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The Developmental Path of Metacognition From Toddlerhood to Early Childhood and Its Influence on Later Memory Performance

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Recently, several studies have suggested that metacognition emerges early in infancy and toddlerhood. However, to date, the developmental trajectory of these early metacognitive monitoring and control processes and their influence on children's later memory functioning remains poorly understood. The aim of this study was to longitudinally document the development of metacognition between the ages of 2.5 and 4.5 years and to examine the link between these early metacognitive skills and later memory performance. To do so, 69 children initially aged 29–33 months old ($N_{T0} = 69$; 32 females; $M_{age} = 32.3$ months; $SD = 1.6$) were tested at three time points (12-month intervals) with a recognition memory paradigm designed to assess both metacognitive monitoring, through retrospective confidence judgment, and metacognitive control, through a cue selection task (i.e., children had the opportunity to ask for a cue to help them change their memory decision). In addition, at the last session, an episodic memory task (story recall) was also administered. Our results revealed an improvement in monitoring and control processes between 2.5 and 4.5 years with above-chance performance from around age 3.5. Mixed-effects modeling also indicated that metacognitive monitoring at ages 2.5 and 4.5, but not—unexpectedly—metacognitive control, was related to children's memory performance at age 4.5. Overall, our results provide evidence to enhance our understanding of the developmental course of metacognition from toddlerhood to early childhood and suggest that metacognitive processes are involved in memory performance much earlier than had previously been shown.

Public Significance Statement
Metacognition is a key factor for successful learning. Here, by studying how early metacognitive skills improve in toddlers and young children, we found evidence suggesting that early metacognitive skills could be related to children's memory functioning up to two years later. Such results suggest that early metacognition could be linked to children's later cognitive development.

Keywords: metacognition, memory, longitudinal design, cognitive development

Metacognition—defined as the process whereby people monitor and regulate their cognitive performance—is composed of two distinct and interactive processes: (a) metacognitive monitoring (i.e., processes allowing a person to judge the quality of their cognitive operations); and (b) metacognitive control (i.e., processes involved in the strategic regulation of cognitive activity). Over the past few decades, metacognition has been shown to be a key factor in learning and cognitive performance (see Roebers, 2013, for an overview). Regarding its developmental course, several studies have recently revealed that even preverbal infants can access their internal states to regulate their cognitive decisions albeit not explicitly (e.g., Balcomb & Gerken, 2008; Geurten & Bastin, 2019; Goupil et al., 2016). To date, however, the question of how these early metacognitive abilities develop during the transition from toddlerhood to early childhood and whether these skills might influence cognitive performance in the same way as more mature metacognitive abilities affect performance later in childhood remains poorly understood.

Although the importance of metacognition has been established in a wide variety of cognitive domains (e.g., Carr et al., 1994; Tibken et al., 2022), the field where its influence has been best documented is probably memory. Results of past studies conducted in the memory domain usually show that metacognition is involved in children's

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Marion Gardier served as lead for formal analysis, investigation, visualization, and writing–original draft. Marie Geurten served as lead for conceptualization, funding acquisition, methodology, resources, and supervision. Marion Gardier and Marie Geurten contributed equally to writing–review and editing.
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memory functioning (e.g., Fandakova et al., 2018; Geurten, Lejeune & Meulemans, 2015; Koriat et al., 2009). For instance, Koriat et al. (2009) found that, when studying a list of related and unrelated paired associates, school-aged children were able to strategically allocate their study time to the more difficult items (i.e., more time spent on unrelated than related pairs) to improve their memory performance.

Until recently, studies examining the development of metacognition mainly suggested that metacognition emerges and exerts an influence on memory functioning only at a relatively late stage of child development (i.e., at around age 6; see Flavell et al., 1970; Ghetti et al., 2002, 2013). Over the last decade, however, studies have shown that children are able to access (e.g., Destan et al., 2014; Hembacher & Ghetti, 2014) and act upon their internal operations at an extremely young age (e.g., Balcomb & Gerken, 2008; Geurten & Bastin, 2019; Goupil & Kouider, 2016), provided that the paradigm used is appropriate. Specifically, regarding monitoring processes, when children aged between 3 and 5 are asked to perform a retrospective confidence judgment (RCJ) using a pictorial paradigm (i.e., pointing to a character expressing either confidence or doubt) instead of a classical abstract scale, Hembacher and Ghetti (2014) found that children as young as 4 could distinguish correct from incorrect recognition memory responses, reporting lower confidence rates for incorrect answers than for correct ones. Destan et al. (2014) reached similar conclusions with 5-year-old children using a judgment of learning (JOL) paradigm.

Even more interesting findings have been reported about control processes. For example, using an opt-out paradigm where children aged 3.5 were given the option to skip uncertain trials before undertaking a recognition memory test (for similar procedures, Destan et al., 2014; Hembacher & Ghetti, 2014; Lyons & Ghetti, 2013), Balcomb and Gerken (2008) showed that the accuracy of memory decisions for accepted items was significantly higher than the accuracy for skipped items. However, the sorting procedure is only comprehensible from 3.5 years old. Following these early findings, new and increasingly sensitive paradigms (e.g., seeking help from an informant rather than a noninformant in an uncertain situation) were developed, revealing the existence of basic metacognitive responses as early as 12–18 months (Bazhydai et al., 2020; Goupil & Kouider, 2016; Goupil et al., 2016).

Interestingly, based on these data, it appears that metacognitive control develops earlier than metacognitive monitoring (Geurten & Bastin, 2019; Hembacher & Ghetti, 2014). Indeed, when they directly compared the two processes within a single age group using an opt-out paradigm to assess metacognitive control and a pictorial RCJ to assess metacognitive monitoring, Hembacher and Ghetti (2014) showed that children as young as age 3 excluded their least confident correct answers when deciding which items they wanted to be evaluated on. This pattern was observed, even though at age 3, the accuracy of the children's confidence judgments was at chance, suggesting that 3-year-old children were able to regulate their memory decisions on the basis of their subjective uncertainty before they became able to make accurate judgments on their performance.

According to models of metacognition (Koriat, 2007; Nelson & Narens, 1990), once individuals are able to correctly assess their own mental operations, they are more likely to develop increasingly complex, situationally appropriate regulatory behaviors. As evidence for this, previous studies have revealed that preschool children are able to use some metacognitive inference rules arising from the automatic association between a specific mnemonic cue detected throughout monitoring processes (e.g., the quality of the memory trace) and a specific memory decision resulting from metacognitive control (Geurten & Willems, 2016). For instance, Geurten, Meulemans, and Willems (2015; see also, Geurten, Willems, & Meulemans, 2015; Geurten, Meulemans, & Willems, 2018) found that children as young as 4 were able to rely on the memorability heuristic—which shows the implementation of a more conservative response criterion for items considered highly memorable than for items considered less memorable—to guide their memory decisions, at least when the distinction between memorable and less memorable items was particularly salient.

It therefore appears that both qualitative (e.g., emergence of monitoring skills) and quantitative (increasing complexity in interactions between monitoring and control processes) changes occur at the metacognitive level during the transition from early childhood to the preschool years. To date, however, no studies have longitudinally examined the development of these two processes during this period. Indeed, all previous studies have used cross-sectional designs and relied on different paradigms depending on the children's age to capture metacognitive skills (Geurten & Bastin, 2019; Goupil & Kouider, 2016; Hembacher & Ghetti, 2014). This circumstance makes it difficult to compare studies. Furthermore, in addition to the lack of a comprehensive understanding regarding the developmental trajectory of early metacognition, the question of whether and how basic monitoring and control processes are related to later memory functioning is still to be determined. Thus far, only one study has examined the relations between early metacognition and memory performance in a group of children aged from 2.5 to 4.5 years (Geurten & Léonard, 2023). A positive correlation was reported between a measure of metacognitive control (i.e., asking for a cue after incorrect decisions) and children's performance on an associative memory task. Although promising, the cross-sectional nature of these results and the broad age range examined prevent us from drawing strong conclusions regarding the nature of the relations between early metacognition and memory performance.

This Study

This study had two main goals: (a) longitudinally document the developmental trajectory of early explicit metacognitive monitoring and control processes during the transition from toddlerhood to preschool years; and (b) examine the relations between these early explicit metacognitive skills and later memory functioning. To do so, children aged 2.5 years were recruited and tested once a year until they reached 4.5 years (i.e., three assessment points). A memory recognition task was used to assess both monitoring and control processes. Regarding metacognitive monitoring, the pictorial RCJ procedure proposed by Hembacher and Ghetti (2014) was used so participants could state their level of confidence after each memory decision. As for metacognitive control, a procedure similar to the one used by Geurten and Bastin (2019) and shown to be successfully used by children as early as age 2.5 to discriminate correct from incorrect decisions was selected. The opt-out paradigm, while quite common in the field, has, to the best of our knowledge, never been used with children under the age of 3. Specifically, in the cue selection paradigm employed here, children were given the possibility to ask for a cue when they thought they had given an incorrect answer. Finally, to assess memory performance, an additional story-recall task followed by a true–false recognition test was presented at age 4.5. In this task, children were questioned about the truth of some statements about events that happened in the story that had been read to them previously.

Regarding the developmental path of the two metacognitive components (i.e., monitoring vs. control), metacognitive control was expected to be present earlier than metacognitive monitoring, possibly as early as age 2.5 (if our results were similar to those observed outside the memory domain, see Geurten & Bastin, 2019). These processes were then anticipated to show continuous improvements as children mature. Based on previous research showing that 4-year-old, but not 3-year-old, children are able to make accurate confidence judgments (Hembacher & Ghetti, 2014), we expected to see an improvement in metacognitive monitoring with age, with above-chance discrimination between correct and incorrect memory decisions by the age of 3.5 or 4.5 at the latest.

As for the relations between early metacognition and children's memory performance, given that memory performance is supposed to rely on both monitoring and control abilities through error detection and strategy implementation (Geurten & Willems, 2016; Koriat et al., 2009; Metcalfe, 2008; Son, 2010), we hypothesized that both monitoring and control processes at prior and concurrent time points would be related to children's memory performance on the story-recall task. Indeed, children's memory performance may be influenced by both (a) previously automatized strategies learned with prior metacognitive skills (e.g., metacognitive heuristic) and (b) currently available metacognitive skills used to identify ongoing cognitive challenges and overcome them by implementing appropriate strategies.

Method

Participants

The initial sample included 69 typically developing children aged 2.5 years ($N_{T0} = 69$; 32 females; $M_{age} = 32.3$ months; $SD = 1.6$). The native language of all children was French, and all were from homes with a middle- to upper-class socioeconomic status (mean parental education level [T0] = 14.23; $SD = 2.58$). Data were collected at three time points from October 2020 to December 2022; each child was tested every 12 months. They were recruited by word of mouth and from pre-K schools in the province of Liège (Belgium).

Transparency and Openness

The sample size was determined a priori from previous studies to reveal a small to medium-sized effect ($d = 0.35$) for the least powerful analyses conducted here: that is, a standard deviation *t* test with a desired power of .80 at an alpha level of .05. According to this power analysis, a minimum sample of 52 participants was required. As a dropout rate of around 30% is common in longitudinal studies, 17 additional children were included in the final sample. Two children actually dropped out between T0 and T1 for family reasons and inability to recontact ($N_{T1} = 67$; 31 females; $M_{age} = 43.57$ months; $SD = 1.7$) and four children dropped out between T1 and T2 for unspecified reasons ($N_{T2} = 63$; 27 females; $M_{age} = 55.68$; $SD = 1.63$). All analyses reported were conducted using JASP 0.17.1 (JASP Team, 2023) and JAMOVI 2.3.21 (The Jamovi project, 2022). This study was not preregistered. Data and research material are available on our institutional repository using the following link: https://hdl.handle.net/2268/313828.

Material and Stimuli

The task of assessing children's metacognitive abilities was presented on the experimenter's computer using ToolBook and E-Prime software. It was calibrated so that stimuli appeared the same size regardless of the screen dimensions. In this task, 180 stimuli consisting of colored images of objects and animals were retrieved from the study by Geurten and Bastin (2019). These stimuli were randomly divided into three lists of 60 items, one for each assessment time. Each list included 20 target items, 20 distractors (combined to create 20 target–distractor pairs), and 20 cues, which were presented to the children upon request. At each time point, two target–distractor pairs of images were used as examples and 18 target–distractor pairs as test stimuli. To create pairs of varying difficulty at each time point, the perceptual proximity between the target and the distractor of each pair could be either low, medium, or high (six pairs in each category determined on the basis of pretests conducted by Geurten & Bastin, 2019).

Procedure

Institutional review board approval was obtained from the local ethics committee (1920-33; January 5, 2020) as well as the consent of parents before the first data collection. Each child was tested in the morning in a quiet room in their home or at school. The assessment sessions at T0 and T1 lasted approximately 20 min, during which children were presented with a metacognitive paradigm including a recognition memory task followed by item-by-item metacognitive evaluations. The T2 session lasted approximately 35 min as a story-recall memory task was administered in addition to the metacognitive paradigm (see Figure 1).

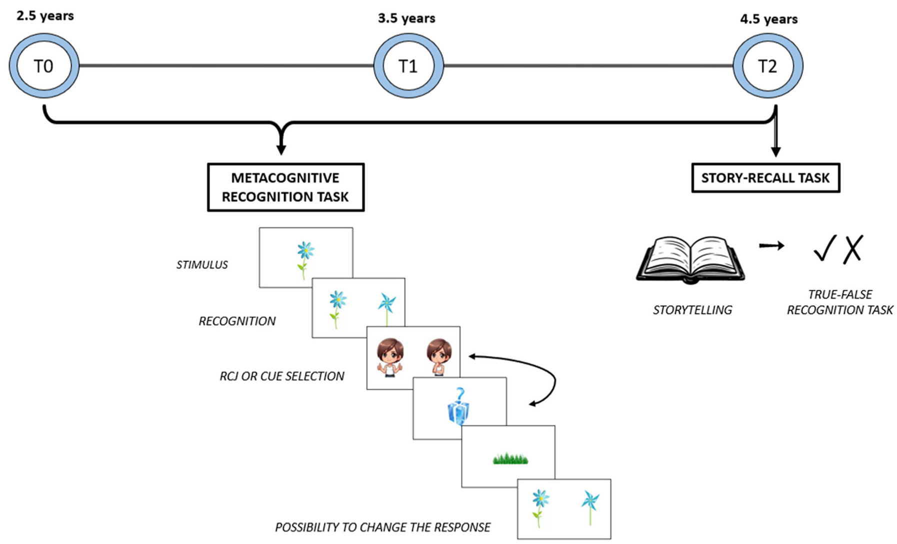
Metacognitive Recognition Task

To assess participants' metacognitive skills, a paradigm inspired by the one used in Geurten and Bastin's (2019) study was used and adapted to assess metacognition in the memory domain. The task consisted of four successive phases: (a) an encoding phase, (b) a recognition phase, (c) an RCJ phase, and (d) a cue selection phase. The latter two phases were counterbalanced so that half of the participants were presented with the RCJ phase before deciding whether they wanted a helping cue while the other half of the participants received the two metacognitive evaluations in the reverse order. This procedure was chosen to ensure that the order of the two metacognitive phases did not influence the outcome of the task. Following the two metacognitive measures, children were given the opportunity to change their responses.

The metacognitive recognition task was preceded by two practice trials so that participants could become familiar with the general procedure of the four phases of the test. During these trials, children were given feedback on the basis of the correspondence between their memory decision and their cue selection or their choice on the confidence scale (e.g., if participants selected the high-confidence option or declined the cue after a correct recognition, they received positive feedback). After the end of these practice trials, the experimenter kept a warm but neutral attitude toward the participants and stopped providing any feedback on their cognitive and metacognitive responses.

Figure 1

Description of the Experimental Procedure and the Longitudinal Design



Note. T0 = first assessment at 2.5 years; T1 = second assessment at 3.5 years; T2 = third assessment at 4.5 years; RCJ = retrospective confidence judgment. See the online article for the color version of this figure.

Encoding Phase. One of the three randomly selected sets of 18 pictures was presented one by one in the center of the screen for 1 s each. Children were asked to look carefully at each picture as they would be required to remember them later. After each stimulus, a blank screen appeared for 100 ms.

Recognition Phase. Directly following the encoding phase, children were required to perform a forced-choice recognition test. Specifically, they were randomly presented with a target–distractor pair of stimuli for an unlimited time and were instructed to point to the drawing they had seen before. The experimenter then encoded the children's responses using the keyboard keys. The side of the screen in which the target stimulus was displayed was randomized over the trials. After each response, a blank screen appeared for 100 ms, followed by either the RCJ or the cue decision.

RCJ Phase. After each memory decision, children were asked to make an RCJ: that is, they had to describe their degree of certainty about their response, using the pictorial judgment procedure described by Hembacher and Ghetti (2014). Specifically, two pictures of gender-neutral characters appeared on the screen: one character expressed confidence and the other expressed doubt. Children were asked by the experimenter to point the confident character if they were sure of their answer or to point the doubt character if they were not sure of their answer. If children looked at or asked the experimenter for help, the experimenter repeated the same instruction and explained again the differences between the two characters. Each choice was followed by a blank screen for 100 ms. Choosing the character expressing confidence was coded 1 and the character expressing doubt was coded 0.

Cue Selection Phase. For each trial, children were given the opportunity to ask for a cue to help them to find the target item. Concretely, a mystery box and two response buttons appeared in the center of the screen. For each item, children were told by the experimenter that they could ask for a cue to help them make a correct decision if they felt they had made an error when selecting their response. If children looked or asked for help during this phase, the experimenter repeated the same instruction and explained to the children that they had to ask for the cue only when they felt like they needed it to select the correct response. The experimenter pressed the "yes" button when a cue was requested and the "no" button otherwise. Each choice was followed by a blank screen for 100 ms. Accepting the cue was coded 1 and declining the cue was coded 0.

Depending on the experimental order, the cue appeared either directly after the blank screen or after the RCJ phase so that participants' judgment was never influenced by the presentation of the cue. If a cue was requested, it appeared for 3 s in the center of the screen, followed by a blank screen for 100 ms.

Story-Recall Task

To assess memory skills, a story-recall task taken from Léonard et al. (2023) and based on a book whose vocabulary was recommended for 4- to 5-year-olds (Agnès Bertron, ISBN: 274701116X) was administered to the participants at the third time point, when the children were 4.5 years old. This type of memory task was used because it is similar to an activity that is frequently performed by young children in their daily lives. The story talked about a young girl looking for a birthday present for her mom who ended up in the garden of a wicked witch. To better suit both the age of our participants and the testing constraints, the original story's complexity and length were modified.

Encoding Phase. Children were asked to listen carefully to the story read by the experimenter (reading time was around 5 min), while pictures illustrating Anna's adventures were presented for the most memorable events of the story (Ghetti et al., 2002).

Recognition Phase. Immediately following the end of the encoding phase, children were asked to orally complete a true–false recognition task composed of 32 statements about facts, contextual information, and perceptual details included in the story. Among the 32 questions, four blocks of statements were created, two of which asked questions about memorable events (e.g., As Anna tries to escape, huge blue creepers wrap around her waist), while the other two blocks questioned less memorable events (e.g., Anna finds a piece of paper on the ground while walking in the street). This procedure was used to assess children's ability to rely on the memorability heuristic, that is, the ability to form expectations about the memorability of an event and use them to guide memory decisions. The data regarding the participants' use of the heuristic, however, will be analyzed elsewhere. To avoid bias in the sampling of the questions, two versions of the recognition task were created and randomly assigned to the participants (i.e., the true statement in Version 1—e.g., "At the beginning of the story, the flyer for the contest was lying on the ground in the street behind Anna's house."—was the lure in Version 2—e.g., "At the beginning of the story, the flyer for the contest was lying on the ground in Anna's garden."). For each statement, children were asked to answer true if they considered the whole sentence to be correct and false if at least one element of the sentence was incorrect. The experimenter was allowed to provide general encouragement (e.g., "ok, another one done, let's move to the next"), but did not give any feedback on the children's responses.

Measures

Metacognitive Monitoring Score. The meta-d'/d' ratio (M-ratio; Fleming & Lau, 2014; Masson & Rotello, 2009) was used to estimate the accuracy of participants' RCJ regarding their memory performance (i.e., giving a sure response after a correct memory choice and an unsure response after an incorrect memory choice). Specifically, the M-ratio is a measure of the degree to which a participant can discriminate correct from incorrect cognitive decisions when judging their own performance while estimating the discrimination value underlying the participant's actual confidence ratings that would be expected if the participants responded in an ideal way in their confidence ratings, thus providing some sort of control over the influence of basic performance at the cognitive level. A higher M-ratio indicates better metacognitive accuracy.

Metacognitive Control Score. As with the RCJ, the M-ratio was used to evaluate the adequacy with which children requested a cue to strategically control their memory performance, namely asking for a cue after an incorrect recognition and declining the cue following a correct recognition.

Story-Recall Memory Score. To estimate children's memory performance, a 0 or 1 coding system was used. For each item, a correct answer was coded 1, and an incorrect answer was coded 0.

Data Analyses

The first goal of this study was to document the developmental trajectory of two main metacognitive components (i.e., monitoring and control) between the end of toddlerhood and the beginning of childhood. To do so, a repeated measures analysis of variance (ANOVA) was carried out to examine the effect of time (T0, T1, and T2) on the M-ratio index computed for each metacognitive process. Correlations between the M-ratio index computed at each point for each metacognitive measure were also examined to explore possible changes in the interrelations between monitoring and control processes with age. Although the M-ratio index is an interesting measure for estimating metacognitive efficiency, it is subject to certain biases (e.g., it requires many items to be estimated accurately). For this reason, we also estimated children's metacognitive performance using a more direct method. Specifically, item-by-item binomial mixed models were conducted to determine whether children's raw RCJ (coded 0–1), or their cue selection (coded 0–1) were related to the accuracy of the previously given memory response (coded 0–1), and whether this relation differed across our three assessment times.

Secondly, the influence of early metacognitive skills on later memory performance was examined using mixed-effects modeling. Specifically, to test whether children's monitoring and control skills at the three assessment points could be linked to their memory performance at age 4.5, a mixed-effects logistic model was performed on an item-by-item basis using the story-recall memory score as a dependent variable. Participant was modeled as a random effect. The model included random intercepts and by-participant random slopes. For the memory score, a binary dependent variable coded whether participants successfully made the correct (coded 1) or incorrect (coded 0) memory decision on each trial. The assessment time (T0 vs. T1 vs. T2) and the type of metacognitive process (M-ratio for RCJ vs. M-ratio for cue selection) were added as fixed factors to the model. The main effect estimates were conditional upon set default values. Thus, the estimate of one level of the predictor represented its effects when the other was at its default value. The default values for our fixed factors were "T0" and "RCJ," respectively.

Unless otherwise mentioned, all results were considered significant when the p value was lower than .05. All analyses reported were conducted using JASP Version 0.17.1 (JASP Team, 2023) and JAMOVI Version 2.3.21 (The Jamovi project, 2022).

Results

The descriptive statistics on the main variables are available in Table 1. Preliminary analyses showed no order effect for the two metacognitive processes (RCJ–Cue vs. Cue–RCJ), all Ws < 749, ps $> .24$, $r_b < .3$, and comparable memory accuracy for the two versions of the story-recall recognition test, $t(61) = 0.5$, $p = .62$, $d = 0.13$. Correlations between M-ratio and the recognition performance for the metacognitive task showed that neither the pictorial RCJ nor the cue selection correlated with the recognition task performance at T0, $r = .2$, $p = .1$, $r = .12$, $p = .34$, respectively. At T1, pictorial RCJ and the cue selection were both associated with the memory task performance, $r = .3$, $p = .01$, $r = .45$, $p < .001$, respectively. At T2, pictorial RCJ, $r = .27$, $p = .03$, but not the cue selection $r = .2$, $p = .11$, was associated with the memory task performance. As can be seen, the correlations that remain significant with recognition performance for the metacognitive task are usually small.

Developmental Changes in Metacognition

We first examined whether children were able to engage in above-chance RCJ and cue selection at each time point. A Wilcoxon correction was conducted for the variables that were not normally distributed (i.e., the M-ratio score at T1 and T2 for cue selection and at T2 for RCJ). The results of the t tests showed that all the metacognitive coefficients were significantly larger than 0 at T1 and T2. However, at T0, neither the M-ratio computed to assess metacognitive monitoring accuracy (RCJ) nor the M-ratio computed to assess metacognitive control accuracy was higher than the chance level (see Table 2). In addition, a correlation matrix of our main variables (see Table 3)

Table 1

Descriptive Analyses of the Two Metacognitive Measures and the Recognition Rates at Each Time Point (M d′/d′) in the Metacognitive Recognition Task and Recognition Rate in the Story-Recall Task

Variable	*N*	Age (month)	*M*	*SD*	Max.	Min.
T0						
RCJ	69	32.30	−0.55	1.16	2.36	−3.06
Cue	69	32.30	0.15	1.1	3.06	−2.36
RC	69	32.20	0.58	0.15	0.94	0.22
T1						
RCJ	67	43.57	0.35	0.98	2.71	−1.72
Cue	67	43.57	0.59	1.05	3.87	−3.04
RC	67	43.57	0.71	0.19	1	0.22
T2						
RCJ	63	55.68	0.61	0.86	3.06	−2.36
Cue	63	55.68	0.89	0.80	3.06	−3.04
RC	63	55.68	0.85	0.17	1	0.22
Story recall						
RC rate	63	55.68	0.64	0.1	0.375	0.91
Hit	63	55.68	0.65	0.48	0	1
FA	63	55.68	0.41	0.49	0	1

Note. Max. = maximum; Min. = minimum; RCJ = retrospective confidence judgment; Cue = cue selection; RC = correct response rate; FA = false alarm; *M d′/d′* = M-ratio; T0 = first assessment at 2.5 years; T1 = second assessment at 3.5 years; T2 = third assessment at 4.5 years.

was created to observe potential links between the monitoring and control processes at different times. The analyses reveal that the two processes were not related at T0 and T1, but there was a significant correlation at T2 with an effect size of .58.

Next, the developmental trajectory of monitoring and metacognitive control (M-ratio) between the ages of 2.5 and 4.5 was examined. As the Assessment Time × Metacognitive Process interaction violated the sphericity assumption (Mauchly's W), the conservative Greenhouse–Geisser correction was introduced when computing the ANOVAs. The results indicated a main effect of the type of metacognitive process: the M-ratio for RCJ ($M = 0.14$) was significantly lower than the M-ratio for cue selection ($M = 0.53$), $F(1, 62) = 30.3$, $p < .001$, $\eta^2 = .04$. A main effect of assessment time was also found, $F(2, 124) = 24.2$, $p < .001$, $\eta^2 = .16$. The Assessment Time × Type of Processes interaction, however, was not significant, $F(1, 102) = 2.96$, $p = .07$, $\eta^2 = .01$. Given that the primary goal of this study was to better describe the developmental course of monitoring and control processes, respectively, post hoc comparisons with a conservative Bonferroni correction were conducted to better qualify these results. The results revealed a progressive improvement over time in both monitoring and control processes. Specifically, for RCJ, significant differences were found between T0 and both T1, $t(62) = 5.1$, $p < .001$, $d = 0.84$, and T2, $t(62) = 6.44$, $p < .001$, $d = 1.13$. However, no significant differences were found between T1 and T2, $t(62) = 1.34$, $p = 1.00$, $d = 0.26$. Regarding cue selection, significant differences were found between T0 and T2, $t(62) = 3.87$, $p = .002$, $d = 0.72$, but not between T0 and T1, $t(62) = -2.23$, $p = .40$, $d = 0.40$, or T1 and T2, $t(62) = 1.64$, $p = 1.00$, $d = 0.31$. Interestingly, these analyses also revealed that, while the M-ratio for RCJ was significantly lower than the M-ratio for cue selection at T0 ($M = -0.57$ vs. 0.18), $t(62) = 4.78$, $p < .001$, $d = 0.47$, no such difference was found at T1 ($M = 0.36$ vs. 0.59) or T2 ($M = 0.61$ vs. 0.89), all ts < 1.42, ps $= 1.00$, $d < 0.33$ (see Figure 2).

Given the possible bias attached to the M-ratio measure, a binomial mixed-effects modeling on children's recognition decision (correct vs. incorrect) was conducted as a follow-up analysis. Time (T0, T1, T2) was added as a first-level predictor, the RCJ (sure vs. unsure) on each trial as a second-level predictor, and the cue section (with vs. without) on each trial as a third-level predictor. Results revealed a main effect of the three factors, with an increase in children's recognition performance over time, $\chi^2 = 41.63$, $p < .001$, an effect of RCJ, $\chi^2 = 4.68$, $p = .03$, and cue selection, $\chi^2 = 14.38$, $p < .001$, the two latter findings being better qualified by their interaction with time. Indeed, confirming the results of the previous analyses, the results revealed a significant RCJ × Time interaction, $\chi^2 = 65.45$, $p < .001$, indicating that participants were more likely to express high confidence than low confidence after making a correct recognition at T1 ($M = 0.83$ vs. 0.76; i.e., indicating that high confidence was expressed after 83% of the correct trials and 76% of the incorrect trials) than at T0 ($M = 0.57$ vs. 0.63; i.e., indicating that high confidence was expressed after 57% of the correct trials and 63% of the incorrect trials), $OR = 3.36$, $SE = 0.30$, $z = 4.03$, $p < .001$. A similar, but smaller, effect was found between T2 ($M = 0.91$ vs. 0.81; i.e., indicating that high confidence was expressed after 91% of the correct trials and 81% of the incorrect trials) and T1 ($M = 0.83$ vs. 0.76), $OR = 1.68$, $SE = 0.21$, $z = 2.47$, $p = .014$. Note that the fact that children were more likely to give a "sure" response after an incorrect decision ($M = 0.63$) than after a correct decision ($M = 0.57$) at T0 explained why the M-ratio for RCJ was negative at the first assessment point.

Table 2

Means and Standard Deviations for Raw Retrospective Confidence, Cue Selection, and Memory Performance at the Item Recognition Task. Means, Effects Sizes, and Tests of Metacognitive Sensitivity (M-ratio) for the Two Metacognitive Indices (RCJ and Cue Selection) at the Three Assessment Times (T0, T1, T2)

				M-ratio					
				RCJ			Cue		
Time points	RCJ	Cue	Rec.	*M*	d/r_b	*p*	*M*	d/r_b	*p*
T0	0.61 (.5)	0.51 (.5)	0.58 (.49)	−0.54 (1.16)	−0.47	1.00	0.15 (1.1)	0.14	.12
T1	0.8 (.4)	0.35 (.48)	0.71 (.45)	0.35 (0.97)	0.36	.002	0.59 (1.05)	1.9	<.001
T2	0.9 (.31)	0.21 (.41)	0.85 (.35)	0.61 (0.86)	1.96	<.001	0.89 (0.78)	3.53	<.001

Note. Wilcoxon signed-rank tests were used to assess the accuracy of RCJ at T2 and of cue selection at T1 and T2, Pearson *t* tests were used for the other scores. Children were aged 2.5 at T0, 3.5 at T1, and 4.5 at T2. M-ratio = meta-*d′*/*d′* ratio; RCJ = retrospective confidence judgment; Cue = cue selection; Rec. = rate of correct recognition at the item recognition task; T0 = first assessment at 2.5 years; T1 = second assessment at 3.5 years; T2 = third assessment at 4.5 years.

Table 3
Pearson and Spearman Correlations Between the Two Metacognitive Measures (RCJ and Cue Selection) at the Assessment Times (T0, T1, T2)

Variable	T0 Cue	T1 RCJ	T1 Cue	T2 RCJ	T2 Cue
T0 RCJ	.12	.04	.20	−.10	.20
T0 Cue		−.03	−.14	−.08	.13
T1 RCJ			.19	.24†	.19
T1 Cue				.12	−.02
T2 RCJ					.58**

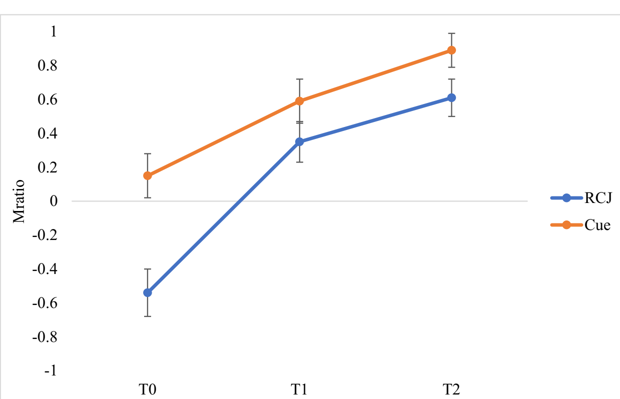
Note. RCJ = retrospective confidence judgment; Cue = cue selection; T0 = first assessment at 2.5 years; T1 = second assessment at 3.5 years; T2 = third assessment at 4.5 years.
† Nonsignificant effect of small size (i.e., $.2 > r < .3$). ** $p < .001$.

Regarding cue selection, a Cue × Time interaction was also found, $\chi^2 = 18.48$, $p < .001$, revealing that participants were more likely to decline than to ask for the cue following a correct recognition at T2 ($M = 0.18$ vs. 0.34; i.e., indicating that the cue was requested after 18% of the correct trials and after 34% of the incorrect trials) than at T0 ($M = 0.49$ vs. 0.53; i.e., indicating that the cue was requested after 49% of the correct trials and after 53% of the incorrect trials), $OR = 0.37$, $SE = 0.27$, $z = 4.63$, $p < .001$. No significant differences were found with T1 ($M = 0.32$ vs. 0.45, i.e., indicating that the cue was required after 32% of the correct trials and after 45% of the incorrect trials), all $ps > .07$.

Metacognition and Memory

To document the possible effect of early metacognitive abilities on memory performance, a mixed-effects logistic regression was performed. The M-ratio scores computed for our two metacognitive measures at each time point were used as predictors as these indices allowed us to control for children's performance at the cognitive level when estimating their metacognitive accuracy. Correlations

Figure 2
Average M-Ratio and Standard Errors as a Function of Time (T0, T1, T2) and Type of Metacognitive Process (RCJ, Cue)



Note. Children were aged 2.5 at T0, 3.5 at T1, and 4.5 at T2. M-ratio = meta-d'/d' ratio; RCJ = retrospective confidence judgment; Cue = cue selection; T0 = first assessment at 2.5 years; T1 = second assessment at 3.5 years; T2 = third assessment at 4.5 years. See the online article for the color version of this figure.

between memory performance at the forced-choice metacognitive task and the story-recall task are presented in Table 4.

According to the guidelines (Meteyard & Davies, 2020), all possible models were compared using a forward procedure starting with the most parsimonious models including only one of the six main possible effects and moving toward more complex models including several main effects and interactions. The best-fitting model presenting the relation between metacognition and memory over time was selected based on the Akaike Information Criterion (AIC). Specifically, the model with the lowest AICs was retained as it explained the largest variance while also including the smallest possible number of predictors. The best-fitting model (AIC = 2,636.52) emerging from the analyses included a main effect of metacognitive monitoring (RCJ) accuracy at T0 and T2; these two scores were significantly related to memory performance on the story-recall task, $OR = 0.09$, $SE = 0.04$, $t = 2.06$, $p = .04$, and $OR = 0.19$, $SE = 0.06$, $t = 3.04$, $p = .002$, for T0 and T2, respectively. Specifically, these results indicated that, for each one-point increase in metacognitive monitoring effectiveness at T0, children's likelihood of giving a correct answer on the memory test at T2 increased by 9%, while for each one-point increase in monitoring effectiveness at T2, the likelihood of giving a correct answer increased by 19%.

Discussion

The main goals of this study were to longitudinally document the developmental trajectory of metacognition in early childhood and to observe the potential links between early metacognitive skills and later memory functioning. An experimental paradigm adapted to young children and allowing the evaluation of both monitoring (RCJ) and control (cue selection) processes was used in children aged from 2.5 to 4.5 years; we then examined the relations of these two processes with children's memory performance at age 4.5. Our results indicated an increase in both metacognitive monitoring and control across our three time points; both processes showed above-chance performance from the age of 3.5 years. Regarding the relations between early metacognition and children's memory performance, our data suggest that both prior and concurrent metacognitive monitoring abilities, but not—unexpectedly—metacognitive control, were associated with children's memory performance at age 4.5.

Developmental Changes in Metacognition

By examining the development of control and monitoring skills from a longitudinal perspective, our study provides significant information for understanding metacognitive changes before the preschool

Table 4
Pearson and Spearman Correlations Between the Recognition Rate at Each Time in the Metacognitive Task (T0 RC, T1 RC, T2 RC) and the Story-Recall Rate (T2)

Variable	T0 RC	T1 RC	T2 RC	Story recall (RC rate)
T0 RC		−.04	.23†	.21†
T1 RC			.25†	.05
T2 RC				.14

Note. RC = recognition rate; T0 = first assessment at 2.5 years; T1 = second assessment at 3.5 years; T2 = third assessment at 4.5 years.
† Nonsignificant effect of small size (i.e., $.2 > r < .3$).

years. First, the finding that metacognitive control is better than metacognitive monitoring at 2.5 years and that metacognitive control overall is higher than monitoring accuracy when considering all time points seems to confirm our assumption, based on prior findings that control develops earlier than monitoring processes (Geurten & Bastin, 2019; Hembacher & Ghetti, 2014). If this lag truly results from a developmental dissociation between these two processes and not from the fact that the selection cue paradigm may simply have been easier for young children to understand than the pictorial RCJ procedure, this finding could have important implications for our understanding of metacognition. Interestingly, some results in the present experiment seem to run against the hypothesis of a mere "difficulty" effect. Indeed, at each time point, roughly 20% of the children (i.e., 23.18% at T0, 31.34% at T1, and 12.7% at T2) showed higher metacognitive accuracy for the RCJ than for the cue selection task. If the cue paradigm was truly easier to understand than the pictorial RCJ procedure, better performance for RCJ would probably not have been found in such a significant portion of our sample at each time point.

Nevertheless, although 2.5-year-old children's performance in metacognitive control is higher than in metacognitive monitoring, neither score differs significantly from the chance level. Again, this result is consistent with prior findings relying on explicit measures of metacognition (see Hembacher & Ghetti, 2014), which showed no evidence of monitoring and only emergent control processes at age 3. This absence of effect, however, could possibly result from a lack of sensibility of the metacognitive paradigms used here as other studies have been able to capture metacognitive behaviors as early as infancy (e.g., Bazhydai et al., 2020; Goupil & Kouider, 2016; Goupil et al., 2016). The paradigms in these studies, however, were all implicit in nature (e.g., the postdecision persistence paradigm where how long children persist in their decision after giving an answer was used as a measure of metacognitive skills). This means that the results of the metacognitive evaluations were not necessarily accessible to children's consciousness. In our study, our aim was to examine the developmental path of explicit metacognition. For this reason, while the monitoring and control assessments were pictorial, they still required children to explicitly evaluate their internal states, explaining the later onset.

Compared with studies using explicit measures of metacognition, however, our results still seem to contradict those of Geurten and Bastin (2019), who showed above-chance metacognitive control accuracy at age 2.5 using the same selection cue paradigm we used here. Based on these results, we expected 2.5-year-old children to show above-chance cue selection accuracy in the present experiment. Interestingly, however, Geurten and Bastin's (2019) study was not conducted in the area of memory, but in the context of a perceptual discrimination task. This finding is interesting since recent studies in adults have suggested that while some metacognitive processes may apply generally across different cognitive domains (e.g., a *G*-factor for metacognition; Mazancieux et al., 2020), perception appears to be more specific (Lehmann et al., 2022), leading the authors to propose that metacognition for the information delivered by the external environment differs from metacognition for the information generated by the internal environment (e.g., memory retrieval). Moreover, in children, studies have revealed that even the domain-general metacognitive components for internal cognition are not yet mature (Vo et al., 2014) and that metacognition appears to remain domain-specific until the age of 10 (Geurten, Meulemans & Lemaire, 2018). Thus, the differences from Geurten and Bastin's (2019) study observed here are not surprising but seem to reinforce the idea that studying the developmental trajectory of metacognition in a single domain is not sufficient to decipher the underlying functional architecture in childhood. To confirm or refute these hypotheses, a study using these metacognitive measures on both memory task and perceptual task is needed.

On a related note, the fact that the cue selection paradigm was previously found to be successfully used by 2.5-year-old children to discriminate correct and incorrect perceptual decisions suggests that the performance at chance levels reported here might not be due to the fact that the paradigm was too difficult to understand by young children. In the present study, 52.17% of our sample had scores greater than chance when using the cue selection paradigm at T0. When using the RCJ procedure, this rate reached 27.53%, suggesting that the pictorial judgment procedure was also understood by a significant part of our sample at the first time point.

Another critical finding of our research concerns how metacognitive skills develop in early childhood. Our results revealed both similarities and differences between the developmental curves for the two metacognitive processes. First, as expected in view of previous cross-sectional findings, both metacognitive monitoring and control are above chance from 3.5 years and continue to improve with age. However, our longitudinal design allowed for a finer-grained examination of this developmental path. Specifically, we found a strong improvement in monitoring between ages 2.5 and 3.5 followed by stabilization between 3.5 and 4.5, whereas less abrupt but more constant growth is observed for control across our three assessment points. Once again, such a pattern could indicate a real developmental dissociation between the two processes or might simply reflect a sudden understanding of the monitoring paradigm by most children around age 3.5. Another element supporting the idea that the two metacognitive tasks are dissociated, however, is provided by exploring changes in the correlations between the monitoring and the control measures over time. Indeed, correlations between the two processes are small at ages 2.5 and 3.5 ($r = .13$ and .07, respectively), but large at 4.5 years ($r = .44$). Thus, it is important to note that, at T1, while both metacognitive scores were higher than chance, no correlations were found between these two measures. In addition to suggesting that our two paradigms might indeed capture different components of metacognition, this shift in correlations indicates an increase in the interdependence of basic monitoring and control mechanisms around age 4.5. This finding is interesting since Roebers and Spiess (2017) showed similar changes in the relation between monitoring and control processes in school-aged children when they used more complex metacognition measures than we used here. Specifically, no correlations were found between the accuracy of children's verbal metacognitive judgment and their opt-out decisions at age 8, but a relation between the two measures was found at age 9. In fact, although they are underpinned by different brain substrates (e.g., Qiu et al., 2018), the behavioral interdependence of monitoring and control is well established in the literature. Data show not only that monitoring operations could influence control operations, but also that the outcome of control operations could be used as a cue to improve the quality of monitoring evaluations (Koriat et al., 2006). By suggesting that the two processes are initially independent of each other but that some basic forms of monitoring and control could already start to interact around age 4.5, our study provides critical information to enrich our understanding of the developmental architecture of metacognition. Future studies should address the question of the factors influencing this metacognitive development and whether such factors are the same for both metacognitive monitoring and metacognitive control to provide further evidence of dissociation between these two processes.

Metacognition and Memory

The presence of metacognitive monitoring and control processes in preschoolers raises the question of their relation with memory performance. Consistent with our hypotheses, our results show that monitoring processes at age 4.5 and—to a lesser extent—at age 2.5 can be related to 4.5-year-old children's recognition memory performance for a story-recall task. Nevertheless, contrary to our expectations, control processes do not seem to be linked to memory performance at 4.5. At first sight, this result seems to contradict those obtained by Geurten and Léonard (2023), who found that children's performance on an associative episodic memory task (the "House Test"; Picard et al., 2012) was associated with the effectiveness of their cue selection but not to the accuracy of their metacognitive judgments. Several possible explanations could be found for these inconsistencies, however. First, because we adopted a statistical approach based on the most parsimonious model, it is possible that performance on metacognitive control was also somewhat related to our participants' memory performance but did not provide sufficient additional explanatory power to be included in the model. Second, it is likely that the nature of the memory task presented to the children influenced the results obtained here. Indeed, in Geurten and Léonard's (2023) study, a free recall task was administered. Yet, of all the types of retrieval conditions, free recall is probably the one for which the implementation of spontaneous strategies leads to the greatest improvement. Performance on that type of task could therefore depend more on control processes than the task employed here. Conversely, recognition retrieval requires people to check and ascertain that a piece of information is correct, which could involve more verification than strategic processes; the former may be more dependent on metacognitive monitoring.

In any case, it appears that both the metacognitive abilities available at the time of the memory evaluation and the initial metacognitive skills are important in guiding memory performance. Such findings suggest that, while children's current ability to observe their mental operations—for example, by detecting important mnemonic cues online to help them make a memory decision—is indeed involved in memory performance, certain metacognitive skills acquired much earlier in their development continue to be related to performance years later. This kind of association could be explained if, over time, children develop and internalize some basic metacognitive rules learned through their early monitoring and control processes and still use them to make their memory decisions more efficient (for similar reasoning, see Geurten & Willems, 2016).

Limitations and Future Research Avenues

Although this study is promising, it still has some limitations that future studies should address. The first limit is the choice of the paradigms used to assess metacognitive monitoring and control abilities (i.e., RCJ and cue selection). As neither metacognitive monitoring nor metacognitive control is a unitary construct (e.g., Kelemen et al., 2000), their developmental trajectory could vary considerably depending on how they are assessed (e.g., in older children, dissociation has been, for instance, shown between early developing retrospective judgments and later developing prospective judgments; Bayard et al., 2021). In this context, our results should be replicated and generalized using other paradigms (prospective judgment, opt-out paradigm, or more implicit measures such as postdecisional perseveration) before a comprehensive picture of early metacognitive development can be drawn. Until future studies have established with certainty that the present findings are not due to a lack of sensitivity of one or both of the metacognitive measures used in the present study, our results should be interpreted with caution.

Along the same lines, to achieve a full understanding of the interrelations between metacognition and memory performance, the relations between these two functions should be examined using different memory tasks, which potentially rely on different monitoring and control processes. Indeed, the slightly different results obtained here compared to those of Geurten and Léonard (2023) suggest that the nature of the metacognitive processes involved could differ depending on whether the memory task requires, for example, spontaneous retrieval or post-retrieval verification mechanisms. Finally, on a more general note, it is important to mention that our sample was mostly composed of children from middle to high socioeconomic homes. It is therefore possible that our results could not generalize to lower socioeconomic communities.

Conclusion

Our findings of above-chance metacognition around age 3.5, improved monitoring and control abilities between 2.5 and 4.5, and an increase in the size of the correlation between these two processes as children grow older mostly confirm the hypotheses regarding the developmental path of early metacognition drawn by previous cross-sectional data. The longitudinal design employed here, however, provides additional evidence to further our understanding of the developmental course of metacognition from toddlerhood to early childhood. Furthermore, our study is the first to reveal that both current and early metacognitive monitoring abilities, but not—unexpectedly—metacognitive control, were related to children's memory performance at age 4.5. Such findings are critical as they open avenues for new studies to determine how concurrent and earlier metacognitive processes influence memory performance during the preschool years. From a theoretical point of view, our data also represent a major contribution toward the updating of developmental memory models since, to date, conceptions of memory in childhood still mostly operated on the premise that strategic metacognitive processes only start affecting memory functioning at around age 6 (see Ghetti & Bauer, 2012, for an overview). From a practical perspective, our data reveal the importance of providing metacognitive support at the earliest stage of children's development, as it appears that good metacognitive skills at age 2.5 could continue to have positive impacts on children's memory performance up to 2 years later.

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