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I think therefore I learn: metacognition is a better predictor of school readiness than executive functions

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Previous research suggests that metacognition (the knowledge and skills related to knowledge acquisition) and executive functions (skills needed to plan and execute goals) are possible predictors of academic performance, including math and reading abilities. This study sought to clarify the relationship between school readiness and these abilities. A visual identification task was used to measure preschool children's metacognitive skills, specifically their ability to monitor their confidence on their answers (explicit) and ability to ask for a clue only when necessary (implicit). Response time to answering was also measured to obtain a non-verbal implicit measure of metacognition. Executive functions were measured using the Flanker and Dimensional Change Card Sorting (DCCS) tasks from the NIH toolbox. It was hypothesized that both metacognition and executive functions would predict school readiness and that implicit metacognitive skills would be more highly related to school readiness than explicit skills. A hierarchical linear regression was run with age and sex as control variables, and with executive function and metacognition (implicit and explicit) as predictors. Results indicated that both implicit and explicit metacognition remained significant predictors of school readiness scores beyond age and sex. In addition, we found correlations between explicit metacognition and executive functions and a relationship between response time and explicit metacognitive skill. Results highlight the importance of early metacognitive abilities beyond other cognitive skills and the importance of being able to effectively use metacognitive strategies from a young age. The implications relating to academic abilities are discussed.

KEYWORDS

school readiness, metacognition, executive functions, cognition, development

1 Introduction

School readiness or preparedness can be defined as the social, cognitive, and emotional skills required to succeed in an academic environment (sometimes grouped under the concept of self-regulation; Blair, 2002; Mashburn and Pianta, 2006; Blair and Raver, 2015) and whether their family and community environment is ready to support them (Williams et al., 2019). Because school readiness is such a broad concept, it is important to define which aspect is being measured in any assessment. The most commonly measured aspect of school readiness is whether children have accumulated the basic knowledge needed to understand what is taught in school (e.g., language, numbers). These types of assessments are routinely used to determine whether younger children are ready to enter either

Kindergarten or Grade 1. It has been argued that such assessments put certain economic or racial minorities at a disadvantage (Bierman et al., 2008; Evans and Schamberg, 2009; Blair et al., 2011; Ursache et al., 2013; Fitzpatrick et al., 2014; Blair and Raver, 2015; Micalizzi et al., 2019). To remediate such discrepancies and close this gap, it may be beneficial to study the skills that knowledge accumulation requires to encourage their development. Indeed, understanding what skills contribute to these individual differences in school readiness scores is essential, as they have been shown to predict academic, social, and behavioral outcomes later in life (La Paro and Pianta, 2000; Lonigan et al., 2000; Lonigan, 2006; McClelland et al., 2006; Duncan et al., 2007; Bernier et al., 2017; Mariano et al., 2019; Williams et al., 2019).

Although the environment has a significant role to play in precocious academic competence, children's cognitive skills can have a significant effect on academic achievement, making them an interesting focus of study (McClelland et al., 2006; Bernier et al., 2017; Mariano et al., 2019). The present study focuses on the main cognitive abilities that have been linked to early school performance: metacognition (e.g., Veenman and Spaans, 2005; Schraw et al., 2006; Schneider, 2015; Freeman et al., 2017) and executive function (e.g., Bierman et al., 2008; Fitzpatrick and Pagani, 2012; Bernier et al., 2020) by comparing their respective contribution to school readiness in a cross-sectional design. This differs from most other studies on this topic as it measures both abilities in a number of ways, which will be detailed below.

Metacognition is the ability to reflect upon personal thoughts, or "thinking about thinking" (Flavell, 1979; Schneider, 2008; Heyes et al., 2020). People display metacognition in their daily lives when they assert confidence in their knowledge or beliefs, or reflect upon their own emotions, for example. Broadly, metacognition can be separated into two distinct skills: metacognitive knowledge and metacognitive skills (Nelson, 1990; Nelson and Narens, 1994; Efklides, 2008; Schneider, 2008). Metacognitive knowledge, or declarative metacognition, encapsulates the knowledge one has about learning strategies and factors that can affect learning. Metacognitive skill, also known as procedural metacognition, includes the ability to monitor ones confidence and apply learning strategies when appropriate (e.g., Flavell, 1979; Nelson, 1990; Schneider, 2008). Metacognitive skills can be measured explicitly ("Are you sure?") or implicitly, by measuring behaviors such as eye-gaze, response time to a decision, or persistence behavior (Roderer and Roebers, 2014; Goupil and Kouider, 2016; Leckey et al., 2020; Resendes et al., 2021). Indeed, to make decisions based on their knowledge, individuals can rely on various cues such as their explicit monitoring skills (e.g., "Am I sure? Am I ready?") or implicit monitoring skills, which amounts to relying on performance cues such as response fluency (Simmons and Nelson, 2006; Thompson, 2010; Geurten and Willems, 2016), or how long it takes for one to answer, and perceptual fluency (Alter et al., 2007), or how easily a problem can be perceived and interpreted. Metacognitive skills can also be measured by assessing how efficiently one puts learning strategies to appropriate use. The latter can be measured by asking individuals if they want to use a particular metacognitive strategy in the context of a learning activity, for example if they want help on a task or not (e.g., Geurten and Bastin, 2019). Some consider this an implicit measure of metacognition, as it does not necessarily rely on individuals' explicit ability to articulate confidence but can instead rely on an implicit 'feeling-of-knowing' (Koriat, 1993, 2007) or even on response fluency cues (Geurten and Willems, 2016) which even toddlers and infants may have access to (e.g., Balcomb and Gerken, 2008; Hembacher and Ghetti, 2013; Lyons and Ghetti, 2013; Goupil and Kouider, 2016).

Together, the metacognitive abilities described above allow individuals to self-regulate by identifying mistakes or errors and selecting and applying strategies to improve their performance (Hembacher and Ghetti, 2013; Destan et al., 2014; Geurten and Bastin, 2019). In summary, much like many cognitive mechanisms, metacognition involves an implicit process in addition to a more deliberate and conscious one (Thompson, 2010; Henrich and Broesch, 2011). Individuals would then be able to weigh both implicit and deliberate metacognitive cues to make decisions (Stanovich, 2009). Studies have reported significant concurrent relationships between metacognitive skills where monitoring one's confidence correctly may allow for more efficient strategy use (Roderer and Roebers, 2014; Roebers and Spiess, 2017; Marulis and Nelson, 2021; Dutemple et al., 2023) but this relationship is inconsistent in young children (e.g., Roebers and Spiess, 2017). Though they might be measuring related constructs, they may therefore be distinct from one another. This strongly suggests that they should be investigated separately in relation to other cognitive skills and outcomes, especially when measuring younger children.

Research on metacognition has a long history (Flavell, 1979; Efklides, 2008) including research about metacognition's role in learning and school achievement (e.g., Sternberg, 1998; Efklides and Misailidi, 2010; Efklides, 2011). Metacognition has been related to better theory of mind (Feurer et al., 2015), better executive function and motivation (Marulis and Nelson, 2021), and better academic success as measured by language or mathematical skills (Duckworth and Seligman, 2005; Veenman and Spaans, 2005; Schraw et al., 2006; Dunlosky and Metcalfe, 2008; Dunlosky and Rawson, 2012; Schneider, 2015; Freeman et al., 2017), among other things. These studies mostly measured metacognitive control, so implicit metacognition, as they noted how well children engaged in strategies that fostered learning (e.g., selecting relevant information to review, planning studying, etc.; Veenman and Spaans, 2005). As far as we know, no one has yet tested the impact of explicit versus implicit metacognitive skills on most of these outcomes in children who have not yet entered grade school. Evidence suggests that it might be a better predictor of learning performance than general measures of intelligence (Veenman and Spaans, 2005), making metacognition an ideal candidate for cognitive skills to work on and improve from a young age. Metacognitive development has also been known to be intertwined with the development of executive function because it relates to regulation and planning (Marulis et al., 2020).

In the educational literature, metacognition has sometimes been referred to as calibration, which refers to a person's sensitivity to their knowledge, as expressed, for example, in better confidence on correct than on incorrect answers (e.g., Hattie, 2013; Roebers and Spiess, 2017). Calibration has been found to be linked to overall educational performance (Duncan et al., 2007; Hadwin and Webster, 2013), reading comprehension (Dabarera et al., 2014), as well as learning disabilities (Klassen, 2002). In infants and toddlers, metacognition impacts from whom children decide to learn, where better metacognition leads to choosing knowledgeable sources over ignorant ones (Kuzyk et al., 2020; Resendes et al., 2021). As Heyes (2020) suggested, the ability to think about our own thoughts may therefore give us insight into other people's competence and expertise, which in turn informs our decision to learn from them. This suggests that early development and nourishment of these abilities may be pivotal to improving quality of life and learning.

Executive functions are typically split into three abilities, namely inhibition (i.e., controlling impulses), shifting (i.e., switching quickly and efficiently between tasks), and working memory (i.e., holding and manipulating information in your mind; also known as updating) (Diamond, 2013; Weintraub et al., 2013). Together, they allow the planning and execution of actions flexibly (Miyake et al., 2000; Zelazo and Carlson, 2012). In children, however, some have found that executive functions cannot be reliably parsed into three separate abilities (Hughes et al., 2009; Wiebe et al., 2011; Diamond, 2013; Willoughby et al., 2016), but can rather be grouped into a single unitary construct which differentiate when the children reach older childhood (Lerner and Lonigan, 2014). Despite this, researchers typically evaluate two or three out of these skills when assessing executive functions in children and average them (e.g., Jacob and Parkinson, 2015). Executive functions are also sometimes referred to as "self-regulation" (not to be confused with the broader model of self-regulation; Efklides, 2008) or "effortful control" (Rothbart and Bates, 2006).

Studies have shown that executive functions are related to several positive outcomes including school achievement (e.g., Blair and Diamond, 2008; Razza and Blair, 2009; Monette et al., 2011; Fitzpatrick et al., 2014; Spiegel et al., 2021), mathematics ability (e.g., Espy et al., 2004; Clark et al., 2010; Bull and Lee, 2014; Fuhs et al., 2014), early reading skills (Kieffer et al., 2013), school readiness (specifically updating and set shifting; Bierman et al., 2008; Vitiello et al., 2011; Fitzpatrick and Pagani, 2012; Bernier et al., 2020), effortful control (Blair and Razza, 2007), theory of mind (Sabbagh et al., 2006; Hughes and Ensor, 2007; Carlson et al., 2015; Brock et al., 2019), and better metacognitive abilities (Bryce et al., 2015; Roebers, 2017). Some have also suggested that school readiness may in turn promote better executive functioning (Bierman et al., 2008).

The relationship between executive functions and metacognition has been a topic of recent discussion because of the similarities noted between the two abilities (Roebers, 2017; Filippi et al., 2020; Marulis et al., 2020). Indeed, both contribute to a child's ability to self-regulate (Efklides, 2008; Lyons and Zelazo, 2011) and behave in a goal-directed manner, however one is thought of as slower and more deliberate (metacognition) and other more automatic (executive functions). Self-regulation as a broader concept, which has also been known to relate to other factors such as a child's temperament (Chae, 2022), has also been linked to higher school achievement (Blair and Razza, 2007; Pianta et al., 2017; Weimer et al., 2021). In her framework, Roebers (2017) argued that executive functions lay the groundwork for metacognitive abilities; indeed, inhibition may explicitly contribute to metacognitive monitoring, as it allows an individual to pause and reflect on their answer (Bryce et al., 2015), and shifting and updating may be needed to keep in mind the goal of the task and decide, based on what was monitored, whether any control strategies need to be implemented to improve performance. Executive function and metacognition would therefore be highly correlated until children begin attending school, during which time the more deliberative type 2 metacognitive skills become more dependent on feedback from one's environment to improve those skills. In sum, the two cognitive abilities are closely related but grow apart as children begin attending school, which is why assessing their separate contributions to school readiness and performance is essential.

Given the state of the literature, the main goal of the present study is to elucidate with greater specificity the relationship between different subcomponents of metacognition and executive function, and how they differentially contribute to school readiness as measured by children's early arithmetic and language skills using a cross-sectional design. Specifically, it examined whether executive function and metacognition (monitoring, control, and implicitly measured) are longitudinally related to school readiness. School readiness was measured with the Lollipop Test (Chew and Morris, 1984, 1987). The metacognition task consisted of a perceptual discrimination task in which children had to recognize blurry pictures (Geurten and Bastin, 2019) thanks to which we could measure metacognitive monitoring and control in addition to an indirect measure of metacognition. Finally, executive functions (inhibition and shifting) were measured using child-appropriate versions of the Flanker task and of the Dimensional Change Card Sorting Task from the NIH toolbox (Weintraub et al., 2013). Three hypotheses were tested: (1) executive functions and metacognition will be related, (2) executive functions and metacognition will predict school readiness, and (3) metacognition will predict school readiness beyond executive functions. Given previous studies, implicit forms of metacognition, especially control, were expected to be more related to school readiness than implicit metacognition. Other than this, the link between implicit metacognition and school readiness has not been explored, therefore there is no specific hypothesis to be outlined. Together, these results aimed to shed light on the mechanisms that help children become self-sufficient, confident, and successful learners.

2 Methods

2.1 Participants

Participants lived in a large Canadian city and were recruited from a laboratory's database of past participants and through recruitment on social media. Informed consent was obtained before testing. An a priori statistical analysis for a linear regression using G*Power 3.1.9.7 suggested a sample size of 129 (six predictors, four tested predictors, power = 0.95, α = 0.05). We tested 136 participants but had to exclude 6 due to undisclosed developmental delays ($N = 5$) or excessive distractiveness ($N = 1$) leaving a final sample of 130 (Mage = 68.6, SD = 4.12; 63 males). Eighty-three participants were tested in English and 47 in French. Multilingual children were allowed to answer in whichever language they felt most comfortable in. No significant difference was found on any of the reported variables based on language of testing or language status (monolingual vs. multilingual) so these variables were ignored in the main analyses. The median income of the families was between 100,000 and 150,000 CAD per year, making our sample upper middle class. Families primarily identified their children as Caucasian (57%), however 21% identified as Asian, 6% as Latin/Central/South American, 8% as African, 5% as Caribbean, and 4% Middle Eastern. Participants were allowed to choose up to 3 ethnicities with which they identified.

2.2 Measures

2.2.1 School readiness

School readiness was measured using the Lollipop test (Chew and Morris, 1984, 1987). It assesses four aspects of school readiness, specifically children's knowledge of colors and shapes, letters, numbers, and spatial recognition. Each of these four subscales is separately scored, and the total test is scored on 69. This test has good convergent validity with other school readiness tools (Chew and Morris, 1984) and been shown to predict academic achievement in both English and French (Chew and Morris, 1989; Chew and Lang, 1990; Venet et al., 2003; Boivin et al., 2014), lending credence to its validity as a tool to measure school ability. The French translation was also found to have good internal consistency ($\alpha = 0.89$), test-retest reliability (Venet et al., 2003), and was found to be the variable most related to various academic achievement measurements (Hammes et al., 2016).

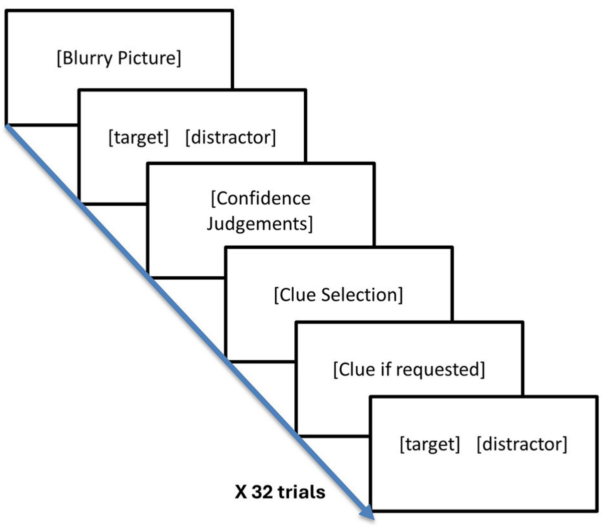

FIGURE 1
Schematic of the metacognition task.

2.2.2 Metacognition

We adapted the visual discrimination task from Geurten and Bastin (2019) and translated the procedure into French (Dutemple et al., 2023). A visual representation of the task can be found in Figure 1. The task was run on PsychoPy (version 2022.2.2). Children first practiced the task on three trials, after which they were given test trials and standardized metacognitive feedback (see Table 1). This also allowed the experimenter to explain to the child what a clue was if they did not know (i.e., "a clue is something that can help you decide which picture looked the most like the blurry picture.") If the child still did not understand they were given additional support (e.g., "the clue was a candle! Which picture is like the candle? Yes, because the light bulb makes light!") We also used the synonym "hint" if they preferred and understood that word. They were not given any feedback during the 32 following test trials.

Children were seated at a table roughly 60 cm (arm's length) from the computer screen. They were then shown blurry pictures which appeared on the screen for 1 s. Two clear but similar pictures appeared on the screen. The experimenter asked the children "which of the two pictures looks the most like the blurry picture you just saw?" Their time to answer was automatically recorded by Python to get an indication of their answer fluency. After their selection came the metacognitive monitoring trial. Two drawings of a boy appeared on the screen (e.g., Lyons and Ghetti, 2013; Geurten and Bastin, 2019). They were asked whether they were "very sure" or "not sure at all" about their answer, like the boy on the right or the boy on the left. Next, we tested their metacognitive control by assessing if they could appropriately apply the strategy of asking for help. The image of a gift with a question mark appeared on the screen with the words "yes" and "no". They were given the option to ask for a clue (or a "hint" if they preferred that word) if they believed they made a mistake. The hints were semantically or visually related to the blurry pictures (e.g., grass as a hint for a flower) thus pointing the child toward the correct answer. Finally, they were offered the opportunity to change their initial answer. In total, therefore, three measures of

TABLE 1 Metacognition task feedback according to children's answers.

	Correct	Incorrect
Confidence	You selected the correct picture and that's great because you told me you were really sure of your answer.	You selected the wrong picture, but you told me you were really sure of your answer. Here, maybe you were not so sure of your answer.
Not confident	You selected the correct picture, but you told me that you were not sure of your answer. Here, maybe you were really sure of your answer.	You selected the wrong picture but that's okay because you told me you were not sure of your answer.
Selected a clue	You selected the correct picture, but you asked for a clue. Maybe here, you did not need a clue.	You selected the wrong picture, but that's okay because you asked me for a clue to help you.
Did not select a clue	You selected the correct picture and what's great is that you didn't ask me for a clue because you didn't need help.	You selected the wrong picture, but you didn't ask me for a clue to help choose. Here, you could have asked me for help.

metacognition were recorded: (1) implicit metacognition (response fluency), (2) confidence monitoring, (3) metacognitive control (clue selection/help seeking).

The difficulty of the trials varied according to the child's ability, where more correct responses incurred more difficult trials, and more incorrect trials incurred easier trials. Specifically, there were three levels of difficulty. All children started with "medium" difficulty pictures as defined in the original study. If the child answered two out of three visual discrimination trials correctly, they were given more difficult pictures ("Hard" pictures). If they did not answer at least two out of three correctly, they were given easier pictures ("Easy" pictures). This was repeated throughout the whole task, where children moved between categories as they made mistakes. This served two purposes. For one, it was to ensure that every child would provide both correct and incorrect trials to compare their confidence. In addition, it allowed to more confidently assert that children's individual visual discrimination skills were considered, and that each participant was exercising a similar amount of effort. The only significant changes made between this iteration and the original task were to (1) omit one version of the task where children were exposed to the clue selection before the confidence selection and (2) to reduce the number of practice trials from 6 to 3. This was done to first ensure children would see the clue as soon as they requested it rather than doing their confidence judgement before the clue was revealed to them, and second to cut the time this task would take. Indeed, pilot testing suggested 6 trials were not necessary to understand the task (the original researchers used this task on a younger population and therefore were justified in a longer practice) and shortening testing time increased engagement throughout. In addition, Geurten and Bastin (2019) did not report any order effects, suggesting this deviation would not have major effects on performance.

2.2.3 Executive function

2.2.3.1 Shifting

The NIH toolbox (Weintraub et al., 2013) Dimensional Change Card Sorting Task (DCCS) for 4–7-year-olds was administered. The children were seated approximately 8 inches away from an iPad, which was set up at an angle on the table. During the task, participants were shown pictures of balls or trucks that were yellow or blue. They had to classify them according to shape or color on randomly alternating trials. Children were required to pass 3 out of 4 practice trials before beginning the test trials. The first test block required children to pass 4 out of 5 trials for both the color and shape trials, which were kept apart. The second block was mixed (30 trials), meaning children had to actively alternate between sorting pictures according to color or shape. The children were given raw scores, computed scores, and standard scores, as calculated by the NIH toolbox. Raw scores indicate how many trials were correctly answered by the participant. Computed scores calculate two vectors, one for accuracy and one for speed, both scored on five and then combined, resulting in scores out of 10. Finally, standard scores compare the children's computed scores to a normed sample of scores from other children (see Zelazo et al., 2013 for the mathematical equations used to determine the computed scores).

2.2.3.2 Inhibition

The NIH toolbox (Weintraub et al., 2013) Flanker task for 4–7-year-olds was administered. The set up was identical to that of the DCCS described above. The children first experienced sixteen trials with a row of fish, where the middle fish sometimes pointed in the same or different direction than the fish around it. The children were told that to feed the fish, they had to select the button with the arrow that pointed in the same direction as the middle fish was swimming. The children were given 4 practice trials, three of which had to be correct before moving on to the first block of 20 test trials. To proceed to the second block, children had to commit fewer than two mistakes. The second block of 20 trials replaced the fish with arrows. Once again, children received three scores as described above (raw, computed, and standard).

2.3 Procedure

Parents were seated in the testing room and filled out the demographic sheet while their children participated. The tasks were administered as part of a larger battery of tasks. There were eight possible orders in which the children could complete the tasks. Between 14 and 18 participants completed each counterbalance order. Each task was set up on a different table to allow the child small breaks between the games. The two executive function tasks on the iPad were always split up to ensure children did not need to sit at the same table for more than 15 min. Observation of the children during piloting confirmed that the iPad tasks were the least engaging and therefore not ideal to encourage participation and engagement early in the session, therefore none of the counterbalanced orders began with them. The original design also included the NIH working memory task, however piloting revealed that this task was too difficult for the children to grasp and therefore was dropped. This also had the benefit of keeping the length of the sessions to an hour, which was deemed a reasonable length of testing for children that age. To ensure that no notable order effects were present, we ran t-tests between the groups that were administered each task either early or late (i.e., we assessed whether those who completed the Lollipop early or late showed a difference in their scores, etc.) Between those who were administered the metacognition task early or late in the assessment, there was no difference between their accuracy on the task [$t_{(125)} = -1.54$, $p = 0.126$, $d = -0.27$], their confidence judgements according to their accuracy [$t_{(126)} = 1.15$, $p = 0.126$, $d = 0.20$], their clue selection according to their accuracy [$t_{(125)} = 1.24$, $p = 0.218$, d $= 0.22$], or their response latency according to their accuracy [$t_{(119)} = 0.55$, $p = 0.583$, $d = 0.10$]. Finally, between those who were administered one executive function task before the other, there was no difference between the two groups [$t_{(128)} = 0.83$, $p = 0.41$, $d = 0.15$]. None were therefore significant.

3 Results

Univariate statistical outliers (± 3 standard deviations from the mean) were determined per measure and excluded. Two participants did not complete the metacognition task and one participant's data was partially lost due to a computer malfunction

($N = 127$). Two outliers were identified for the school readiness task (> 44.46, $N = 128$), no outliers were identified for the executive function tasks, one outlier was identified on the clue selection measure of the metacognition task (> 39.06, $N = 126$), and seven were identified for the response time measure (>1.7, $N = 120$).

3.1 Chance analyses

First, it was important to determine whether the metacognitive and school readiness tasks were too difficult for the sample. Chance analyses were therefore run. Overall, participants performed above chance on the visual discrimination task {M =0.63, SD =0.11, $t_{(126)} = 13.36$, p <0.001, 95%CI [0.11-0.15], d = 1.19}. For the metacognitive component of the task, chance analyses were performed according to the proportion of correct and incorrect trials (see Table 2). Difference scores were calculated to obtain a measure of calibration. Confidence on incorrect trials was subtracted from confidence on correct trials; clue selection on correct trials was subtracted from clue selection on incorrect trials; and response time on correct trials was subtracted from response time on incorrect trials. Positive scores are indicative of better metacognition. Participants performed above chance on all three difference score measures (see Table 2), suggesting they could differentiate between correct and incorrect trials based on both explicit and implicit metacognitive measures. Children also performed above chance on the school readiness task [$M = 61.12$, $SD = 4.62$, $N = 128$, $t_{(127)} = 65.2$, $p < 0.001$, $d = 5.76$].

3.2 Task-specific results

To determine the extent to which there were significant differences between children's answers on accurate and inaccurate trials, a series of within-subjects repeated measures one-way ANOVAs were run (accuracy: correct and incorrect) on confidence judgements (metacognitive monitoring), clue selection (metacognitive control), and response time (implicit measure of metacognitive monitoring). Children were more confident on correct than on incorrect trials [$F_{(1,127)} = 24.8$, p <0.001, η^2 =0.01]. Children chose a clue more often on incorrect trials than on correct trials [$F_{(1,127)} = 26.62$, p <0.001, η^2 =0.01] and children were slower on incorrect trials than on correct trials [$F_{(1,122)} = 47.70$, p <0.001, η^2 =0.07].

Performance on the executive function tasks is reported in Table 3. The NIH toolbox provides three scores, and reported in the table below are the computed scores and the standard scores (mean of 100 and standard deviation of 15) comparing the children's performance to that of their same-aged peers. The latter are derived from the computed scores, which take into consideration both the child's performance (scored on 5) and the speed at which they answered (scored on 5) when they performed above a certain threshold (see Zelazo et al., 2013 for more details on the scoring procedure).

3.3 Intertask correlations

Performance on all tasks of interest is included in the following correlation matrix to determine whether they were related in this sample (see Table 4, Figure 2). Bivariate Pearson correlations were run with missing data removed pairwise. School readiness was positively correlated with both explicit ($r_{(124)} = 0.248$, $p = 0.005$) and implicit ($r_{(123)} = 0.222$, $p = 0.013$) metacognition as measured by confidence judgements and clue selection, respectively. Explicit and implicit metacognition were also significantly related to one another ($r_{(125)} = 0.426$, $p < 0.001$). Executive function was significantly correlated with explicit metacognition ($r_{(126)} = 0.239$, $p = 0.006$). This remained true if the average computed scores or the averaged standard scores were used (the standard scores are reported here). Finally, implicit metacognition as measured by response time was related to explicit metacognition ($r_{(119)}$ =0.215, p =0.018). All correlations remained significant after correction for pairwise comparisons with False Discovery Rate analyses (Benjamini and Hochberg, 1995).

3.4 Regression analyses

Multivariate outliers were identified and removed. They were defined as those who had Cook's distances above 4/n (4 divided by our sample size, or 0.032). The final sample for the regression was 118, accounting for 125 participants without any missing data (Mage = 68.69) and 7 multivariate outliers (Mage = 66.86). The two groups are not different in age {$t_{(123)} = 1.14$, p =0.129, d =0.44, 95%CI [−1.35; 5.01]}. All assumptions were then verified and met. Specifically, visual inspection of the residuals confirmed multivariate linearity and homoscedasticity; no collinearity was detected as measured by tolerance values (0.882–0.995 >0.1) and VIF statistic (1.01–1.26 < 5); and autocorrelation was not present as measured by a Durbin-Watson test (1.5 < 2.05 < 2.5).

Following the removal of the multivariate outliers, a hierarchical regression with age and sex as baseline demographic factors was performed. The models were run based on the initial prediction that both executive function and metacognition would contribute to school readiness scores. Model 1 with demographic factors only accounted for 9% of the variance in school readiness scores. Model 2 with executive functions predicted an identical 9% of the variance. Model 3 with all predictors included explained 19% of the variance in school readiness scores (see Table 5). Age remained significantly predictive of school readiness ($B = 0.24$, $\beta = 0.25$, $p = 0.006$). Implicit metacognition remained significant beyond age ($B = 6.01$, $\beta = 0.20$, $p = 0.037$; see Table 6 for model details) as did explicit metacognition ($B = 6.31$, $\beta = 0.19$, $p = 0.047$) though that latter was only marginally significant.

4 Discussion

This study sought to investigate the cognitive predictors of school readiness. Findings suggest significant relationships between implicit and explicit metacognition and school readiness but no such link between school readiness and executive functions. This relationship mostly holds in a hierarchical regression which included age and sex as demographic factors, suggesting metacognition is an important contributor to school readiness. Metacognitive monitoring and control were significantly correlated, and aspects of executive functioning (inhibition and shifting) were related to metacognitive monitoring. Metacognitive monitoring was also related to our implicit metacognitive measure,

TABLE 2 Chance analyses for the metacognition task.

	Confidence (monitoring)		Clue selection (control)		Confidence difference score	Clue difference score	Response time difference score (implicit)
	Incorrect	Correct	Incorrect	Correct			
M	0.74	0.80	0.45	0.39	0.06	0.06	0.63
SD	0.29	0.24	0.37	0.35	0.13	0.13	0.99
N	128	128	128	128	128	127	121
t	9.58	13.83	−1.41	−3.62	4.98	5.16	7.03
df	127	127	127	127	127	126	120
p	<0.001	<0.001	0.08	<0.001	<0.001	<0.001	<0.001
Cohen's d	0.85	1.22	−0.13	−0.32	0.44	0.46	0.64
95% CI	0.19–0.29	0.26–0.34	−0.11–0.02	−0.17–−0.05	0.03–0.08	0.04–0.08	0.45–0.81

Chance was operationalized as 0.5 for the Correct and Incorrect trials and at 0 for the difference scores.

TABLE 3 Descriptive statistics for the executive function tasks.

	Flanker computed	DCCS computed	Executive function mean computed	Flanker standard	DCCS standard	Executive function mean standard
N	130	128	130	130	128	130
M	5.76	4.29	5.03	74.38	69.92	72.14
SD	1.47	2.36	1.52	14.88	20.69	14.10

TABLE 4 Intertask bivariate correlations.

		1	2	3	4	5
1. School readiness	*r*	1	-	-	-	-
	N	128				
2. Executive function	*r*	0.06	1	-	-	-
	N	128	130			
3. Confidence judgements (explicit)	*r*	**0.25***	**0.24***	1	-	-
	N	126	128	128		
4. Clue selection (implicit)	*r*	**0.22***	0.14	**0.43***	1	-
	N	125	127	127	127	
5. Response time (implicit)	*r*	0.10	0.14	**0.22***	0.13	1
	N	119	121	121	120	121

Results that remain significant following the false discovery rate are in bold. *$p < 0.05$.

suggesting 5-year-old children may be able to use processing fluency as a metacognitive cue.

Previous research had shown that metacognition plays an important role in academic achievement and learning, but no study had yet studied how early this link can be observed with a school readiness measure. Another innovative feature of the current study was to investigate this link with a preschool population with explicit and implicit measures of metacognition. Indeed, our children demonstrated that despite the fact that they were somewhat overconfident (as expected in this population; see Lipowski et al., 2013), the more they were able to discriminate between their correct and incorrect answer by asking for help only, when necessary, the better they performed on the school readiness task. This strongly suggests that being able to act upon personal thoughts and knowledge scaffolds early academic development and interest in gaining knowledge. Indeed, some have suggested that metacognition fuels curiosity, or the desire to learn, which implies being able to discern what one knows or does not know (Goupil and Proust, 2023). Curiosity can also be thought of as some sort of implicit metacognitive process as it does not rely on people directly reflecting about their knowledge but asking for information. This may also be related to children's positive approaches to learning (i.e., children's motivation, persistence, and initiative toward learning; Kagan et al., 1995) which have been

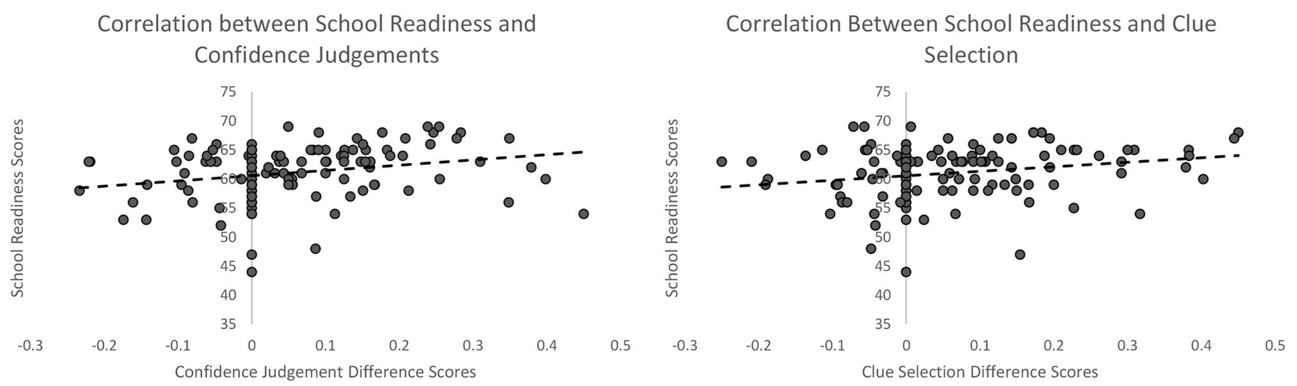

FIGURE 2
Correlations between school readiness and metacognition variables.

TABLE 5 Hierarchical model summary with school readiness as dependent variable.

Model	R	R^2	Adjusted R^2	Std. error of the estimate
1	0.30[a]	0.09	0.08	3.76
2	0.30[b]	0.09	0.07	3.77
3	0.44[c]	0.19	0.16	3.59

[a]Model with sex and age; [b]model with sex, age, and executive functions c. model with sex, age, executive functions, explicit metacognition, implicit metacognition.

TABLE 6 Hierarchical model summary by predictor.

Model		Unstandardized coefficients		Standardized coefficients	t	Sig.
		B	Std. Error	β		
1	(Constant)	41.82	5.88		7.11	<0.001
	Age (months)	**0.29**	**0.09**	**0.30**	**3.37**	**0.001**
	Sex	−0.36	0.69	−0.05	−0.52	0.602
2	(Constant)	41.86	5.91		7.08	<0.001
	Age (months)	**0.29**	**0.09**	**0.31**	**3.29**	**0.001**
	Sex	−0.38	0.70	−0.05	−0.54	0.591
	EF Average	−0.00	0.03	−0.02	−0.19	0.847
3	(Constant)	46.00	5.74		8.02	<0.001
	Age (months)	**0.24**	**0.09**	**0.25**	**2.80**	**0.006**
	Sex	−0.62	0.67	−0.08	−0.92	0.358
	EF average	−0.02	0.03	−0.08	−0.88	0.379
	Confidence judgements	**6.31**	**3.15**	**0.19**	**2.00**	**0.047**
	Clue selection	**6.01**	**2.85**	**0.20**	**2.11**	**0.037**

Significant predictors are bolded.

found to positively predict school readiness (McClelland et al., 2000; Fantuzzo et al., 2004; McWayne et al., 2004). An awareness of what one knows and does not know would therefore encourage aspiring students to seek out and remember new information. It also implies a motivational component or an assumption that the children desire to seek out unknown information, which was not controlled for in this study. An interesting future direction may be to follow a longitudinal sample further into their academic progress and investigate whether this relationship strengthens or disappears with time (e.g., Roebers et al., 2012; Tibken et al., 2022) and how motivation may play a role.

Because the Lollipop did not provide a large variability in scores, it limited our ability to detect a relationship between the skills. Another option as a measure of school readiness would have been the Bracken School Readiness Assessment (Bracken, 1998, 2002; Panter and Bracken, 2009), as it includes 88 items, some of which may have been a little more difficult, thus providing even more variability in scores. It is important to note that these school readiness tasks were designed to identify individuals with difficulties rather than those who have none, meaning high scores on these tasks with a typically developing population is to be expected.

Moreover, we were able to look at the relationship between the different potential predictors of school readiness. We found that metacognitive monitoring and control measured verbally were related and that response fluency (also an index of implicit metacognition), which replicates previous research by demonstrating an even earlier link between verbal monitoring and control skills than previously recorded (e.g., Roebers and Spiess, 2017). This is consistent with results showing that children seek out more information when not confident (Call and Carpenter, 2001) or opt-out of answering when they believe they cannot answer (Balcomb and Gerken, 2008; Bernard et al., 2015), meaning children after age 5 may be able to use their lack of knowledge to guide whether they seek help to obtain information (Hembacher and Ghetti, 2013; Destan et al., 2014; Coughlin et al., 2015; Destan and Roebers, 2015; Goupil and Kouider, 2019; Lapidow et al., 2022). Although other studies have shown children's limited ability to use certain cues such as retrieval fluency to guide their metacognitive monitoring (e.g., Koriat and Ackerman, 2010), the results from this study extend the current research in this area by showing that children may be able to use answering time implicitly to guide monitoring, but maybe not control. In addition, the monitoring metacognition component was correlated with the executive function measure, replicating previous work drawing a link between these abilities (Garner, 2009; Bryce et al., 2015; Spiess et al., 2016; Roebers, 2017). Surprisingly however, it was metacognitive monitoring that was most strongly related to executive function, in conflict with prior research suggesting that metacognitive control was most dependent on skills such as inhibition and shifting (e.g., Bryce et al., 2015; Spiess et al., 2016; Roebers, 2017). It is possible that monitoring in the context of the visual discrimination task required children to inhibit their initial impulse to answer to reflect more on their accuracy. Furthermore, shifting skills may have allowed them to evaluate each image on its own merit rather than automatically declare themselves confident. This relationship is worth investigating in more detail and is a rich area for future work.

This study has many strengths. Adequate statistical power was obtained by testing a large sample size; therefore, results can be confidently interpreted. Next, the impact of metacognition was thoroughly investigated by including explicit and implicit measures of metacognition. To our knowledge, this is the first study to parse metacognition's impact on school readiness this way. In addition, the measurement of executive functions alongside metacognition provides a comprehensive picture of the possible cognitive influences on school readiness. This study is amongst the first to measure these relationships in preschoolers and to directly compare the relative importance of these skills for school readiness. Indeed, these results will hopefully lead developmental psychologists to encourage parents and educators to engage in interactive activities developing metacognition, as the latter has been found to be a trainable skill (De Jager et al., 2005; Michalsky et al., 2009) to set their preschoolers on a path of success in the academic realm. Interestingly however, recent studies have shown that feedback from teachers may not be enough to train metacognitive skills in school-aged children (Buehler et al., 2023) which may further suggest that environmental and motivational factors may be at play in the development of metacognition. Metacognition may operate in a similar way to executive function; Zelazo (2015) indeed makes a distinction between "cold" and "hot" executive functions, the latter being more influenced by an individual's emotional or motivational state during the task (e.g., the marshmallow task; Munakata and Michaelson, 2021). Instead of training metacognition alone, perhaps self-regulation skills (Efklides, 2008) need to be trained in tandem to result in long-term benefits. Future studies may want to further explore the longitudinal relationship between these skills in the context of a training study and extend the findings to other outcomes; for instance, does the training indeed have an impact on metacognitive skills that translates onto school readiness? In addition, because children in lower SES are more likely to have lower school readiness scores, speculating about how this training may be implemented at the community or preschool levels would be essential (e.g., Roberts, 2011; Weiland and Yoshikawa, 2013; Blair and Raver, 2015; Bierman et al., 2020; Joo et al., 2020; Shaw et al., 2021).

Despite our best efforts, this study also has limitations. For one, the scores on the Lollipop test were generally high and somewhat limited in variability. This was surprising, as Venet et al. (2003) used this task in a similar age group (Mean age of 67 months) and had obtained a lower average score of 47.4/69. This task was chosen because it is available in both French and English and has been validated in both languages. The marked difference in scores may be because we were measuring school readiness in a higher SES sample (e.g., Geoffroy et al., 2010). As discussed above, parents from higher SES tend to foster more learning in their young children, perhaps setting them up for better success on these types of school readiness tasks. For the reasons outlined above.

Next, a complete battery of executive function measures generally includes updating, or working memory, as an important component; however, it was not included here as pilot testing suggested the working memory task available was too difficult for children to complete. Future research may wish to consider simpler tasks to measure working memory in preschoolers even if executive functions at that age are not entirely differentiated (Miyake et al., 2000; Jurado and Rosselli, 2007; Garon et al., 2008; Miller et al., 2012; Brydges et al., 2014; Willoughby et al., 2016). In addition, though some have found associations between executive functions and academic performance, the causality of this relationship is less certain, suggesting a link between the two skills need not always be apparent (Jacob and Parkinson, 2015). Finally, the academic performance task was a school readiness task rather than the reading- or mathematic-only tasks reported in other studies, suggesting EF may be important for specific subcomponents of academics rather than overall readiness to learn and participate in school.

Finally, as discussed previously, school readiness is a broad concept that includes more than the basic knowledge children have acquired. Future studies may want to include other factors that some have included in their definitions of school readiness, such as measures of social adjustment, or even measures related to the school or parenting environments, to extend our understanding of which factors are found to be reliably linked to school readiness and later school performance (e.g., McCallan, 2010; Denham et al., 2012; Flook et al., 2015; Darling-Hammond et al., 2020; Joo et al., 2020). Indeed, this would allow researchers to answer interesting questions related to the cognitive correlates of school readiness; does better metacognition compensate for certain environmental deficiencies? Do executive functions play a bigger role in gaining social skills and integrating inside the classroom? Further research on the longitudinal correlates of metacognition (e.g., does it lead to better academic and social success? Is it associated with better health?) may cement metacognition itself as a component of school readiness as a "readiness to learn" and something to be more explicitly encouraged in classrooms from a young age. Furthermore, future studies may want to explore the growth of metacognitive knowledge in parallel with metacognitive skills in the context of school readiness.

In conclusion, school readiness is related to metacognitive control beyond the effects of age. Explicit metacognition was correlated with executive functions and implicit metacognition as measured by asking for clues and reaction time. Finally, executive functions were not related to school readiness in this population. This study aimed to clarify the link between these cognitive skills and school readiness with the hope to better understand which skills are best to nourish early in preschool.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://osf.io/7v5gs/.

Ethics statement

The studies involving humans were approved by Institutional Review Board at Concordia University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

ED: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. CB: Formal analysis, Investigation, Writing – original draft. DP-D: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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