O}, p^*_{e-E}, p^*_{e-C}, p^*_{m-O}, p^*_{m-E},p^*_{m-C}.

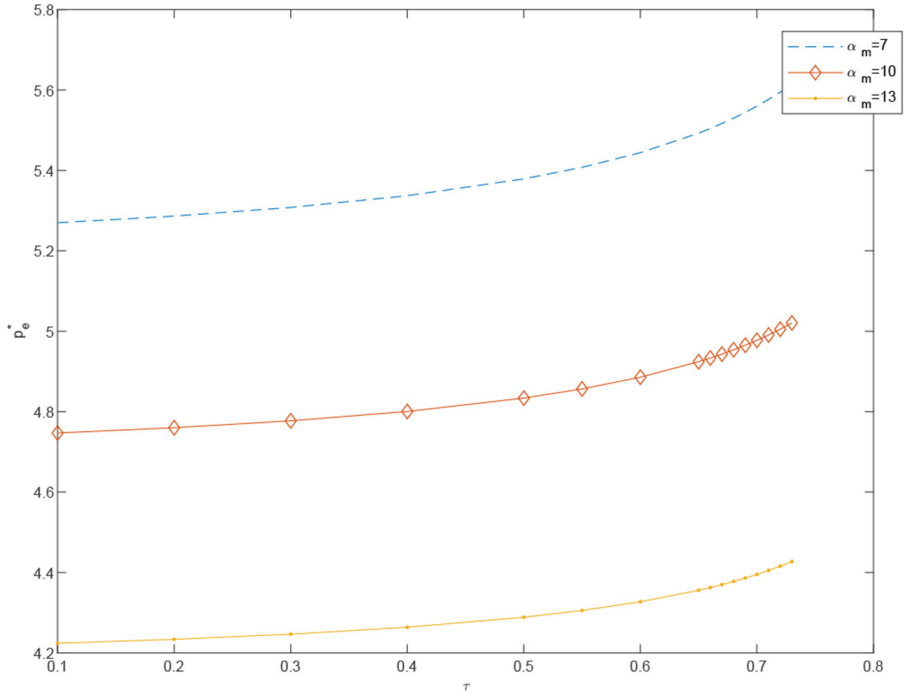

FIGURE 11 | The effect of τ on p^*_{e-O} under different α_m.

product prices and customized product prices of cost-sharing channels, we can get the sales price under coordination mode when $\alpha_m = 7$ *and* $\varphi = 2.6$ *lower than the selling price under centralized decision-making. The sales price under coordinated mode is close to that under decentralized decision-making.*

Proposition 9. *In coordinated case, the price of standardized products* p_e *decreases in* α_m *and increases in* τ. *On the contrary, the price of customized products* p_m *will increase significantly in* α_m, *but decrease slightly by* τ.

In **Figures 6–15**, as α_m increases, the price of standardized products p_e decreases, but the price of customized products p_m increases significantly. In the cost-sharing contract, the change of τ will not significantly cause the change of p_m, but p_e increases with an increase in τ. We conclude that in a cost-sharing contract, the manufacturer takes the initiative to bear part of the cost of standardized channels. The retailer can reduce part of the cost of standardized channel construction, so as to improve their enthusiasm for channel construction, and further promote the perfection of standardized channels. Consumers can enjoy a better service experience with standardized products. Therefore, the price of standardized products will be partially increased.

Proposition 10. *We observe that when the value of* τ *is between 0.1 and 0.55, the total profit of the system is constantly increasing in* **Figure 13**. *When the value of* τ *is higher than 0.55, the total profit of the system declines exponentially. The proportion of the manufacturer's burden of the retailer's standardized costs is not linearly related. Moreover, when the manufacturer covers 50% of the standardized costs, the total profit of the system is maximized. When the manufacturer shoulders more than 55% of the cost of standardized channels, the conflict is not mitigated. When the manufacturer absorbs more than 55% of such costs, the total profit falls sharply. As a result, the manufacturer should induce the retailer to strive to sell standardized products by setting a reasonable cost-sharing ratio.*

The cost-sharing coordination model has an improved effect on the overall profitability of the channel, with the manufacturer bearing part of the standardized costs for the retailer, increasing the retailer's incentive to participate in customization. In addition, the price of standardized and customized products are relatively stable. Customers obtain higher consumer surplus, stimulating the demand for channel standardization and customization and further driving manufacturers to produce more customized and standardized products.

In **Figures 13–16**. It is observed that when the proportion of standardized costs shared by the manufacturer is within a reasonable constraint, the cost-sharing contract can not only effectively motivate the retailer to improve the level of channel sales service, but also achieve Pareto improvement in the interests of the manufacturer, the retailer and the consumers. It will better promote the coordination of the entire system. The reason is that when the manufacturer bears part of the standardized channel construction cost for the retailer,

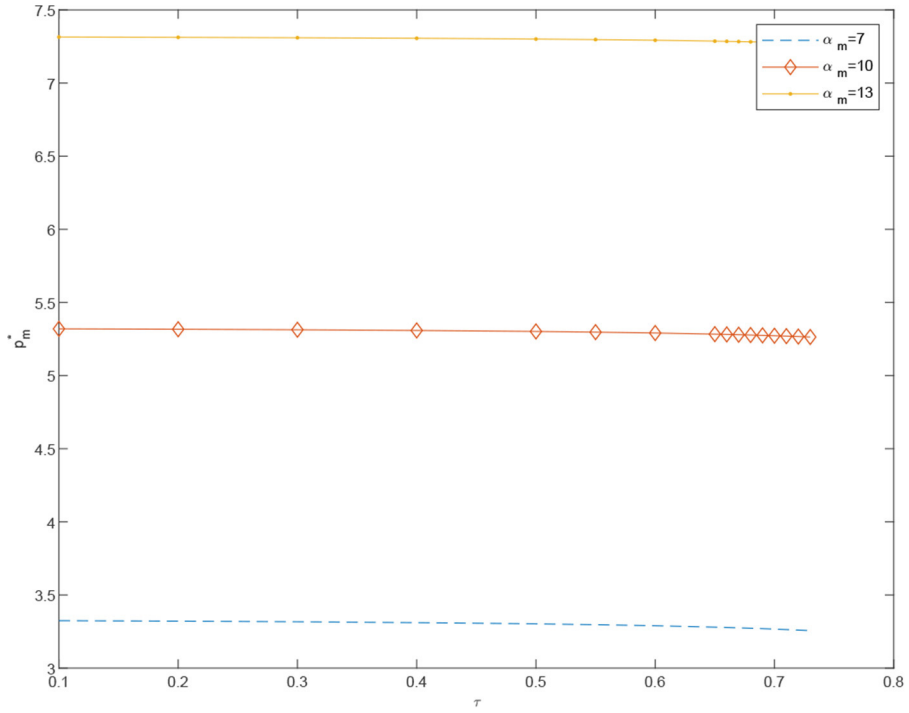

FIGURE 12 | The effect of τ on p^*_{m-O} under different α_m.

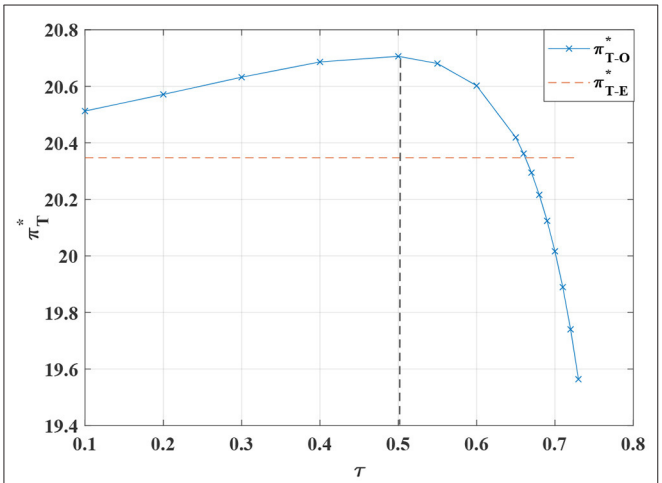

FIGURE 13 | The impact of τ on the overall optimal profit of the system.

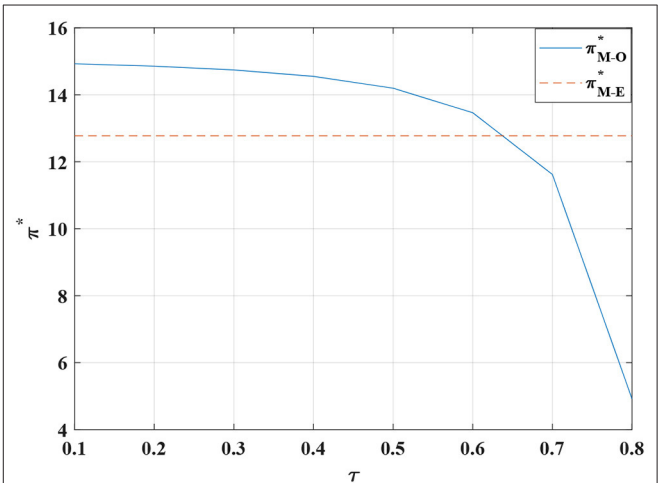

FIGURE 14 | The impact of τ on the manufacturer's optimal profit.

this cost-sharing behavior will have an incentive effect on the retailer, prompting it to actively operate the standardized channel. Therefore, more diversified standardized products and more complete product services provide consumers with a better product consumption experience. Thereby enhancing consumers' willingness to purchase standardized products, expanding market demand, and improving retail sales. For the manufacturer, the cost-sharing contract brings more profit than the cost itself, so it can also obtain a higher level of profit.

Compared with the decentralized dual channel case, the cost-sharing contract has better overall supply chain performance and sales price in both channels. By sharing the cost of the standardized channel, the manufacturer alleviates the channel conflict and retailers' incentive is improved. Although the sales price of customized and standardized products are both slightly higher than those before the channel coordination, but consumers have access to a higher level of customization to meet their

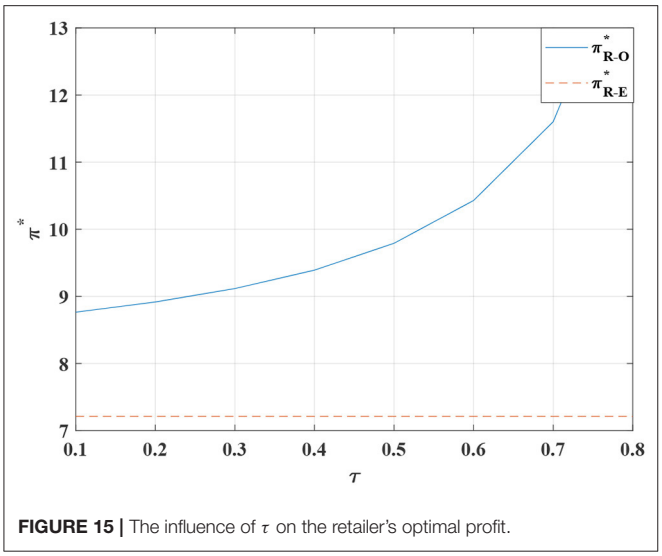

FIGURE 15 | The influence of τ on the retailer's optimal profit.

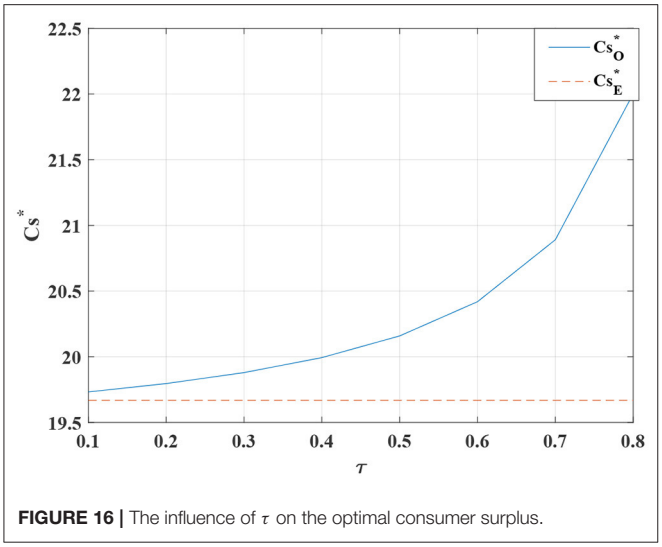

FIGURE 16 | The influence of τ on the optimal consumer surplus.

diverse consumer needs. With the increase of consumers' income and consumption level, high-quality customized products will appeal to a constantly increasing number of consumers.

5. CONCLUSIONS

In this paper, we develop a dual channel two-level supply chain (manufacturer-retailer) system where standardized products are sold through the retail channel and customized products are sold online by the manufacturer. The results show the demand for customized and standardized products and the profits of the dual channel are affected by the price, the degree of customization and the degree of standardization of the products themselves. Sensitivity analysis is also performed to examine the effect of the fluctuations of various input parameters. The results show that changing input parameters λ_m and τ has a significant impact on the optimal decisions of the supply chain system. We build three different scenarios by Stackelberg games, a centralized dual channel decision, a decentralized dual channel decision, and a cost-sharing dual channel decision. Under each scenario, we obtain the optimal degree of customization level, the optimal degree of standardization level, the optimal price, and the optimal profit, and we draw the following conclusions.

1. Under the centralized scenario, the system can achieve the best overall system profitability. However, under the decentralized scenario, the customized and standardized dual-channel system does not achieve the coordinated state of the dual-channel centralized system. With the reasonable cost sharing ratio, the cost sharing contract can effectively alleviate and balances the profits of channel members under the decentralized scenario.
2. The increase in the degree of customization can improve the overall profit of the system and the satisfaction of consumers. In addition, customization strategies can help manufacturers close the competitive gap between direct customization channels and retailers' traditional standardized channels in a decentralized system. On the other hand, managers need to balance the benefits of increased customization with the loss of large costs.
3. The demand in the customized market is positively related to the price of customized products and the degree of customization. However, considering the degree of market competition, the degree of customization under decentralized scenario is greater than that under centralized scenario. In addition, there is no linear growth relationship between the profit of the system and the demand of the customized market. Therefore, managers need to fulfill the market demand as much as possible, so as not only to meet the demand of the consumers, but also to actively attract new consumers. On the other hand, customized decisions need to be further judged based on market conditions.
4. The reasons for the conflict between customized channels and standardized channels are complex. Except incompatible goals, they also need to consider the customized channel market share, the channel substitutability, and the impact of customization sensitivity and standardization sensitivity on those channels.

To summarize this study, we can see that the manufacturer should increase the research and development investment of customization. It can helps to establish the product mode of diversification and customization through a comprehensive transformation from its original business and management processes to meet the individual needs of the customers. This transformation leads to a rapid response and a rapid delivery of the customized orders. The potential market for customized products will then inevitably increase. It suggests that the manufacturer could also share the cost of standardization with the retailer in case to motivate the retailers to participate in the customization process.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

BD: conceptualization and methodology. JZ: investigation. ZL and BD: writing—original draft preparation. BD, WS, and YJ: writing—review and editing. YJ: funding acquisition. All authors have read and approved the final manuscript.

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APPENDIX
PROOFS FOR THEOREMS

Proof for Theorem 1: The profit function of f the centralized dual channel supply chain is

$$\Pi_T(p_e, p_m, e, m) = (p_e - c_e)D_e + (p_m - c_m)D_m - \frac{K_m}{2}m^2 - \frac{K_e}{2}e^2 \tag{A1}$$

Then the Hessian matrix is,

$$H = \begin{bmatrix} -k_e & 0 & \frac{-\theta\lambda_e}{1-\theta^2} & \frac{\lambda_e}{1-\theta^2} \\ 0 & -k_m & \frac{\lambda_m}{1-\theta^2} & \frac{-\theta\lambda_m}{1-\theta^2} \\ \frac{-\theta\lambda_e}{1-\theta^2} & \frac{\lambda_m}{1-\theta^2} & \frac{-2}{1-\theta^2} & \frac{2\theta}{1-\theta^2} \\ \frac{\lambda_e}{1-\theta^2} & \frac{-\theta\lambda_m}{1-\theta^2} & \frac{2\theta}{1-\theta^2} & \frac{-2}{1-\theta^2} \end{bmatrix} \tag{A2}$$

To ensure the existence of the optimal solution, H must be negative definite. We thus have $4k_ek_m(1-\theta^2) - 2k_e\lambda_m{}^2 - 2k_m\lambda_e{}^2 + \lambda_e{}^2\lambda_m{}^2 > 0$. We assume the first order condition equations above are 0, then we get

$$\begin{cases} \frac{\partial\pi_T}{\partial e} = (p_e - c_e)\frac{\lambda_e}{1-\theta^2} + (p_m - c_m)\frac{-\theta\lambda_e}{1-\theta^2} - k_e e = 0 \\ \frac{\partial\pi_T}{\partial m} = (p_e - c_e)\frac{-\theta\lambda_m}{1-\theta^2} + (p_m - c_m)\frac{\lambda_m}{1-\theta^2} - k_m m = 0 \\ \frac{\partial\pi_T}{\partial p_e} = \frac{\alpha_e - \theta\alpha_m - p_e + \theta p_m + \lambda_e e - \theta\lambda_m m}{1-\theta^2} + \frac{-1}{1-\theta^2}(p_e - c_e) \\ \qquad +(p_m - c_m)\frac{\theta}{1-\theta^2} = 0 \\ \frac{\partial\pi_T}{\partial p_m} = (p_e - c_e)\frac{\theta}{1-\theta^2} + \frac{\alpha_m - \theta\alpha_e - p_m + \theta p_e + \lambda_m m - \theta\lambda_e e}{1-\theta^2} \\ \qquad +(p_m - c_m)\frac{-1}{1-\theta^2} = 0 \end{cases} \tag{A3}$$

we solve the first order partial derivatives with respect to p_e, p_m, e and m respectively, and then we can get the optimal results simultaneously.

$$e_C^* = \frac{-\theta\lambda_e\left(2k_m\right)(\alpha_m - c_m) + \lambda_e\left(2k_m - \lambda_m^2\right)(\alpha_e - c_e)}{4k_mk_e\left(1-\theta^2\right) - 2k_e\lambda_m^2 - 2k_m\lambda_e^2 + \lambda_e^2\lambda_m^2} \tag{A4}$$

$$m_C^* = \frac{-\theta\lambda_m\left(2k_e\right)(\alpha_e - c_e) + \lambda_m\left(2k_e - \lambda_e^2\right)(\alpha_m - c_m)}{4k_mk_e\left(1-\theta^2\right) - 2k_e\lambda_m^2 - 2k_m\lambda_e^2 + \lambda_e^2\lambda_m^2} \tag{A5}$$

$$p_{e-C}^* = \frac{-\theta\lambda_e^2\left(2k_m\right)(\alpha_m - c_m) + \left(4k_mk_e\left(1-\theta^2\right) - 2k_e\lambda_m^2\right)\alpha_e}{2} + \frac{\left(4k_mk_e\left(1-\theta^2\right) - 2k_e\lambda_m^2 - 4k_m\lambda_e^2 + 2\lambda_e^2\lambda_m^2\right)c_e}{2} \tag{A6}$$

$$p_{m-C}^* = \frac{-\theta\lambda_m^2\left(2k_e\right)(\alpha_e - c_e) + \left(4k_mk_e\left(1-\theta^2\right) - 2k_m\lambda_e^2\right)\alpha_m}{2} + \frac{\left(4k_mk_e\left(1-\theta^2\right) - 4k_e\lambda_m^2 - 2k_m\lambda_e^2 + 2\lambda_e^2\lambda_m^2\right)c_m}{2} \tag{A7}$$

The optimal profit under the centralized case is

$$\pi_{T-C}^* = \left(p_{e-C}^* - c_e\right)\frac{\alpha_e - \theta\alpha_m - p_{e-C}^* + \theta p_{m-C}^* + \lambda_e e_C^* - \theta\lambda_m m_C^*}{1-\theta^2} + \left(p_{m-C}^* - c_m\right)\frac{\alpha_m - \theta\alpha_e - p_{m-C}^* + \theta p_{e-C}^* + \lambda_m m_C^* - \theta\lambda_e e_C^*}{1-\theta^2} - \frac{k_m m_C^{*2}}{2} - \frac{k_e e_C^{*2}}{2} \tag{A8}$$

Proof for Theorem 2: The profit function of the retailer is,

$$\pi_{\mathrm{R-E}} = (p_e - \omega)D_e - \frac{k_e e^2}{2} \tag{A9}$$

The first order condition (FOC),

$$D_e = \frac{\alpha_e - \theta\alpha_m - p_e + \theta p_m + \lambda_e e - \theta\lambda_m m}{1-\theta^2} \tag{A10}$$

Henceforth the first order condition of π_{R} on p_e and e are

$$\begin{cases} \frac{\partial\pi_{\mathrm{R-E}}}{de} = \frac{\lambda_e(p_e - \omega)}{1-\theta^2} - k_e e = 0 \\ \frac{\partial\pi_{\mathrm{R-E}}}{dp_e} = D_e + (p_e - \omega)\frac{-1}{1-\theta^2} \\ \qquad = \frac{\alpha_e - \theta\alpha_m - p_e + \theta p_m + \lambda_e e - \theta\lambda_m m}{1-\theta^2} + \frac{-(p_e - \omega)}{1-\theta^2} = 0 \end{cases} \tag{A11}$$

Then the Hessian matrix is

$$G = \begin{bmatrix} -k_e & \frac{\lambda_e}{1-\theta^2} \\ \frac{\lambda_e}{1-\theta^2} & \frac{-2}{1-\theta^2} \end{bmatrix} \tag{A12}$$

G must be negative definite. Then we assume that $2(1-\theta^2)k_e - \lambda_e{}^2 > 0$. Thus the retailer's profit function is jointly strictly concave in p_e and e.

We assume the first order condition equations above are 0, then we get

$$\begin{cases} \mathrm{p_e}(p_m, m) = \frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} \\ e(p_m, m) = M(\frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} - \omega) \end{cases} \tag{A13}$$

Solving for the manufacturer's profit function.

$$\pi_{\mathrm{M-E}} = (\omega - c_e)D_e + (p_m - c_m)D_m - \frac{k_m m^2}{2} \tag{A14}$$

The first order condition

$$\begin{cases} \mathrm{p_e}(p_m, m) = \frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} \\ e(p_m, m) = M(\frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} - \omega) \end{cases} \tag{A15}$$

Henceforth, we can get the demand function

$$\begin{cases} D_e = \frac{\alpha_e - \theta\alpha_m - \frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} + \theta p_m + \lambda_e M(\frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} - \omega) - \theta\lambda_m m}{1-\theta^2} \\ D_m = \frac{\alpha_m - \theta\alpha_e - p_m + \theta\frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} + \lambda_m m - \theta\lambda_e M(\frac{\alpha_e - \theta\alpha_m + \theta p_m - M\lambda_e\omega - \theta\lambda_m m + \omega}{2 - M\lambda_e} - \omega)}{1-\theta^2} \end{cases} \tag{A16}$$

so the Hessian matrix is

$$W = \begin{bmatrix} -k_m & \frac{Q\lambda_m}{(1-\theta^2)(2-M\lambda_e)} \\ \frac{Q\lambda_m}{(1-\theta^2)(2-M\lambda_e)} & \frac{-2Q}{(1-\theta^2)(2-M\lambda_e)} \end{bmatrix} \tag{A17}$$

In order to ensure the existence of the optimal solution, W must be negative definite. We assume that $\frac{2Qk_m((1-\theta^2)(2-M\lambda_e))-(Q\lambda_m)^2}{(1-\theta^2)^2(2-M\lambda_e)^2} > 0$, which implies $2Qk_m((1-\theta^2)(2-M\lambda_e)) > (Q\lambda_m)^2$ and $M\lambda_e < 2$.

The optimal price and the degree of customization are obtained as

$$\begin{cases} p^*_{m-E} & = \frac{\alpha_m}{2} + \frac{\lambda_m\left[(\omega-c_e)\frac{-2\theta\lambda_m}{2Nk_m-Q\lambda_m^2} + \left(\alpha_m + \frac{-\theta\alpha_e+(\theta+\theta M\lambda_e)\omega-\theta c_e}{Q} - c_{\mathrm{m}}\right)\frac{Q\lambda_m}{2Nk_m-Q\lambda_m^2}\right]}{2} \\ & \quad + \frac{-\theta\alpha_e+(\theta+\theta M\lambda_e)\omega-\theta c_e}{2Q} + \frac{c_{\mathrm{m}}}{2} \\ m^*_E & = (\omega-c_e)\frac{-2\theta\lambda_m}{2Nk_m-Q\lambda_m^2} + \left(\alpha_m + \frac{-\theta\alpha_e+(\theta+\theta M\lambda_e)\omega-\theta c_e}{Q} - c_{\mathrm{m}}\right)\frac{Q\lambda_m}{2Nk_m-Q\lambda_m^2} \end{cases} \tag{A18}$$

Then we can calculate the optimal standardized product price and standardization degree

$$\begin{cases} p^*_{e-E} & = \frac{\alpha_e-\theta\alpha_m+\theta p^*_{m-E}-M\lambda_e\omega-\theta\lambda_m m^*_E+\omega}{2-M\lambda_e} \\ e^*_E & = M\left(\frac{\alpha_e-\theta\alpha_m+\theta p^*_{m-E}-\theta\lambda_m m^*_E-\omega}{2-M\lambda_e}\right) \end{cases} \tag{A19}$$

From the above equilibrium values we derive the retailer' profit, and the manufacturer's profit.

Proof for Theorem 3: In the cost-sharing contract, we solve for retailer's profit function first.

$$\pi_{\mathrm{R-O}} = (p_e-\omega)D_e - (1-\tau)\frac{k_e e^2}{2} \tag{A20}$$

Then the Hessian matrix is

$$Z = \begin{bmatrix} -(1-\tau)k_e & \frac{\lambda_e}{1-\theta^2} \\ \frac{\lambda_e}{1-\theta^2} & \frac{-2}{1-\theta^2} \end{bmatrix} \tag{A21}$$

In order to ensure that the optimal value exists, Z must be negative definite. Then we assume that $2(1-\tau)(1-\theta^2)k_e-{\lambda_e}^2 > 0$. Thus the retailer's profit function is jointly strictly concave in p_e and e. We assume the first order condition equation above is 0, then we get

$$\begin{cases} \mathrm{p_e}(p_m, m) = \frac{\alpha_e-\theta\alpha_m+\theta p_m-A\lambda_e\omega-\theta\lambda_m m+\omega}{2-A\lambda_e} \\ e(p_m, m) = A(p_e-\omega) \end{cases} \tag{A22}$$

Solving for the manufacturer's profit function.

$$\pi_{M-O} = (\omega-C_e)D_e + (p_m-C_m)D_m - \frac{k_m m^2}{2} - \frac{\tau k_e e^2}{2} \tag{A23}$$

The first order condition of π_{M-O} on m is

$$\frac{\partial\pi_{\mathrm{M-O}}}{\partial m} = (\omega-c_e)D'_e + \left(p_m-c_m\right)D'_m - k_m m = 0 \tag{A24}$$

The first order condition of π_{M-O} on p_m is

$$\frac{\partial\pi_{\mathrm{M-O}}}{\partial_{\mathrm{m}}} = D'_e(\omega-c_e) + D_{\mathrm{m}} + \left(p_m-c_{\mathrm{m}}\right)D'_{\mathrm{m}} = 0 \tag{A25}$$

so the Hessian matrix is

$$Y = \begin{bmatrix} -k_m & \frac{F\lambda_m}{(1-\theta^2)(2-A\lambda_e)} \\ \frac{F\lambda_m}{(1-\theta^2)(2-A\lambda_e)} & \frac{-2F}{(1-\theta^2)(2-A\lambda_e)} \end{bmatrix} \tag{A26}$$

we assume that $2(1-\tau)(1-\theta^2)k_e-{\lambda_e}^2 > 0$. Thus the manufacturer's profit function is strictly concave in p_m and m. We assume the first order condition equations above are 0, then we get

The optimal the degree of customization under the cost-sharing contract is

$$m^*_O = (\omega-c_e)\frac{-2\theta\lambda_m}{2Ek_m-F\lambda_m^2} + \left(\alpha_m + \frac{-\theta\alpha_e+(\theta+\theta A\lambda_e)\omega-\theta c_e}{F} - c_{\mathrm{m}}\right)\frac{F\lambda_m}{2Ek_m-F\lambda_m^2} \tag{A27}$$

The optimal price of the customized products under the cost-sharing contract is

$$p^*_{m-O} = \frac{\alpha_m}{2} + \frac{\lambda_m\left[(\omega-c_e)\frac{-2\theta\lambda_m}{2Ek_m-F\lambda_m^2} + \left(\alpha_m + \frac{-\theta\alpha_e+(\theta+\theta A\lambda_e)\omega-\theta c_e}{F} - c_{\mathrm{m}}\right)\frac{F\lambda_m}{2Ek_m-F\lambda_m^2}\right]}{2} + \frac{-\theta\alpha_e+(\theta+\theta A\lambda_e)\omega-\theta c_e}{2F} + \frac{c_{\mathrm{m}}}{2} \tag{A28}$$

Then we can get the optimal values for p_e and e

$$e^*_O = \frac{\alpha_e-\theta\alpha_m+\theta p^*_{m-O}-\theta\lambda_m m^*_O-\omega}{2-A\lambda_e} \tag{A29}$$

$$p^*_{e-O} = \frac{\alpha_e-\theta\alpha_m+\theta p^*_{m-O}-A\lambda_e\omega-\theta\lambda_m m^*_O+\omega}{2-A\lambda_e} \tag{A30}$$

From the above equilibrium values we derive the retailer' profit, and the manufacturer's profit.

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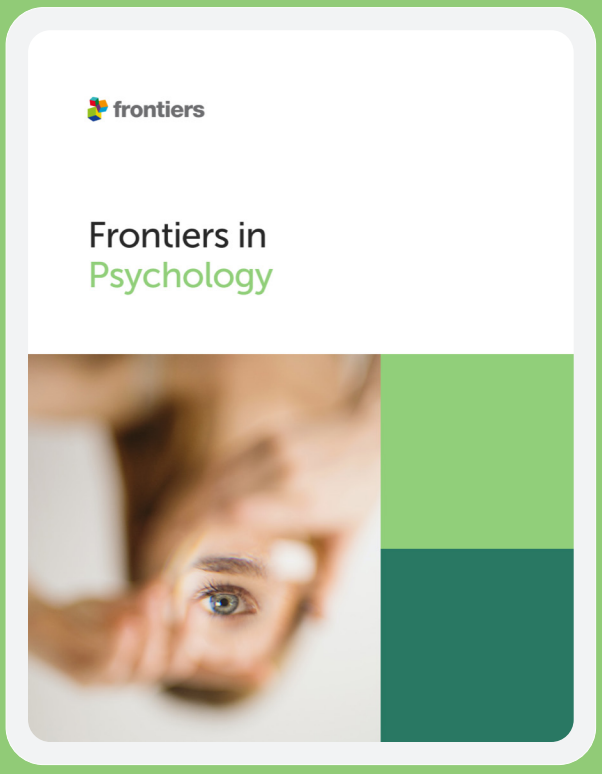

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