frontiers in Audiology and Otology

TYPE Original Research
PUBLISHED 20 March 2026
DOI 10.3389/fauot.2026.1728574

OPEN ACCESS

EDITED BY
Hannes Maier,
Hannover Medical School, Germany

REVIEWED BY
Melanie Ferguson,
Curtin University, Australia
Ian Windmill,
University of Cincinnati, United States

*CORRESPONDENCE
Grant Searchfield
✉ g.searchfield@auckland.ac.nz

RECEIVED 20 October 2025
REVISED 20 February 2026
ACCEPTED 23 February 2026
PUBLISHED 20 March 2026

CITATION
Singh A, Selak V and Searchfield G (2026) A thematic network qualitative study of industry leaders' perspectives on the emerging capabilities of AI-enabled hearables.
Front. Audiol. Otol. 4:1728574.
doi: 10.3389/fauot.2026.1728574

A thematic network qualitative study of industry leaders' perspectives on the emerging capabilities of AI-enabled hearables

Anzel Singh[1], Vanessa Selak[2] and Grant Searchfield[1,3]*

[1]Audiology, Faculty of Medical and Health Sciences, School of Population Health, The University of Auckland, Auckland, New Zealand, [2]Epidemiology and Biostatistics, Faculty of Medical and Health Sciences, School of Population Health, The University of Auckland, Auckland, New Zealand, [3]Faculty of Medical and Health Sciences, School of Population Health, Eisdell Moore Centre, The University of Auckland, Auckland, New Zealand

Objective: This study explores industry experts' views on the future of AI-enabled hearables.

Background: Hearables are electronic, wireless in-ear wearable devices. Hearables are used for music playback, media streaming, and, in the case of over-the-counter and prescription hearing aids, speech amplification. The emergence of AI systems trained on large datasets and sensor technologies raises the possibility of major advances in hearables but also carries risks.

Methods: Semi-structured interviews were conducted with 18 industry experts and thought leaders from the hearing and technology sectors. Participants were asked to imagine the state of hearables in 2030 and 2050 and to describe near-term advancements and long-term capabilities. Attride-Stirling's thematic network method was used to identify and systematize themes related to future hearable capabilities and to clarify the key contributions of expert perspectives.

Results: The analysis identified 22 basic themes and 11 organizing themes, synthesized into six global themes: (1) technology advancement, (2) technical limitations, (3) biometric sensors for health, (4) AI agents, (5) governance and ethics, and (6) society and behavior. Experts predicted that AI would expand the capabilities of hearables, enhancing their role as multimodal health-monitoring devices and voice interfaces for AI assistance. They also highlighted the novel potential of hearables to serve as continuous, context-aware communication and health tools; an area underexplored in current literature.

Conclusion: Both utopian and dystopian futures for AI-enabled hearables were foreseen. Industry leaders believed that future hearables would reduce communication barriers, improve health monitoring, and voice-enabled AI would offer real-time assistance in everyday tasks. However, they warned that these technologies could be manipulated for commercial or even political gain. Future research should explore consumer perceptions of hearable advancements and examine AI governance challenges together with industry to mitigate risks and protect privacy.

KEYWORDS
artificial intelligence, future, hearable, hearing aid, qualitative, technology

1 Introduction

Artificial Intelligence (AI) refers to systems designed to simulate human intelligence, capable of learning and adapting independently to perform tasks of varying complexity, while operating through a form of intelligence that is artificial rather than human. Definitions of AI vary across disciplines, with each emphasizing different aspects and reflecting the evolving nature and inherent limitations of the field (Sheikh et al., 2023). The term "hearables" was first coined in 2014 to describe wireless devices that sit on or within the external auditory canal (Hunn, 2014). Hearables are a subset of the broader category of "wearables". Wearables, such as smartwatches and smart rings, connect to the internet and provide real-time health and fitness feedback (Indrakumari et al., 2020). Hearables may serve multiple functions; their most common uses include audio playback and sound amplification. The term encompasses both consumer devices for media streaming (Sato et al., 2024) and over-the-counter and prescription hearing aids (Ne et al., 2021). There is a convergence of these technologies, fueled by technological advances and the growth of consumer applications of AI (GSMA Intelligence, 2024). Hearing aids have acquired many of the features of earphones, such as streaming, and functionality beyond sound amplification [e.g., fall detection (Burwinkel et al., 2020)] while earphones have acquired hearing aid functionality (Chern and Golub, 2025). AI, exemplified by deep neural network (DNN) chips, is increasingly being used to address long-standing challenges in hearing technology, such as enhancing speech intelligibility in noisy environments (Seitz-Paquette et al., 2024).

As sound processing and AI capabilities have evolved, hearables are increasingly being integrated into daily life and healthcare. The COVID-19 pandemic increased the prevalence of remote work, which increased demand for devices that support video conferencing (Amankwah-Amoah et al., 2021). Audio streaming has become ubiquitous. The rising popularity of lifestyle and health apps, coupled with wrist-worn wearable technology, has opened the gate for alternative biosensor locations, including the ear (Yarici et al., 2024). The ear has even been described as the Universal Serial Bus (USB) port of the brain (Crum, 2019).

As AI continues to evolve, it is poised to drive the next generation of hearable capabilities. AI automation in consumer hearables enables real-time adjustments to audio settings and integration of a voice assistant. These developments suggest AI-enabled hearables could transform communication and healthcare, from enhancing speech intelligibility in challenging environments to enabling more advanced voice interactions and health monitoring. The rapid developments have prompted questions: what does the future hold for these devices? What are their limitations? Has society put safeguards in place for their ethical use? This study interviewed technology and hearing industry leaders to determine their forecasts for the future of AI-enabled hearables.

2 Methods

The research was approved by The University of Auckland Health Research Ethics Committee (AH28072).

2.1 Participants

This study recruited 18 adult participants from New Zealand (n = 12), Australia (n = 2), Italy (=1), the Netherlands (n = 1), Switzerland (n = 1), and the United Kingdom (n = 1). Participants were required to be industry professionals with expertise considered relevant to the future of AI-enabled hearables (consumer hearing technology, artificial intelligence, cybersecurity, cloud computing, the Internet of Things (IoT), ethics, research and development, audiology, and medicine). Industry experts were approached through The University of Auckland (https://www.auckland.ac.nz/en.html), academyEX (https://academyex.com/), Asia New Zealand Foundation (https://www.asianz.org.nz/) and Kea Connect (https://talent.keanewzealand.com/kea-connect). Further referrals and recommendations were obtained from participants.

The experts interviewed had positions or affiliations with the following organizations: Google, Microsoft, Sonova, Amplifon, GN ReSound, National Acoustic Laboratories (NAL), HearingTracker, Computational Audiology Network, Australian Future Hearing Initiative, Resonate Health, Stanford Center for Digital Health, Te Whatu Ora/Health New Zealand, New Zealand Ministry of Health, New Zealand IoT Alliance, academyEX and The University of Auckland. Participants' roles and/or expertise are listed in Table 1, along with their corresponding codes. All perspectives expressed by experts were solely their own and did not represent the views of their employers or affiliated organizations.

2.2 Study design

This study employed a qualitative approach, consisting of 30-min semi-structured interviews conducted via Zoom online video calls, which were automatically transcribed and saved to a local server. Each expert was asked questions from a core set (listed below) designed to explore industry perspectives on the future of AI-enabled hearables. Participants were asked to imagine the state of hearables in 2030 and 2050, providing insight into both near-term advancements and long-term capabilities beyond current expectations. Additional questions explored the potential of advanced medical sensors, user data analysis, and AI integration, including large language models, to assess their societal and individual impact. Follow-up questions were tailored to each participant's expertise, allowing for deeper exploration of specific technological and societal actors influencing hearables. For example, clinicians leading AI initiatives in public health were asked about regulatory or implementation challenges, while hearing device manufacturers were asked about research and development priorities. This hybrid approach ensured both comparability across interviews and richness of context-specific insights.

Key questions:

What insights could be obtained from hearables with more sensors and AI?

What will hearables look like in 2030?

What will hearables look like in 2050?

What types of medical data might these devices collect?

What types of behavioral data might these devices collect?

TABLE 1 Participants' code and role or area of expertise related to the future of hearables.

Participant code	Role/expertise
P1	Cybersecurity consultant
P2	Machine learning specialist
P3	Cloud computing and business leader
P4	Audiologist at a major hearing aid manufacturer
P5	Entrepreneur in audiology
P6	Leader in AI health research
P7	Global expert in mobile health research
P8	Audiologist at a major hearing aid manufacturer
P9	Leader in AI health research
P10	Entrepreneur in audiology
P11	Leader at a major hearing industry entity
P12	Expert in ethical theory and leader in health research governance
P13	Audiologist and entrepreneur
P14	Audiologist and entrepreneur
P15	Mixed reality expert and advisor
P16	Senior healthcare executive
P17	Leader at a major hearing industry entity
P18	Internet of Things and emerging technologies expert

What are some of the AI governance concerns regarding hearables?

What are some of the security and privacy concerns regarding hearables?

Participants' perspectives on AI governance, patient safety, and public risk were considered important for highlighting potential blind spots in current regulatory frameworks for hearables. Transcriptions were double-checked and edited, and then the transcribed documents were reviewed with each participant, who had the opportunity to make revisions before they were used.

2.3 Analysis

A structured analytical approach for systematizing and presenting qualitative findings was used (Attride Stirling, 2001). The six steps were: 1. Code Material. 2. Identify Themes 3. Construct Thematic Networks. 4. Describe and Explore Thematic Networks. 5. Summarize Thematic Networks 6. Interpret Patterns. The methods were checked against standard reporting guidelines (O'Brien et al., 2014). Author "AS" coded responses from which key themes were derived. Each transcript was systematically analyzed, with relevant quotes organized under specific codes. Alongside each code, the concepts discussed were recorded. The coding was checked by "GDS". "AS" and "GDS" identified and separately organizing themes by clustering basic themes, and global themes by clustering organizing themes. The allocation to final themes was revised by "GDS" and "AS" before a consensus. The final themes as text entries were then reviewed by "VS". The analysis yielded 22 fundamental themes, capturing the core aspects of the expert perspectives. These basic themes led to 11 organizing themes and 6 global themes encapsulating the overarching insights. These themes were then visualized through a thematic network (Supplementary Figure 1).

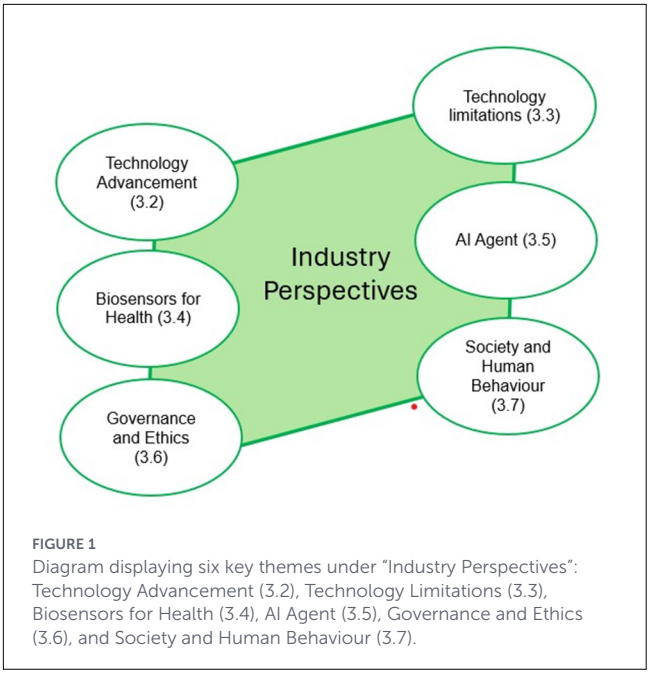

FIGURE 1
Diagram displaying six key themes under "Industry Perspectives": Technology Advancement (3.2), Technology Limitations (3.3), Biosensors for Health (3.4), AI Agent (3.5), Governance and Ethics (3.6), and Society and Human Behaviour (3.7).

2.4 Researcher characteristics and reflexivity

AS is an early-career audiologist, entrepreneur, and technologist. VS is a medically trained public health physician and academic with over 20 years of experience in clinical care, health analytics, and quality improvement. VS contributed expertise in electronic health data, equity, and population health. GS has extensive experience in audiology, behavioral neuroscience, and tinnitus management. GS is a founder of TrueSilence Therapeutics Inc., a technology company. The authors' backgrounds provide valuable insights but may also influence the framing of research questions and the interpretation of participant narratives, particularly in relation to evidence-based and patient-centered approaches. The authors acknowledge their positionality and have made an effort to minimize potential biases.

3 Results

3.1 Thematic analysis of interviews

Selected quotes are provided as evidence for each of the six global themes (Figure 1).

3.2 Global theme: technology advancement

3.2.1 Organizing theme: short-term innovations

3.2.1.1 Basic theme: advanced hearing features

Most of the participating experts predicted that AIs would, in the short term, advance hearing aid functionality, including "intelligent" microphone beamforming and environmental sound classification, enabling more precise and personalized scene detection, noise reduction, and automatic program adjustments.

> P8: *"What will come is tuning into my child's voice, that's the voice that I want to listen to. So always prioritize that voice over other voices… personal to me and my preferences."*

AI-enabled monitoring of the auditory nerve would allow for real-time personalization of sound amplification. Devices that automatically steer microphones toward relevant sound sources, without user intervention, would revolutionize sound extraction for listening.

> P17: *"If it could monitor the auditory nerve… it could automatically adjust the gain…"*

One participant predicted that users would "zoom in" on distant sounds or selectively control auditory input within an environment. AI could push the boundaries of human auditory perception beyond the normal human hearing range; inaudible sounds may be converted into haptic feedback or audible frequencies.

> P12: *"There might be ways of extending the zone of hearing from what the natural kind of periphery of what a human ear can capture."*

Another innovation anticipated was that real-ear probe-microphone measurements used for hearing aid fitting could be conducted directly by the hearable. Allowing for more personalized amplification for hearing aid users.

> P14: *"Real-ear measurement run inside the ear canal with the device itself to try to get the output to where it needs to be… that would be a huge milestone in any kind of self-fitting device…"*

Bluetooth Auracast (enabling streaming to multiple devices), and future wireless technologies, were seen as being key innovations for user interactions in different environments (the smart city concept in which urban environments use interconnected digital technologies and data-driven systems to improve the efficiency of infrastructure and services). Hearables could receive real-time, personalized broadcasts at airports and train stations, ensuring users only hear relevant announcements. In cinemas, hearables could provide real-time multilingual audio without relying on external devices.

> P10: *"Hearing devices becomes like wearing a smartwatch because of how many things people are going to be able to interact with on a daily basis through Auracast… Walk into the train station and get the announcements or get the cinema audio of the movie streamed in whatever language they want."*

3.2.1.2 Basic theme: advanced AI capabilities

Hearables could record environmental sound exposure and user responses to assist audiologists in providing personalized care. AI-integrated chatbots could enhance the hearing healthcare journey by proactively detecting early signs of hearing loss, prompting users to take hearing tests, and guiding them through the process of seeking specialist care, obtaining the right device, and ensuring consistent use. Communication functionality will broaden from amplification to interpretation. In the pediatric context, this was described as the ability to infer hearing status from everyday auditory exposure and speech behavior:

> *P4: "In the pediatric space we'd be thinking about how many words is someone actually hearing? There could be like a two, three year old just walking around talking and then an AI model will analyse the data and say, oh, you've got a speech delay, which means you could have a hearing loss."*

Participants also anticipated that AI-enabled conversational systems embedded within hearables could guide users through the hearing healthcare journey by helping them interpret their data, articulate their needs, and navigate toward appropriate services or devices:

> *P14: "That's always been the holy grail to me… a destination where anyone can send… whoever it is, where they can effectively get navigated to the most suitable product and or service for them that's going to meet their needs…"*

Beyond clinical assessment and navigation, participants highlighted the value of real-time, context-aware feedback to support everyday listening. Hearables were described as potential tools for providing in-the-moment coaching, enabling users to better understand their listening performance and adapt their behavior in challenging environments:

> *P8: "Instead of a client going back to an audiologist two weeks later… there could be some real-time feedback saying, 'hey, you're missing half of the conversation'… or 'you need to position yourself differently'… that real-time coaching for people with hearing loss is going to be invaluable."*

3.2.1.3 Basic theme: technology convergence

The convergence of hearing aids and consumer hearables, particularly with the integration of biosensors, was a trend

highlighted by the industry leaders. As hearables begin conducting hearing tests and hearing aids incorporate features previously exclusive to consumer devices, the lines between the two are becoming increasingly blurred.

> P8: *"Hearing aids as a restricted medical product and over-the-counter technology are going to blur. It could be very easy to put the existing technology that's in hearing aids into… a hearable."*
>
> P11: *"In the future… the hearing healthcare industry will be much closer to the hearable as a commercial headset… they will really get close with the time."*

Consumer devices were considered by some experts as being unlikely to replace prescription hearing aids. While they offer some benefits, such as technology integration and modern form factor, they were viewed as falling short in meeting the communication needs of individuals with hearing loss. For the foreseeable future participants believed that people would still prefer discrete devices, less noticeable in social settings, such as restaurants.

> P17: *"We did a study… on whether people would like to use AirPods in a bar or a noisy restaurant… Most people… they didn't like these visible devices in a social situation. If there's going to be widespread use of hearables, the first problem… is making them not noticeable… Focusing on invisibility to overcome… stigma is going to be a huge improvement in usability and help with adoption."*

Several participants believed that consumer hearables will not fully meet the needs of hearing aid users until they become more miniature and discreet. They thought that AI-enabled hearables will likely remain separate from hearing aids, with tech companies prioritizing visible, fashionable products and expanding the digital ecosystem.

> P14: *"At what point can you show up to dinner with AirPods in your ears with a new group of people and have them see that as an accessibility device… not something that's distracting you..."*

3.2.1.4 Basic theme: accelerated advancement and hype

The influx of data could drive new hearable capabilities and insights. However, several experts cautioned that research backing technological claims can sometimes be inflated, with many innovations failing to deliver clinically meaningful benefits.

> P16: "*…when you've got devices in the community with millions of participants, we could potentially feed the rate of innovation. It's done today and makes it more user focused."*
>
> P12: *"We can sometimes overinflate what technology can deliver and sometimes technology exists in a form that isn't very user friendly… AI seems to have become so much more usable very quickly."*

3.2.2 Organizing theme: long-term uncertainty

3.2.2.1 Basic theme: hearables to be replaced by brain computer interfaces

The experts anticipated that by 2050, Brain-Computer interfaces (BCIs) would enable direct neural interaction with the internet, allowing users to issue voice commands through thought. Beyond hearables, experts foresee the integration of technology into the body through skin-worn devices, smart clothing, ingestible devices, and nanotechnology.

> P3: *"There'll be implants… augmented people… You won't even see the hearables; they'll be in us… there'll be… different touch points in our skin… you don't need to have something on the outside of your ear. You'll… have hearables in your clothes… and there may even be things in your teeth."*
>
> P18: *"Nanotechnology… other sensor-based technologies, ingestibles… it might not be a hearables market going forward. We might not see external devices… but… internal devices… that… starts to enable a science fiction future of… agent-based nanobots… in every place on our body, operating to help augment, complement human capabilities."*

3.3 Global theme: technology limitations

3.3.1 Organizing theme: hardware and user barriers

3.3.1.1 Basic theme: usability

One of the key concerns from participants was usability; currently users find it uncomfortable to wear devices for extended periods (e.g., sleeping) which limits the overall effectiveness of continuous health monitoring.

> P2: *"It's not realistic to expect someone to wear their Airpods 24 hours a day… If you're asleep, it might be pressing in your ear, it might not be comfortable, it might block the actual sound… There has to be something that compensates for that."*
>
> P12: *"We can sometimes overinflate what technology can deliver and sometimes technology exists in a form that isn't very user friendly… "*

Participants provided examples, such as early hearables like Bragi's Dash and devices like the Humane AI Pin and Meta Glasses, to illustrate how innovation can struggle in the absence of market readiness.

> P11: *"…a 3D menu that you can interact with by moving your head … people were not ready for that kind of innovation."*

Most commercial earphones block the ear, this provides noise reduction. But in so doing do not allow for sound leakage from the ear, an occlusion effect results, leading to poor sound quality of the

users voice. Hearing aids have largely overcome is problem through open-ear couplings.

> P5: *"AirPods Pros give me much better sound because they're occluding my ear canal vs. hearing aids where we want that natural sound..."*

3.3.1.2 Basic theme: hardware and batteries

The experts highlighted battery life as one of the greatest limiting factors. As the goal of expanding hearable functionalities with sensors and AI grows, the demand for longer battery life becomes more critical. Hearables need to last long enough to meet users' expectations for music streaming, run data tracking, and collect ongoing data without requiring constant recharging.

> P10: *"We want the battery life to be practical so someone doesn't stop using it because the battery's run out or we don't want it to be giant, so they don't want to wear it because it's too big on their ear."*

A participant believed that the rise of edge computing, where processing happens directly on the device, may increase power consumption, but it could also lead to better efficiency through optimizing processes.

> P11: *"There is a parallel industry that… will affect the hearable or… hearing aid industry. Computational on edge, the idea to run… models basic or more complex right on the device. Battery life will dictate the pace of this innovation."*

Despite the rapid pace of development, participants stressed that transformative change does not always result in improvements. Increased diagnosis of health complaints will lead to greater healthcare demands. The healthcare system may not be prepared to handle the influx of new data.

> P1: *"We're going to see innovation and digital creativity rapidly outstrip the ability to manage."*
>
> P2: *"There's a line here… between something that's genuinely useful and something that's actually a bit of a... At some point it's technology for the sake of technology and it's not solving a clear problem that people have expressed."*

3.4 Global theme: biosensors for health

3.4.1 Organizing theme: hearables as health monitoring devices

3.4.1.1 Basic theme: ear as recording site

There was a consensus in opinions that the ear was a prime location for biometric sensing, offering advantages over wrist- and finger-worn devices due to its stable positioning and proximity to the brain. Hearables may surpass smartwatches and rings in data accuracy. Consumer hearables and hearing aids were expected by the experts to follow the trajectory of smartwatches, integrating more biometric sensors tailored to ear-based measurements (heart rate, heart rate variability, and blood pressure). Electrical sensors for electroencephalography (EEG) could provide deeper health insights. Motion and speech analysis will be used for fitness, mental and cognitive health tracking.

> *P16: "Once you get the movement data you can look at neurodegenerative conditions. If you listen to someone's speech pattern you can diagnose mental health issues as well as respiratory conditions, the EEG… useful for epilepsy. You can monitor someone's sleep and understand whether they have sleep apnea and we're increasingly seeing novel digital biomarkers help us understand health and wellbeing in ways that we didn't know before."*
>
> *P8: "The ear canal is quite a sensitive place to be measuring biometric data… this technology has already been launched not in its full future capacity.… We already have some biometric data that can be recorded through hearing aids."*
>
> *P2: "Monitoring, collecting data in the real world… hearables will… be able to do well. The question to me is what things can we sense in the ear that we really cannot sense well elsewhere. One example… head motion. The other obvious example… hearing and speech. ECG and EEG… there's also… photoplethysmography, PPG. Using this for heart rate, heart rate variability, and blood pressure. I'm most excited about someone coming up with some new sensing that only works in the ear."*

3.4.1.2 Basic theme: role for audiologists

As hearables are ear level devices with hearing functions the participants mentioned Audiologists as key clinical stakeholders. Advancements in technology may make hearables desirable leading to earlier adoption of amplification.

> *P5: "Hearing aids now are hearables to the degree."*
>
> P10: *"The number of people out there… with a hearing loss and no formal amplification… If this is something that helps those people… to start getting amplification a bit earlier… It should only really grow the hearing aid industry… they'll see the benefit… that'll… drive them toward getting hearing aids… earlier than they may have done otherwise."*

Technology is likely to change clinical roles with routine hearing problems being managed with minimal clinical contact.

> P8: *"Most people will have their basic hearing measured through hearables and only see an ENT or an audiologist… if it's very complex… I think self-fitting will definitely be a thing…and adjustments…based on real time data and information giving 'I can't remember how to change the battery'...all of that counseling about the equipment will be done through AI…"*

Over time, AI-enabled hearables could offer a wide range of services, from general hearing tests and amplification to counseling and support. Clinicians may only be required for more complex cases, with AI taking on much of the routine care. There is growing concern about the future of traditional audiology roles.

> P13: *"Clinicians are afraid that their work will change and that it may even replace their work."*

Hearables may empower patients by collecting real-world health data accessible to clinicians in real-time, remotely from clinics.

> P13: *"One way forward could be teleaudiology… collecting data at home of the end user in situations they're working, going to school, all daily life situations and do this in a controlled way…, owned by the user and this user can give permission to share it within the global ecosystem."*

While the audiology experts believed that the need for traditional hearing aid fittings would decline, other opportunities would arise that could expand clinical roles, creating opportunities such as patient health technology advisors. Audiologists could help patients interpret their data, make informed decisions, and collaborate across disciplines for more holistic care. As AI takes on data-driven tasks, healthcare professionals may shift toward a more integrative model, using technology to enhance rather than replace their expertise.

> P9: *"The future is… tech not being specific to a specialty… It might be a hearing aid, but the hearing aid might also be doing something to do with cardiology."*
>
> P13: *"It could… unlock a lot of power for the clinician… to oversee all these different measurements, you can give better advice and… help really large… populations by better data analysis… letting people do measurements at home for instance."*

One of the main values of AI in hearables lies in predicting health issues, ranging from speech delays in children to cognitive issues in the elderly. For example, AI could distinguish whether hearing difficulties stem from hearing issues or cognitive decline. By detecting early signs of auditory fatigue, listening effort, and difficulty hearing speech in noise, clients' needs can be objectively assessed.

> *P5: "Sonde Health… developed speech biomarkers to do early detection for… Parkinson's, Alzheimer's, amongst others… you could pick up the speech patterns… before you would see any tremors… We started analyzing the speech patterns of our customers… you get an aggregated cognitive load score, as well as a brain health score… we want to understand what happens when you start wearing hearing aids. Does a cognitive load score go down… It really is a proof of concept."*

With broader data collection capabilities, including EEG and electrocardiograms (ECG), it is unclear who is responsible for clinical decision-making. Ensuring patient safety in the face of these new capabilities will necessitate a multidisciplinary approach between audiology and specialists from neurology, cardiology, and other fields.

> P7: *"...it just really needs true multidisciplinarity… Being able to think of all the upstream, downstream... potential opportunities, potential... negative impacts."*

3.4.1.3 Basic theme: justification for biometric integration into hearables

Participants were unequivocal that innovations had to come with purpose and genuine benefit to the user and not be driven by innovation alone.

> *P2: "There has to be some fundamental advantage for why you want to do it with a hearable… having it in the ear…. "*
>
> *P17: "Start with the need and then see if doing things in the ear is a better solution…."*

3.5 Global theme: AI agent

3.5.1 Organizing theme: personal and social assistant

3.5.1.1 Basic theme: everyday assistant

Hearables could become personal assistants embedded in everyday life. Several participants described a future in which AI-driven hearables offer ultra-convenience through voice-based execution. Users will interact, control devices, and complete tasks effortlessly, anytime and anywhere. AI could eliminate language barriers by translating speech into a user's preferred language. Experts also noted that AI assistants will become increasingly natural to interact with. Users may form stronger connections with these assistants as they learn personal preferences and proactively enhance daily life. One participant related this vision to the AI from the film "*Her*", in which an advanced AI personal assistant, develops human-like emotional intelligence.

> P17: *"You can have a hearable that will translate in real-time… the far future of hearables was pretty well depicted in the film "Her"... an assistant in your ear."*

These AI personal agents could help individuals with tasks such as booking appointments, managing finances, and ensuring safety through timely alerts. Experts envision hearables offering instant knowledge on various topics.

> P14: *"OpenAI is already talking about the next big thing is… agents. Book me a flight, book me a nice pizza restaurant tonight, whatever… could be done just without even looking at your phone or your computer just through your earbuds."*

Hearables, experts believed, would act as AI agents operating in the background anticipating needs, providing information, and taking actions without requiring direct commands. A hearable could provide real-time, hands-free, context-aware and voice-based guidance. This would make health insights more immediate, actionable, and seamlessly integrated into daily life.

> P3: *"It'll… listen to my discussions during the day and know that I'm going to the airport in the afternoon… it will book my Uber… know I need to leave by this time and it will let me know saying, "your Ubers arrived. I also know that you haven't had any dinner, so I've booked an Uber to pick up some food for you…"*

The hearable agent would act as an ever-present assistant, ensuring that everything runs smoothly. These devices could help individuals navigate the world more easily, provide support earlier, and assist in tailoring learning to suit individual needs.

> P15 "*the tool becomes part of you. Digital agents… They are persistent. It's there doing stuff for you even if you're not currently interacting with it."*
>
> P2: *"I do things like mountain biking, road cycling. I might want to get directions so I… ask an assistant, should I turn left or right at this intersection. It would be fantastic not to have to pull out a map on a phone, to… have this communication channel through a hearable…I think maps without actually having to use maps… it's going to be like having a local expert beside you."*

3.5.2 Organizing theme: healthcare assistant

3.5.2.1 Basic theme: early diagnosis and intervention

One specialty area that a personalized AI assistant would exist is healthcare. Several participants proposed hearables would shift the focus of healthcare from being reactive to proactive, enabling more holistic care. The industry leaders thought the main values of AI in hearables would be in predicting health issues, ranging from speech delays in children to cognitive issues in the elderly.

> P11: *"The best use case is… medical data powered by AI… to prevent disease at an early stage and that's kind of a basic thing that will happen but still very useful."*

3.5.2.2 Basic theme: supporting health systems

Early intervention by a hearable assistant could reduce hospital admissions and ease the burden on healthcare systems by preventing conditions from worsening. The participants believed AI will play a crucial role in processing and providing the right information to clinicians, ensuring that health data is actionable and relevant to the patient's condition. AI could also help individuals cope with their health conditions.

> P16: *"The opportunity to prevent disease, navigate illness and even manage illness instead of being admitted to hospital... It offers so many opportunities to solve A. the consumer demand for self-empowerment, and B. the healthcare system demands to do things at scale for people."*
>
> P2:*"there are doctors who will ask their patients to go and wear an Apple Watch or something like this and get that data and so the same could apply to hearables."*

3.5.2.3 AI is already aiding client centered interactions and history taking

> P16: *"In primary care, we're seeing a lot of AI Scribe use… an accurate summary of a long discussion in medical form… that can be translated between languages and translated from technical language… through to lay language… Scribes are changing a lot of practice because… you can look at your patient and connect with them as a human rather than look at your computer."*

The experts raised caveats as to how the volume of data will be managed if digital health systems are not prepared for the influx of this data.

> P16: *"The rate at which we're accumulating new information is rapidly increasing but the risk is you can't possibly stay on top of all these new biomarkers and technologies… we're going to need automation to… get through all of that information… "*

3.5.2.3 Basic theme: hearing and wellbeing

An AI assistant could support individuals in social interactions

> P8: *"While the client's in the restaurant, there could be… real-time feedback saying…"do you know that Bob on the left was talking to you?" or "you need to position yourself differently" or "the noise levels are too high, you need to get out of the building" …that real-time coaching for people with hearing loss is going to be invaluable."*

There is also significant potential for AI-enabled hearables to benefit people with disabilities or learning differences, dyslexia, or the elderly. By detecting early signs of auditory fatigue, listening effort, and difficulty hearing speech in noise.

> P5: *"Imagine if the hearing aids… were capturing all of the things that you were doing on a daily basis … to build a picture for how you're developing from a healthy aging perspective and… encourage you to do things that might improve your cognitive load score, sleep… etcetera."*

Voice data from hearables may provide valuable insights for mental health assessments, such as diagnosing depression or anxiety. One expert mentioned a study they conducted in which a wearable prediction when a person was anxious and sent a calming message, successfully mitigating their anxiety.

> P9: *"We used… common wearables to predict when people were anxious. We worked with young people… we were able to send them messages in the moment that we predicted that they would be anxious to try and mitigate that anxiety. We got really, really positive responses to that intervention."*
>
> P16: *"Speech patterns will reveal a lot more about us than we realize. Including… mental health diagnoses… nine out of 10 of those mental health assessments could be done with a really smart hearing aid. You could probably diagnose a psychosis or bipolar disorder or even a thought disorder, depression and anxiety..."*

3.6 Global theme: governance and ethical gaps in AI regulation

3.6.1 Organizing theme: regulatory deficiencies and risks

3.6.1.1 Basic theme: data accuracy and use

Most of the participants highlighted the numerous opportunities that AI-enabled hearables present for health data collection and processing, but emphasized the need for stricter regulations due to significant risks. A key concern was who will have the responsibility for ethical data collection and its use.

> *P1: "Speech processing… enhancement… what happens to that information?... Is that data being collected for the purposes of large language models… further refinement of the device… or… next iteration of that… product?... Data is just… consumed and there's been no real thought to what the consent framework looks like and how do you appropriately articulate it to the end consumer."*

3.6.1.2 Basic theme: regulation

AI regulation in medical devices, particularly hearables, remains fragmented and underdeveloped, with experts highlighting gaps in oversight across various jurisdictions. Participants hoped for improved AI governance to ensure safety, fairness, and effectiveness in AI-enabled hearables.

> P6: *"In the EU… GDPR* [General Data Protection Regulation] *prohibits what you can and cannot do with consumer data… you goto America where you do whatever you want. If you sign some terms and service… anything that's being collected can be used for product development or given to law enforcement."*

3.6.2 Organizing theme: power imbalances and corporate interests

3.6.2.1 Basic theme: big tech

A key theme that emerged was the immense influence of prominent technological companies in shaping AI-enabled hearables and their broader role in society. Experts noted that large companies such as Apple and Google are not only driving innovations but also consolidating power acquiring startups for intellectual property or market dominance, and, if truly invested in hearing care, possessing the financial means to purchase major hearing aid manufacturers.

> P4: *"The hearing aid manufacturers… play a really big role… second to your consumer electronic manufacturers… We probably have a really big responsibility in the hearing space of hearables because that's where our bread and butter is."*

Clinicians will have some culpability in recommending technology that gathers data that is not essential for clinical practice.

> P9: *"By saying to someone, "hey wear this or use this" you are effectively endorsing that company to that patient... I'm sure audiologists would struggle with this; do you completely align with these companies that are developing these technologies?"*

Industry experts were concerned that without legal obligations to ensure consumer safety. The concentration of power within both big technology and hearing aid manufacturers means that the future capabilities of AI-enabled hearables will be dictated by their decisions.

> P7: *"Huge amounts of data will be collected by these amazing new startups in AI who will then be bought up by someone else… There's so much concentration of power and money in the big multinationals, who will then pick off all the little new great ideas and buy them up to put them on their platforms… there's lots of potential issues… around data ownership, data sharing, data transfer."*

3.6.3 Organizing theme: ethics and consumer protection

3.6.3.1 Basic theme: equity

The rapid advancement of hearable technology also risks widening equity gaps. If big tech focuses on the broader population, it may neglect individuals with higher support needs. As a result, certain groups may be excluded from the benefits of AI-hearables, exacerbating existing societal disparities. This could manifest as a focus on common health issues to the detriment of rarer disorders.

> P13: *"The largest group of people has not such complex health issues so a lot of resources could be focused on these groups, but it could also limit… resources… on the complex cases… focusing… more on hearables for the large groups… could… be counterproductive."*

There are concerns in New Zealand that languages with fewer users, and therefore less commercially interesting, such as Te Reo Māori may not be adequately supported, and that indigenous data may be at risk of exploitation.

> P6: *"Models… out by companies like Google, Microsoft… are fine tuned to the common languages… When it comes to… how Te Reo will be understood, we are such a small market the likelihood of those technologies being fine-tuned toward the New Zealand population, those… issues are likely to persist."*

These equity issues may extend to the financially disadvantaged.

> P9: *"Anything we do in AI should be about addressing… inequities, not increasing them. Apple AirPods, they're never going to be accessible to a massive chunk of our population… they're going to need to download an app…have storage capacity… a credit card on the app store… all of those things make these things inaccessible."*

3.6.3.2 Basic theme: self-owned data

Some solutions proposed by the expert participants to address these ethical and governance challenges included greater emphasis on self-ownership of data. One expert suggested shifting from large language models to smaller, more manageable ones.

> P14: *"Your own… localized LLM…that's completely private… There are already people running LLMs… on their own computers… there's organizations doing that… so they have complete privacy."*

Another proposal involved applying Māori cultural concepts to data management, such as legal personhood, to ensure that data is protected and not misused. In this view data is seen as part of the person.

> P3: *"The large language models… their mistake is to think that data is data. Data has a Mauri life force… a wairua, a spirit… would you value data about your nana and data about your address differently?… the future will be small language models… data will be able to weave through Facebook… LinkedIn… ChatGPT… no one will be able to own it, they won't be able to commercialize it, because the legal personhood aspect will be applied."*

The ability to simulate voices and personalities also emerged as a controversial feature. Experts feared the potential for intrusive experiences, such as advertisements being directly implanted into a user's perception.

> P15: *"… they'll just be there and it'll be like a voice inside your head for better or worse… getting advertising all the time.. privacy, annoyance factor… are worth considering."*

3.7 Global theme: society and human behavior

3.7.1 Organizing theme: psychosocial impact

3.7.1.1 Basic theme: AI influence on behavior

AI's consciousness-like traits could influence how humans interact with each other. Ethicists highlighted a significant shift from traditional search engines to AI technologies, which now carry the risk of anthropomorphism. As AI technologies like chatbots develop playful interactions and as hearables enable real-time conversations directly in our ears, we face the possibility that these interactions may alter the way we communicate with other humans.

> P12: *"A search engine doesn't have… humanized features of… AI which invites you to think about it as a person… playful interactions… sense of humor… you… easily fall into the idea that this is a relationship with a person-like entity…"*

AI, by design, does not require reciprocity; it is always available and always pleasant. As one expert put it, we may begin ascribing personality to these devices, based on psychotherapeutic models of care that prompt us to open up by asking the right questions.

> P15: *"We're… now… talking to technology and as it talks to us, we're anthropomorphizing it even more than… in the past and we're ascribing it… personality."*

Emotional bonds could form between individuals and their hearables or voice assistants, and it might eventually become the norm. As AI assists in emotional support, some of the experts suggested we may come to expect more from our clinicians and partners. The question then arises will we need to actively choose

to engage more with humans and less with AI, ensuring that we do not become overly dependent on these devices?

> P12: *"It doesn't have a need for reciprocity. . . . There could be a concern that the more we interact with AI, the more we will come to see that transactional extractive way of relating as the norm . . . . Why wouldn't AI change our capacity to have reciprocal relationships?"*

3.7.2 Organizing theme: Utopian vs. dystopian future

3.7.2.1 Basic theme: Utopian vision - AI hearables enhance our lives

In this vision experts see AI improving quality of life, reducing disabilities, preventing chronic illness as well as improving communication.

> P1: *"Greater empowerment for digital health users, particularly for the elderly or for those who may have mental health challenges or differences with auditory issues."*
>
> P3: *"This will be able to coach him [Son] saying, okay, "this is what the teacher means. . . " it will know how he needs to learn. It'll just speed everything up."*
>
> P11: *"Improving your social life. . . They can assess. . . vocal tone. . . emotional state. . . prevent depression. . . help you have some interpersonal engagement with people. For younger people. . . they can. . . identify. . . signs of isolation. The hearable can understand. . . I speak very few words in a day. . . Maybe I'm losing a lot of social interaction. . . "*

3.7.2.2 Basic theme: dystopian vision—big brother

Privacy concerns around the use of hearables to monitor citizens, especially in authoritarian regimes were raised.

> P12: *"Imagine. . . being in a country that has an authoritarian government. . . who sees spying upon its own populace as being integral to its maintenance of authority, you can see how devices that increased a person's scope of hearing. . . could be really threatening."*

AI-driven diagnostics could have severe consequences if speech pattern models fail to account for individual variation, potentially leading to false diagnoses of mental health conditions and involuntary interventions. There is also the risk of AI hallucinations, where hearables misinterpret speech, resulting in incorrect conclusions.

> P1: *"Questions around the integrity of the text to speech type capability that would certainly have knock-on effects in a medical context, making sure things were heard accurately. . . in a legal context, whether or not if someone particularly heard something. . . the evidence. . . was being used in legal proceedings."*

AI-enabled hearables could subtly influence behaviors without the user's awareness. There are concerns that LLMs could understand individuals better than they understand themselves, predicting aspects such as sexuality and gender before the user is consciously aware.

> P12: *"Social media algorithms can make diagnoses of teenagers' sexuality or whether they might be transgender. . . before that person has expressed any consciousness of that. . . I don't think when people started using social media, they had any idea that it wasn't just their gaze on social media that it was social media's gaze back at them."*

When combined with calm technologies, such as those that adjust sound, AI could manipulate moods and behaviors in ways that are not immediately visible to the user. While not intentional, these capabilities could have harmful outcomes, particularly when exploited with malicious intent. There have already been incidents where chatbots have inadvertently led to harmful consequences, including suicides.

> P9: *"A case in Europe where the coroner has ruled that a death by suicide was the result of a chatbot. In New York. . . a young person also died by suicide following advice from a chatbot."*

4 Discussion

Participants from major technology companies, hearing aid manufacturers and academia were asked about existing AI-enabled consumer technology and their vision for next-generation products. This study aimed to achieve broad representation from leaders across the industry, incorporating perspectives from experts with diverse backgrounds in technical, clinical, research, and entrepreneurial fields. This approach enabled a multifaceted analysis of the future trajectory of AI hearables. The participants described similar hopes and concerns for the future of these devices, characterized by six global themes: 1. Technology Advancement; 2. Technical limitations; 3. Biometric sensors for health; 4. AI agents, 5. Governance and ethics and 6. Society and behavior.

4.1 Technology advancement

In the near future, participants expected advancements in both hearing-related features and AI-specific capabilities, with hearables enhancing auditory experiences while also serving as intelligent assistants in daily life. The augmentation of sensory experience was seen as a key auditory feature of AI-enabled hearables. Innovations such as Auracast streaming (Bruce et al., 2025),

hearing aid processing (Khristo and Fawzi, 2025) and increasing miniaturization of powerful processing chips (Wang et al., 2024) all signal advancement in hearables. Experts foresee the integration of technology into the human body through skin-worn devices, smart clothing, ingestible devices, and nanotechnology. These innovations could expand human capabilities and redefine how individuals interact with their environments. However, as these technologies advance, participants believed they may eventually overshadow hearables entirely, shifting the landscape of human augmentation beyond audio-focused interfaces.

Twenty-five years ahead of now, experts envisioned concepts that today may appear to be science fiction. One of those futures included Brain Computer interface (BCI) technologies, which enable direct communication between the brain and external devices. Several of our interviewees identified BCIs as technology that may replace wearables. These would bypass conventional control modalities such as manual input or voice commands (Gordon and Seth, 2024). The primary objective of BCIs is to allow individuals to control devices or interact with computational systems through neural activity alone. This technology holds value for individuals with physical disabilities or paralysis, offering alternative means of communication and interaction. Typically recorded via EEG, electrocorticography (ECoG), or invasive neural implants (Kawala-Sterniuk et al., 2021), electrical signals are processed by software that translates neural patterns into actionable commands. These can enable users to perform tasks such as moving a wheelchair or typing on a digital interface (Ansari et al., 2019). While BCIs have already demonstrated promise in restoring mobility and communication for individuals with motor impairments, ongoing research is exploring their potential applications in sensory augmentation, including hearing enhancement (Gordon and Seth, 2024). Currently, Neuralink and Synchron are leading advancements in BCI technology. Neuralink's system involves a brain implant equipped with a small chip that reads neural activity and transmits it to external devices. This chip could theoretically bypass damaged sensory pathways, such as those responsible for hearing, by directly stimulating the auditory cortex (Umashankar et al., 2021). Synchron's Stentrode, in contrast, is designed as an endovascular stent-like device inserted into blood vessels near the brain. This approach allows for neural signal recording without direct brain penetration, possibly reducing surgical risks while maintaining effective brain interfacing (Mitchell et al., 2023). The primary hearing implants used in audiology are cochlear implants, which bypass damaged hair cells by providing direct electrical stimulation to the auditory nerve. This enables individuals with profound hearing loss to perceive sound, allowing them to distinguish pitch, rhythm, and speech clarity (Mudry and Mills, 2013). For conditions with damaged auditory nerves, Auditory Brainstem Implants (ABIs) are an alternative, albeit more invasive, solution (Peng et al., 2018). These devices are surgically placed along the brainstem to stimulate the cochlear nucleus directly, though they generally provide only basic sound awareness rather than full speech comprehension (Deep et al., 2019). A BCI designed for hearing restoration would function similarly to an ABI by bypassing both the cochlea and the auditory nerve entirely, but would interface with higher auditory processing centers, such as the auditory cortex. Unlike cochlear implants, information would be bidirectional, to and from the brain. Research has already explored the feasibility of using ECoG signals in speech and auditory cortices to decode neural activity related to hearing and speech processing (Leuthardt et al., 2009).

4.2 Limitations of technology

Whilst most of the participants were enthusiastic about the future of AI-enabled hearables, they did identify current hardware limitations (e.g., batteries) and errors in decision making as limitations. AI voice assistants can perform predictive tasks, but data biases, especially in speech patterns, can impact accuracy. The power demands of AI-driven processing onboard hearables exceed the capabilities of current battery technology, posing a significant barrier to hearables and other devices with limited battery capacity. Until more advanced battery solutions emerge, power constraints will continue to limit the full potential of AI integration. Addressing power consumption and AI transparency will be crucial for realizing AI's full potential in this domain.

4.3 Biosensing

Most of the experts who participated in the study believed real-time biosensing could revolutionize healthcare. Researchers are exploring the ear as a recording site for a wide range of applications. The ear as an excellent location for biometric sensing, offering advantages over wrist- and finger-worn devices due to its stable positioning and proximity to the brain (Crum, 2019), though it remains less precise than internal body sensors (Ne et al., 2021). Hearables may surpass smartwatches and rings as wearable sensing technology for measuring body movement, vagus nerve activity, blood oxygen levels, skin resistance, heart rate, temperature, stress, mental effort, engagement, attention, and overall physical health (Crum, 2019). Hearables' ability to measure total energy expenditure and VO2 max during cardiopulmonary exercise tests has been demonstrated (Masè et al., 2020). Additionally, hearables have demonstrated potential for ECG-based heart condition monitoring, with real-world applications such as heart rate tracking while driving (Yarici et al., 2024). Since current consumer hearables are predominantly used for music, one emerging area of interest is detecting vocal reactions to understand users' listening experiences (Lee et al., 2020). This could enable devices to better learn media preferences through voice analysis. AI could leverage microphone data for diagnostics. Research has shown that AI can detect respiratory illnesses such as pneumonia, asthma, pertussis, and COVID-19 through cough sound analysis (Alqudaihi et al., 2021). Another avenue of exploration is in-ear motion detection. OESense has demonstrated how acoustic sensing via the occlusion effect could improve the measurement of both intense and subtle movements (Ma et al., 2021). This could result in possibilities for head and facial gesture-controlled hearables, as well as enhance fitness tracking accuracy. While smartphones rely on phrases like "Hey Siri" or "OK Google," technologies such as EarVoice aim to activate voice assistants without the need for microphones,

improving hands-free usability (Chen et al., 2024). Similarly, concepts like EarBuddy showcase how microphones in hearables could detect sliding and tapping gestures near the ear, enabling users to interact with their devices without directly touching them (Xu et al., 2020). One expert noted that the novel switching methods need to provide a demonstrable benefit over standard interfaces before they will be widely accepted.

Participants envisaged that AI-enabled hearables would shift the focus of healthcare from reactive to proactive, enabling more holistic care. As AI-driven voice interfaces become more advanced, hearables could serve as seamless intermediaries between users and technology, enabling natural voice interactions and allowing users to obtain information or execute actions solely through speech. LLMs such as ChatGPT and Gemini have recently introduced voice-driven prompting (Barra et al., 2024). Users could ask their hearables to write code, create documents, or complete complex tasks. AI-powered workplace assistants could also be integrated with hearables, allowing users to generate presentations or automate workflows while on the move (Saha and Chandrasekharan, 2023). While these tasks can be performed on smartphones, hearables may offer a more intuitive alternative, eliminating the need to pick up or raise a phone or smartwatch.

Brain activity monitoring (not through a direct BCI) could provide significant value for evaluating neurological conditions. Behind-the-ear electrodes have already proven effective for EEG-based seizure detection in epilepsy (Lehnen et al., 2025). In 2023, Apple patented EEG technology for a future AirPods-like device, described as a Biosignal Sensing Device with Dynamic Selection of Electrodes (Azemi et al., 2023). The patent suggests that future hearables could measure EEG for neural activity, as well as electromyography (EMG), electrooculography (EOG) and ECG, galvanic skin response, and blood volume pulse.

Hearables equipped with AI-driven health monitoring capabilities could alert users to potential health concerns and offer personalized recommendations. For example, Apple AirPods already offer hearing tests (Kim et al., 2024). In the future, AI could assess whether a user requires professional intervention and autonomously schedule an audiology appointment. Similar to Google Duplex AI, AI agents may even place calls and make bookings using realistic synthetic voices, raising both opportunities and ethical challenges (O'Leary, 2019). Some of the study participants were concerned that the abundance of AI-driven health monitoring may result in overdiagnosis; uncertain interpretations of heart rate variability could prompt unnecessary tests or interventions due to risk-averse decision-making.

4.4 AI agents

In November 2023, Microsoft founder Bill Gates predicted AI-powered agents (or agentic AI) as the future of computing (Gates, 2023). He described a shift from manual tasks like writing emails or booking flights to AI systems acting autonomously. Unlike generative AI, which assists users in content creation, AI agents will make decisions independently (Larsen et al., 2024). They are designed to understand users deeply and take action with minimal input. Agents are autonomous systems that utilize sensors to gather data and effectors to act upon it. Agentic AI is expected to drive virtual co-workers and reduce manual effort in professional settings. Big tech is already building AI agents (Yee et al., 2024). Microsoft's Co-Pilot integrates AI into productivity tools, handling tasks like spreadsheet analysis, presentation design, and calendar management. As these systems evolve, users will spend less time typing and more time interacting with AI to complete tasks efficiently.

A participant had a long-term vision resembling the AI from *Her (*Murphy, 2018). A film in which an advanced AI operating system, designed as a personal assistant, develops human-like emotional intelligence. Although *Her* was released in 2013, its setting in 2025 enables a comparative analysis between the film's fictional predictions and present-day technological realities. *Her* depicts an AI system that not only can support conventional task execution but also demonstrates autonomous decision-making and deep contextual awareness. This aligns with expert visions of hearables evolving into sophisticated, interactive companions. Another feature expected soon is real-time language translation. AI could eliminate language barriers by not only translating speech into a user's preferred language but also preserving the speaker's voice through voice cloning. AI-powered hearables could 1 day allow users to silently issue commands and receive responses through discreet audio feedback. MIT's experimental *AlterEgo* explores this concept, using neuromuscular signals to detect subvocalized speech, allowing users to communicate without speaking aloud (Kapur et al., 2018).

The ease of use in voice-activated hearables raises privacy concerns, as users may unintentionally disclose sensitive personal information. An expert noted that psychological data is particularly difficult to de-identify, making it a prime target for misuse. Additionally, storing and processing voice data introduces security risks, as stolen voiceprints could be exploited for biometric authentication fraud, potentially compromising financial and personal accounts. These factors underscore the pressing need for robust AI governance.

4.5 AI governance

AI governance refers to the policies, regulations, and ethical frameworks designed to oversee the development, deployment, and use of AI systems (De Almeida et al., 2021). Its primary goal is to ensure AI advances responsibly, aligning with societal values while minimizing risks and maximizing benefits. The need for AI governance has grown as AI rapidly transforms industries and accelerates innovation (Batool et al., 2025). As AI becomes increasingly embedded in daily life, robust governance structures are crucial for aligning AI with human intent (Mäntymäki et al., 2022). Data governance is equally crucial, as data quality directly impacts model accuracy and fairness. Poor data management can lead to biased algorithms and adverse outcomes. Improper data use or flawed models can erode trust and enable exploitation, ultimately threatening AI's transformative potential.

Examples of AI governance include the General Data Protection Regulation (Intersoft Consulting, 2018) in the European Union and the California Consumer Privacy Act [CCPA (Bonta,

2022)] in the United States. These laws enforce transparency, safeguard personal data, and impose strict compliance requirements. For instance, the GDPR grants citizens control over their data across physical, code, and informational layers (Mügge, 2024). This protection extends to personal data processed and stored within cloud infrastructure, particularly in healthcare applications. The need for protection from data misuse was highlighted by many of the participants. Edge AI builds upon this by enabling artificial intelligence models to be trained and executed locally without relying on external servers (Shi et al., 2020). This results in faster decision-making and improved privacy, as sensitive data remains on the device rather than being transmitted to cloud servers. Additionally, Edge AI reduces bandwidth usage by transmitting only essential data to the cloud, optimizing network efficiency and power consumption (Gujar, 2024).

Evolving legal frameworks present challenges. AI systems introduce risks such as algorithmic bias, data misuse, and privacy violations that may cause harm. Intellectual property rights protect proprietary AI algorithms, fostering innovation while ensuring security. Regulatory standards define safety and performance benchmarks, ensuring AI-powered devices comply with legal and user expectations (De Almeida et al., 2021). Privacy and cybersecurity are critical for AI-powered hearables. A major concern is the risk of data breaches and hacking, where attackers exploit system vulnerabilities to access private information. Hearables primarily rely on Bluetooth for data transmission, using adaptive frequency hopping to minimize interception risks. However, weak encryption, poor device configuration, and outdated software can still leave systems vulnerable. Research has also shown that frequency hopping can be exploited for covert communication, posing risks of undetected data theft and privacy breaches (Vogel et al., 2020). Emerging AI applications in hearables, such as hands-free voice assistants, present additional security risks. Research has demonstrated that these devices are inherently vulnerable to ultrasonic attacks. *EchoAttack*, a proposed hearable exploitation system, highlights how attackers can use ultrasound to trigger smartphone voice assistants, compromising user privacy. Such attacks could occur in public spaces, including bus stops, gyms, and workplaces (Li et al., 2023).

4.6 Society and behavior

The societal impact of AI-powered hearables is unclear. The current limitations of hearables make it difficult to predict future capabilities. Assessing potential risks before widespread adoption is essential (Grewal et al., 2024). Our participants foresee both utopian and dystopian futures for hearables.

Hearables may also develop an intimate understanding of their users, not only through biosensors but also via voice data. Conversational AI is already being integrated into everyday life, with chatbots like Replika and Pi providing emotional support (Maples et al., 2024). The more users interact with AI, the more they may attribute human-like intelligence and emotions to these systems (Shanahan, 2024). Future AI-powered hearables may analyze voice patterns to infer mental states, track emotional wellbeing, and predict personal attributes, such as political leanings, all without explicit user disclosure (Singh, 2023). This presents significant ethical challenges, particularly in the field of mental health. AI has shown promise in identifying individuals at risk of suicide (Lejeune et al., 2022) and could act as a supportive companion during crises. However, participants raised cases where chatbots contributed to users' suicides. If a hearable detects suicidal tendencies or other health risks, what is its responsibility to intervene?

Another critical consideration is the role of AI in shaping access to information. Currently, most people consume news online, where AI-driven algorithms influence the content they see. Social media has already demonstrated how algorithmic curation can spread misinformation, deepen ideological divides, and negatively affect mental health (Gausen et al., 2025). AI-hearables, bringing AI-curated news directly to users' ears, could exacerbate these effects, reinforcing ideological echo chambers. The risk is especially high as misinformation safeguards on social media continue to weaken (Shaw, 2023). The auditory nature of hearables may also enhance AI's persuasive power. Research suggests that people perceive voices in headphones as warmer and more empathetic, making them more likely to trust and be influenced by the speaker (Lieberman et al., 2022). If AI-powered hearables operate as persistent conversational agents, how might this influence decision-making and beliefs?

Unlike clinical trials, FDA regulation alone does not mandate real-world validation of AI-driven health insights, raising concerns about accuracy and potential bias. For instance, pulse oximeters trained predominantly on Caucasian datasets, as seen during COVID-19, may yield inaccurate readings for people of color (Sudat et al., 2023). Broad, adaptable AI frameworks are necessary to regulate the evolving landscape of hearables and wearables without becoming obsolete. There is a need to educate clinicians and the general public so they understand the implications of using AI-enabled hearables. Big tech companies, hearing aid manufacturers, clinicians, technical professionals, ethicists, and most importantly, consumers should engage in debate of what data can be used for. This collaborative approach would allow big tech to pursue its interests while ensuring that other stakeholders have confidence that harm is minimized. The data collected should be focused on solving specific problems and addressing users' needs.

4.7 Implications for audiology

Although AI's role in audiology was not the primary focus of this study, experts noted that audiology as a profession could benefit from hearables. Audiologists are expected to play a key role in recommending and dispensing these devices, but AI will change their role. There may be a shift to a greater focus on human interaction, counseling, and personalized care. Experts believed that audiology cannot fully be automated, given the desire for human interaction. AI-generated health insights could expand clinical roles in which audiologists are patient health technology advisors. Clinicians can help patients interpret their data, make informed decisions, and collaborate across disciplines to provide more holistic care. As AI takes on data-driven tasks, healthcare professionals can shift toward a more

integrative model, using technology to enhance rather than replace their expertise.

AI is expected to streamline multiple aspects of audiological diagnostics and treatment. Pure-tone audiometry and amplification have already begun to incorporate automation (Kim et al., 2024). Patients who have already recognized their hearing loss through these digital tests may be more open to amplification. Speech audiometry, a key component of audiological testing, has also shown potential for automation. AI-based systems can now perform patient speech scoring at the same level as human experts in clinical settings (Jean et al., 2025). AI has also demonstrated the ability to analyze tympanograms and detect middle ear diseases, expanding diagnostic capabilities in tympanometry (Jin et al., 2023). AI's integration into hearables could enable hearing protection. Smartphones already feature sound level meter (SLM) applications (Huyan et al., 2023), and this functionality could extend to hearables, potentially serving as evidence for noise-induced hearing loss claims in insurance cases.

AI is likely to play a role in automating real-ear measurements to improve fitting accuracy (Brockmeyer et al., 2021). AI could also enhance needs assessments by recommending hearing aids based on audiograms, individual user preferences, and experiences. AI-powered patient counseling tools may provide tailored guidance and education, helping individuals better understand and manage their hearing problems. The automation of patient report generation, already expanding in healthcare, may also become a standard feature in audiology (Frosolini et al., 2024). However, participants noted that automatic scribes risk AI hallucinations that can be very harmful. AI scribes cannot be safely used without clinicians reviewing notes.

AI is also advancing hearing healthcare through predictive modeling. Machine learning has shown promise in classifying audiograms and predicting hearing loss (AlSamhori et al., 2024). The experts noted that technological disruptors to audiology, such as over-the-counter hearing aids, have met resistance by some audiologists. Audiology scope of practice may be shaped to some degree by the capabilities offered by hearables. Will audiologists be responsible for all data acquired from the ears, such as markers of cognition, mental and cardiac health? What liability would audiologists have from measurement of heart activity as a marker of tinnitus stress if a serious cardiac problem goes undiagnosed?

We propose that audiology education and professional development should shift toward structured upskilling in AI, both in audiology curricula and in continuing education. These educational initiatives would address the benefits and risks of AI, including data use, privacy, and informed consent. Educational frameworks should therefore prepare clinicians for evolving professional roles and skill sets, ensuring they possess the knowledge central to patient-centered hearing healthcare in the context of increasing technological automation and extended capabilities. As a specific example, audiology curricula may need to include training in biometrics (physical and mental health) to ensure the safe application of these tools in audiology practice.

4.8 Study strengths and limitations

Qualitative research aims to uncover deeper insights into real-world phenomena by exploring participant perspectives. The semi-structured approach maintained consistency across interviews while allowing for unique insights essential to understanding the key considerations for the future of AI-enabled hearables. The global themes were consistent across many participants, while basic themes included unique perspectives raised by individuals with specific expertise. Although participants had broad interests and expertise, not all technology companies were represented, and so there is a risk of bias. Experts may, consciously or unconsciously, withhold information or fail to elaborate on certain aspects of future hearables due to their involvement with specific organizations or proprietary knowledge. Any undisclosed concepts could play a crucial role in shaping the future capabilities of hearable devices. These limitations may have impacted the comprehensiveness of the insights provided. Key areas such as AI governance and the impact of AI on healthcare are very complex. Further exploration is needed to fully understand the need for regulation of AI in hearable devices, and to predict the likely broader effects of AI on the healthcare industry.

Participants were asked to reflect on potential developments in the hearing field at two time horizons: 2030 and 2050. 2030 predictions tended to focus on near-term, incremental technological developments, such as automatic real-ear measurement in hearing devices or simpler chatbot-based interactions to support user engagement. In contrast, 2050 predictions were far more speculative, often incorporating emerging or "science fiction-adjacent" technologies. Examples included brain-computer interfaces for hearing support and agentic AI integrated into hearables that interprets speech and facilitates interaction with the surrounding environment. Many participants noted that while near-future developments could be anticipated, imagining technologies in 2050 was inherently challenging. Because of this the two timelines were not analyzed separately.

4.9 Opinion on key opportunities, risks and future research needs

There are several key opportunities for AI-enabled hearables. Emerging hearing technologies present opportunities to move beyond traditional sound amplification toward personalized auditory augmentation. This includes not only improved speech perception in noise and cancellation of unwanted sounds, but also the ability to layer adaptive audio filters over the environment based on individual preferences. Advances such as Auracast and Bluetooth LE Audio may enable seamless access to streamed audio across public spaces, allowing users to connect directly to city infrastructure. This could support improved access to performances, real-time language translation, and personalized transport or public announcements, strengthening users' connection to their surroundings. In the longer term, brain–computer interface (BCI) technologies could fundamentally reshape hearing care by augmenting or replacing the mechanical

and algorithmic processing currently performed by hearing aids. Such approaches may enable new forms of hearing and communication that partially bypass the ear altogether. Hearables may also function as biosensing platforms, utilizing the ear as a site to monitor physiological and behavioral signals, such as movement, heart rate, blood oxygen levels, temperature, stress, mental effort, attention, sleep, fatigue, and broader indicators of physical and cognitive health. The integration of agentic AI could further transform user interaction. Autonomous AI agents embedded in hearables may proactively assist with daily tasks, such as summarizing emails, generating responses, coordinating transportation or food orders, allowing users to interact with digital systems in a more natural and low-effort manner. For audiology specifically, automation may play a greater role, including *in-situ* real-ear measurements, speech testing, and continuous monitoring of hearing and cognitive change. This could support earlier detection of hearing loss or cognitive decline and provide clinicians with richer longitudinal data prior to appointments.

These opportunities are accompanied by significant risks. As hearables increasingly rely on continuous listening and sensing, data privacy and security become critical concerns. The collection of voice, behavioral, and biometric data raises the risk of data compromise, misuse, or unauthorized access. Persistent monitoring also introduces the potential for surveillance, particularly in contexts where data access is poorly regulated or where users live under restrictive political systems. What individuals say or hear could be monitored or repurposed without their consent. Stored voice data may be vulnerable to hacking and misuse, including the creation of deepfakes or exploitation by scammers. In addition, algorithmic bias in AI systems could lead to unequal or harmful outcomes, particularly when analyzing speech patterns or biometric data across diverse populations. Finally, increased reliance on intelligent hearables and AI agents may reshape human behavior and social relationships, potentially fostering overdependence on technology, reducing interpersonal engagement, or reinforcing feedback that negatively affects users' wellbeing.

Future research should include consumer viewpoints, as there is potentially a gap in public awareness regarding the capabilities of hearable devices and their potential societal impact. It is essential to explore consumer views of informed consent and understanding. Further research should focus on deepening the understanding of AI governance in the context of hearables. This includes exploring the ethical, regulatory, and privacy concerns that arise as these devices collect and process biometric data. Such studies will be vital in ensuring that both consumers and regulators are equipped to navigate the challenges posed by AI-enabled hearables, promoting responsible and transparent development of this emerging technology.

5 Conclusion

This study delivered insights from a diverse group of industry leaders across professions on the future capabilities of AI-enabled hearables. The findings reveal a broad range of possibilities for the future of hearables. The most common expectations centered on enhanced sensory augmentation, particularly in hearing-related AI features, and the role of hearables as intuitive voice interfaces to increasingly capable AI agents. Alongside these opportunities, experts also raised concerns about potential risks. If AI assistants become deeply integrated into daily life, their constant presence may lead users to perceive them less as tools and more as entities. Our participants identified governance challenges and the need for consumer input in shaping AI hearable capabilities. While the trajectory of hearable developments is uncertain, the convergence of key technologies suggests they may materialize sooner than anticipated, impacting on audiology and wider society. By beginning conversations about what these devices might be, now, we can better anticipate their impact and ensure they evolve in ways that align with societal needs and expectations.

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 humans were approved by the University of Auckland Health Research Ethics Committee (AH28072). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AS: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. VS: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. GS: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This research was funded by a student research grant to AS from the School of Population Health, The University of Auckland.

Acknowledgments

The authors acknowledge the time and expertise of our expert participants without whom this research would not have been possible.

Conflict of interest

GS is a founder and Chief Scientific Officer of TrueSilence Therapeutics Inc a Digital Therapeutics company.

The remaining author(s) declared that that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The author GS declared that they were an editorial board member of Frontiers at the time of submission. This had no impact on the peer review process and the final decision.

Generative AI statement

The author(s) declared that generative AI was not used in the creation of this manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fauot.2026.1728574/full#supplementary-material

References

Alqudaihi, K. S., Aslam, N., Khan, I. U., Almuhaideb, A. M., Alsunaidi, S. J., Ibrahim, N. M. A. R., et al. (2021). Cough sound detection and diagnosis using artificial intelligence techniques: challenges and opportunities. *IEEE Access* 9, 102327–102344. doi: 10.1109/ACCESS.2021.3097559

AlSamhori, J. F., AlSamhori, A. R. F., Amourah, R. M., AlQadi, Y., Koro, Z. W., Haddad, T. R. A., et al. (2024). Artificial intelligence for hearing loss prevention, diagnosis, and management. *J. Med. Surg. Public Health* 3:100133. doi: 10.1016/j.glmedi.2024.100133

Amankwah-Amoah, J., Khan, Z., Wood, G., and Knight, G. (2021). COVID-19 and digitalization: the great acceleration. *J. Bus. Res.* 136, 602–611. doi: 10.1016/j.jbusres.2021.08.011

Ansari, M. F., Edla, D. R., Dodia, S., and Kuppili, V. (2019). Brain-computer interface for wheelchair control operations: an approach based on fast fourier transform and on-line sequential extreme learning machine. *Clin. Epidemiol. Glob. Health* 7, 274–278. doi: 10.1016/j.cegh.2018.10.007

Attride Stirling, J. (2001). Thematic networks: An analytic tool for qualitative research. *Qual. Res.* 1, 385–405. doi: 10.1177/146879410100100307

Azemi, E., Moin, A., Pragada, A., Lu, J. H.-C., Powell, V. M., Minxha, J., et al. (2023). *Biosignal sensing device using dynamic selection of electrodes (U.S. Patent Application No. US20230225659A1)*. U.S. Patent and Trademark Office.

Barra, F. L., Costa, A., Rodella, G., Semeraro, F., and Carenzo, L. (2024). Shaping the future of simulator interactions: the role of ChatGPT's advanced voice mode. *Resuscitation* 205:110452. doi: 10.1016/j.resuscitation.2024.110452

Batool, A., Zowghi, D., and Bano, M. (2025). AI governance: a systematic literature review. *AI Ethics* 5, 1–15. doi: 10.1007/s43681-024-00653-w

Bonta, R. (2022). *California Consumer Privacy Act (CCPA)*. California Department of Justice. Available online at: https://oag.ca.gov/privacy/ccpa

Brockmeyer, A., Voss, A., Wick, C. C., Durakovic, N., and Valente, M. (2021). Accuracy of an automated hearing aid fitting using real ear measures embedded in a manufacturer fitting software. *J. Am. Acad. Audiol.* 32, 157–163. doi: 10.1055/s-0041-1722947

Bruce, I. C., Armstrong, S., Bosnyak, D. J., and Tawfik, H. (2025). "Opportunities and challenges for Bluetooth LE audio assistive listening systems," in *ICASSP 2025 – IEEE International Conference on Acoustics, Speech and Signal Processing* (IEEE). doi: 10.1109/ICASSP49660.2025.10889430

Burwinkel, J. R., Xu, B., and Crukley, J. (2020). Preliminary examination of the accuracy of a fall detection device embedded into hearing instruments. *J. Am. Acad. Audiol.* 31, 393–403. doi: 10.3766/jaaa.19056

Chen, T., Yang, Y., Qiu, C., Fan, X., Guo, X., Shangguan, L., et al. (2024). "Enabling hands-free voice assistant activation on earphones," in *Proceedings of the 22nd Annual International Conference on Mobile Systems, Applications, and Services (MobiSys 2024)* (ACM). doi: 10.1145/3643832.3661890

Chern, A., and Golub, J. S. (2025). Over-the-counter hearing aid-enabled earbuds-merging hearing health and technology. *JAMA Otolaryngol. Head Neck Surg.* 151, 423–424. doi: 10.1001/jamaoto.2025.0095

Crum, P. (2019). Hearables: here come the: technology tucked inside your ears will augment your daily life. *IEEE Spectr.* 56, 38–43. doi: 10.1109/MSPEC.2019.8701198

De Almeida, P. G. R., Dos Santos, C. D., and Farias, J. S. (2021). Artificial intelligence regulation: a framework for governance. *Ethics Inf. Technol.* 23, 505–525. doi: 10.1007/s10676-021-09593-z

Deep, N. L., Choudhury, B., and Roland Jr, J. T. (2019). Auditory brainstem implantation: an overview. *J. Neurol. Surg. B. Skull Base* 80, 203–208. doi: 10.1055/s-0039-1679891

Frosolini, A., Franz, L., Caragli, V., Genovese, E., de Filippis, C., Marioni, G., et al. (2024). Artificial intelligence in audiology: a scoping review of current applications and future directions. *Sensors* 24:7126. doi: 10.3390/s24227126

Gates, W. H., III. (2023). *AI is About to Completely Change How You Use Computers*. GatesNotes. Available online at: https://www.gatesnotes.com/meet-bill/tech-thinking/reader/ai-agents

Gausen, A., Guo, C., and Luk, W. (2025). An approach to sociotechnical transparency of social media algorithms using agent-based modelling. *AI Ethics* 5, 1827–1845. doi: 10.1007/s43681-024-00527-1

Gordon, E. C., and Seth, A. K. (2024). Ethical considerations for the use of brain-computer interfaces for cognitive enhancement. *PLoS Biol.* 22:e3002899. doi: 10.1371/journal.pbio.3002899

Grewal, D., Guha, A., and Becker, M. (2024). AI is changing the world: for better or for worse? *J. Macromarketing* 44, 870–882. doi: 10.1177/02761467241254450

GSMA Intelligence (2024). *Global Mobile Trends 2024*. GSMA. Available online at: https://www.gsmaintelligence.com/research/global-mobile-trends-2024

Gujar, V. (2024). Data optimization using edge AI: a framework for efficient real-time analytics-A case study of IndoAI AI camera. *Int. J. Sci. Res.* 13, 577–582. doi: 10.21275/SR241006200634

Hunn, N. (2014). *Hearables – the New Wearables*. Nick Hunn Blog. Available online at: https://www.nickhunn.com/hearables-the-new-wearables/

Huyan, J., Ramkissoon, C., Laka, M., and Gaskin, S. (2023). Assessing the usefulness of mobile apps for noise management in occupational health and safety: quantitative measurement and expert elicitation study. *JMIR mHealth uHealth* 11:e46846. doi: 10.2196/46846

Indrakumari, R., Poongodi, T., Suresh, P., and Balamurugan, B. (2020). "The growing role of Internet of Things in healthcare wearables," in *Emergence of Pharmaceutical Industry Growth with Industrial IoT Approach* (Elsevier), 163–194. doi: 10.1016/B978-0-12-819593-2.00006-6

Intersoft Consulting (2018). *General Data Protection Regulation (GDPR)*. Retrieved from: https://gdpr-info.eu/ (Acessed October 2024).

Jean, H., Wallaert, N., Dreumont, A., Creff, G., Godey, B., Paraouty, N., et al. (2025). Automating speech audiometry in quiet and in noise using a deep neural network. *Biology* 14:191. doi: 10.3390/biology14020191

Jin, F. Q., Huang, O., Robler, S. K., Morton, S., Platt, A., Egger, J. R., et al. (2023). A hybrid deep learning approach to identify preventable childhood hearing loss. *Ear Hear.* 44, 1262–1270. doi: 10.1097/AUD.0000000000001380

Kapur, A., Kapur, S., and Maes, P. (2018). "Alterego: a personalized wearable silent speech interface," in *Proceedings of the 23rd International Conference on Intelligent User Interfaces (IUI 2018)* (ACM). doi: 10.1145/3172944.3172977

Kawala-Sterniuk, A., Browarska, N., Al-Bakri, A., Pelc, M., Zygarlicki, J., Sidikova, M., et al. (2021). Summary of over fifty years with brain-computer interfaces-a review. *Brain Sci.* 11:43. doi: 10.3390/brainsci11010043

Khristo, Y. G. D., and Fawzi, S. A. (2025). "Hearing aids and speech intelligibility enhancement," in *Interdisciplinary Studies on Digital Transformation and Innovation: Business, Education, and Medical Approaches* (IGI Global Scientific Publishing), 235–262. doi: 10.4018/979-8-3373-1132-6.ch009

Kim, G-. Y., Yun, H. J., Jo, M., Jo, S., Cho, Y. S., Moon, I. J., et al. (2024). Apple airpods pro as a hearing assistive device in patients with mild to moderate hearing loss. *Yonsei Med. J.* 65:596. doi: 10.3349/ymj.2023.0375

Larsen, B., Li, C., Teeuwen, S., Denti, O., DePerro, J., Raili, E., et al. (2024). *Navigating the AI Frontier: A Primer on the Evolution and Impact of AI Agents*. World Economic Forum. Available online at: https://reports.weforum.org/docs/WEF_Navigating_the_AI_Frontier_2024.pdf

Lee, E., Kim, D., Min, C., and Kang, S. (2020). "Automatic recognition of vocal reactions in music listening using smart earbuds," in *Proceedings of the 18th Conference on Embedded Networked Sensor Systems (SenSys '20)* (Association for Computing Machinery). doi: 10.1145/3384419.3430466

Lehnen, J., Venkatesh, P., Yao, Z., Aziz, A., Nguyen, P. V., Harvey, J., et al. (2025). Real-time seizure detection using behind-the-ear wearable system. *J. Clin. Neurophysiol.* 42, 118–125. doi: 10.1097/WNP.0000000000001076

Lejeune, A., Le Glaz, A., Perron, P.-A., Sebti, J., Baca-Garcia, E., Walter, M., et al. (2022). Artificial intelligence and suicide prevention: a systematic review. *Eur. Psychiatry* 65:e19. doi: 10.1192/j.eurpsy.2022.8

Leuthardt, E. C., Schalk, G., Roland, J., Rouse, A., and Moran, D. W. (2009). Evolution of brain-computer interfaces: going beyond classic motor physiology. *Neurosurg. Focus* 27:E4. doi: 10.3171/2009.4.FOCUS0979

Li, G., Cao, Z., and Li, T. (2023). "Echoattack: Practical inaudible attacks to smart earbuds, in *Proceedings of the 21st Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '23)* (Association for Computing Machinery). doi: 10.1145/3581791.359683

Lieberman, A., Schroeder, J., and Amir, O. (2022). A voice inside my head: the psychological and behavioral consequences of auditory technologies. *Organ. Behav. Hum. Decis. Processes* 170:104133. doi: 10.1016/j.obhdp.2022.104133

Ma, D., Ferlini, A., and Mascolo, C. (2021). "Oesense: Employing occlusion effect for in-ear human sensing," in *Proceedings of the 19th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '21)* (Association for Computing Machinery). doi: 10.1145/3458864.3467680

Mäntymäki, M., Minkkinen, M., Birkstedt, T., and Viljanen, M. (2022). Defining organizational AI governance. *AI Ethics* 2, 603–609. doi: 10.1007/s43681-022-00143-x

Maples, B., Cerit, M., Vishwanath, A., and Pea, R. (2024). Loneliness and suicide mitigation for students using GPT3-enabled chatbots. *npj Mental Health Res.* 3:4. doi: 10.1038/s44184-023-00047-6

Masè, M., Micarelli, A., and Strapazzon, G. (2020). Hearables: new perspectives and pitfalls of in-ear devices for physiological monitoring. A scoping review. *Front. Physiol.* 11, 568886. doi: 10.3389/fphys.2020.568886

Mitchell, P., Lee, S. C., Yoo, P. E., Morokoff, A., Sharma, R. P., Williams, D. L., et al. (2023). Assessment of safety of a fully implanted endovascular brain-computer interface for severe paralysis in 4 patients: the stentrode with thought-controlled digital switch (SWITCH) study. *JAMA Neurol.* 80, 270–278. doi: 10.1001/jamaneurol.2022.4847

Mudry, A., and Mills, M. (2013). The early history of the cochlear implant: a retrospective. *JAMA Otolaryngol. Head Neck Surg.* 139, 446–453. doi: 10.1001/jamaoto.2013.293

Mügge, D. (2024). EU AI sovereignty: for whom, to what end, and to whose benefit? *J. Eur. Public Policy* 31, 2200–2225. doi: 10.1080/13501763.2024.2318475

Murphy, P. (2018). "You feel real to me, Samantha": The matter of technology in Spike Jonze's Her. *Technocult. Online J. Technol. Soc.* 7.

Ne, C. K. H., Muzaffar, J., Amlani, A., and Bance, M. (2021). Hearables, in-ear sensing devices for bio-signal acquisition: a narrative review. *Expert Rev. Med. Devices* 18, 95–128. doi: 10.1080/17434440.2021.2014321

O'Brien, B. C., Harris, I. B., Beckman, T. J., Reed, D. A., and Cook, D. A. (2014). Standards for reporting qualitative research: a synthesis of recommendations. *Acad. Med.* 89, 1245–1251. doi: 10.1097/ACM.0000000000000388

O'Leary, D. E. (2019). GOOGLE'S duplex: pretending to be human. *Intell. Syst. Account. Finance Manag.* 26, 46–53. doi: 10.1002/isaf.1443

Peng, K. A., Lorenz, M. B., Otto, S. R., Brackmann, D. E., and Wilkinson, E. P. (2018). Cochlear implantation and auditory brainstem implantation in neurofibromatosis type 2. *Laryngoscope* 128, 2163–2169. doi: 10.1002/lary.27181

Saha, K., and Chandrasekharan, E. (2023). "Future of workplace conversational AI-driven personal assistants: promises and perils," in *Proceedings of the 15th Annual Meeting of the Forum for Information Retrieval Evaluation* (New York, NY, United States: Association for Computing Machinery). doi: 10.1145/3632754.3632939

Sato, Y., Amesaka, T., Yamamoto, T., Watanabe, H., and Sugiura, Y. (2024). Exploring user-defined gestures as input for hearables and recognizing ear-level gestures with IMUs. *Proc. ACM Hum. Comp. Interact.* 8, 1–23. doi: 10.1145/3676503

Seitz-Paquette, K., Keller, M., Miller, A., Wright, A., Kuehnel, V., Latzel, M., et al. (2024). Leveraging deep neural networks in hearing aids. *Hear. Rev.* 31, 8–15.

Shanahan, M. (2024). Talking about large language models. *Commun. ACM* 67, 68–79. doi: 10.1145/3624724

Shaw, A. (2023). Social media, extremism, and radicalization. *Sci. Adv.* 9:eadk2031. doi: 10.1126/sciadv.adk2031

Sheikh, H., Prins, C., and Schrijvers, E. (2023). *Mission AI: The New System Technology*. Springer Nature. doi: 10.1007/978-3-031-21448-6

Shi, Y., Yang, K., Jiang, T., Zhang, J., and Letaief, K. B. (2020). Communication-efficient edge AI: algorithms and systems. *IEEE Commun. Surv. Tutorials* 22, 2167–2191. doi: 10.1109/COMST.2020.3007787

Singh, T. (2023). "AI-driven surveillance technologies and human rights: balancing security and privacy," in *International Conference on Smart Systems: Innovations in Computing* (Springer Nature). doi: 10.1007/978-981-97-3690-4_53

Sudat, S. E., Wesson, P., Rhoads, K. F., Brown, S., Aboelata, N., Pressman, A. R., et al. (2023). Racial disparities in pulse oximeter device inaccuracy and estimated clinical impact on COVID-19 treatment course. *Am. J. Epidemiol.* 192, 703–713. doi: 10.1093/aje/kwac164

Umashankar, A., Umashankar, A. A., Pachaiappan, C., and Pachaiappan, C. (2021). Applications of artificial intelligence in hearing aids and auditory implants: a short review. *J. Hear. Sci.* 11, 20–23. doi: 10.17430/JHS.2021.11.3.2

Vogel, D., Akhmedjanov, U., Ohm, M., and Meier, M. (2020). "An investigation on the feasibility of the Bluetooth frequency hopping mechanism for use as a covert channel technique," in *Proceedings of the 15th International Conference on Availability, Reliability and Security (ARES '20)* (Association for Computing Machinery). doi: 10.1145/3407023.3409218

Wang, Y., Yang, T., Wang, C., Li, F., Hu, P., Shen, Y., et al. (2024). BudsAuth: toward gesture-wise continuous user authentication through earbuds vibration sensing. *IEEE Internet Things J.* 11, 22007–22020. doi: 10.1109/JIOT.2024.3380811

Xu, X., Shi, H., Yi, X., Liu, W., Yan, Y., Shi, Y., et al. (2020). "EarBuddy: Enabling on-face interaction via wireless earbuds," in *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)* (Association for Computing Machinery). doi: 10.1145/3313831.3376836

Yarici, M., Von Rosenberg, W., Hammour, G., Davies, H., Amadori, P., Ling, N., et al. (2024). Hearables: feasibility of recording cardiac rhythms from single in-ear locations. *Royal Soc. Open Sci.* 11:221620. doi: 10.1098/rsos.221620

Yee, L., Chui, M., Roberts, R., and Xu, S. (2024). *Why Agents are the Next Frontier of Generative AI*. McKinsey Digital. Available online at: https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/why%20agents%20are%20the%20next%20frontier%20of%20generative%20ai/why-agents-are-the-next-frontier-of-generative-ai.pdf