Time's Up! Involvement of Metamemory Knowledge, Executive Functions, and Time Monitoring in Children's Prospective Memory Performance

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Abstract

This study examined time-based prospective memory (PM) in children and explored the possible involvement of metamemory knowledge and executive functions in the use of an appropriate time monitoring strategy depending on the ongoing task's difficulty. Specifically, a sample of 72 typically developing children aged 4, 6, and 9 years old were given an original PM paradigm composed of both an ongoing procedural activity and a PM task. Half of the participants (expert group) were trained in the ongoing activity before the prospective test. As expected, results show that time monitoring had a positive effect on children's PM performance. Furthermore, mediation analyses reveal that strategic time monitoring was predicted by metamemory knowledge in the expert group but only by executive functions in the novice group. Overall, these findings provide interesting avenues to explain how metamemory knowledge, strategy use, and executive functions interact to improve PM performance during childhood.

Keywords: Prospective Memory, Metamemory, Strategy Use, Children

Over the past few decades, much of the research on episodic memory has focused on the study of mechanisms and variables that increase memory performance. One of the best-supported findings in this area involves the influence of metamemory skills. Specifically, several studies have shown that people's knowledge of memory functioning (i.e., metamemory knowledge) can improve their memory performance by causing them to implement appropriate strategies (Hutchens et al., 2012; Lachman & Andreoletti, 2006; McNamara & Scott, 2001). Hutchens et al. (2012), for instance, established that adults' performance on the delayed recall task of the California Verbal Learning Test (CVLT-II; Delis, Kramer, Kaplan, & Ober, 2000) is positively related to the use of strategic clustering (e.g., semantic clustering) in the study phase, which, in turn, is shown to be predicted by the participants' metamemory knowledge.

Similar findings have been highlighted in children (DeMarie, Miller, Ferron, & Cunningham, 2004; Grammer, Purtell, Coffman, & Ornstein, 2011; Kron-Sperl, Schneider, & Hasselhorn, 2008; Meijs et al., 2009). Developmental studies tend to demonstrate that children's implementation of strategic memory behaviors is linked to both their metamemory knowledge and their memory capacity (i.e., the amount of information that can be held in memory for a short length of time). In other words, when their strategic metamemory repertoire is well stocked with knowledge and memory capacities are well developed, children are more likely to be able to employ one or more strategies to effectively increase their memory performance (DeMarie et al., 2004).

However, although this indirect relationship between metamemory knowledge, strategy use, and memory performance seems well established when tasks assessing retrospective memory (RM) are used, few studies have examined this relation using tasks that assess prospective memory skills (for recent studies on this topic in adulthood, see Hutchens et al., 2012; McFarland & Glisky, 2012; Rummel & Meiser, 2013). In fact, to our knowledge, no previous study has investigated this specific topic in children. The present study is an attempt to fill this gap.

Prospective memory (PM) refers to the ability to remember to perform an action in the future, which is a crucial process in achieving goal-directed activities in daily life (Causey & Bjorklund, 2014; Kliegel & Martin, 2003). As evidence of this claim, Kvavilashvili, Messer, and Ebdon (2001) report that PM failures represent 50% to 70% of everyday memory problems (see also Crovitz & Daniel, 1984; Terry, 1988). From a developmental perspective, the ability to carry out an intended activity is a critical skill that children must acquire as they gain independence from their caregivers (Kvavilashvili et al., 2001). Indeed, even very young children are required to call upon their PM skills to do things on their own (e.g., wishing a friend a happy birthday, returning homework, or feeding the dog after school) so they can function properly in daily life.

Traditionally, two main types of PM tasks are distinguished: event-based and time-based PM tasks (Einstein & McDaniel, 1990). In event-based memory tasks, the appropriate time to perform an action is indicated by an external cue whose occurrence is generally unpredictable, whereas, in time-based memory tasks, the action has to be executed at a prearranged time point in the future or after a specific period of time has elapsed. In both cases, the main barrier to success is that the prospective task must be carried out at the same time as a cognitively demanding ongoing activity; in an experimental setting, the ongoing activity might be an n-back working memory task, for example (Ellis & Kvavilashvili, 2000; Zinke et al., 2010). In this context, like adults' performance (e.g., Schnitzspahn, Stahl, Zeintl, Kaller, & Kliegel, 2013), children's PM performance is usually shown to be related to the difficulty of the ongoing task as well as to their level of executive abilities (Kliegel et al., 2013; Mackinlay, Kliegel, & Mäntylä, 2009; Mahy, Moses, & Kliegel, 2014; Ward, Shum, McKinlay, Baker, & Wallace, 2007; for a review of the involvement of executive functions in children's PM development, see Mahy, Moses, & Kliegel, in press). In addition, time-based memory performance is also shown to be linked to participants' use of an effective time monitoring strategy (Kretschmer, Voigt, Friedrich, Pfeiffer, & Kliegel, 2013; Mäntylä, Carelli, & Forman, 2007; Voigt, Aberle, Schonfeld, & Kliegel, 2011; Voigt at al., 2014; Zinke et al., 2010). For instance, using an experimental paradigm in which children had to drive a vehicle (ongoing task) and to remember to refuel it before running out of gas (time-based memory task in which the fuel gauge served as an equivalent of the clock), Voigt et al. (2011) demonstrated the involvement of strategic time monitoring in enhancing PM performance in children aged between 7 and 9 years old (for similar findings in preschool and early-school-aged children, see Kretschmer et al., 2013).

In view of the purpose of this experiment, the latter finding is particularly interesting. It indicates that the implementation of an appropriate strategic behavior can have a positive influence on PM, as it does on RM. Specifically, many authors assume that the best time monitoring strategy to perform time-based memory paradigms and succeed at both the ongoing activity and the PM task involves, first, making fewer time checks at the beginning of the PM interval in order to allocate cognitive resources to the ongoing task and, second, increasing the frequency of time checks at the end of the PM interval so as not to miss the PM target time (Costa et al., 2010; Voigt et al., 2011; Zinke et al., 2010). As mentioned above, the results of earlier studies reveal that children who demonstrate this strategic pattern of time monitoring also show better PM performance.

According to DeMarie et al.'s (2004) RM model of strategy use, two variables can be expected to predict children's implementation of a memory strategy: (a) knowledge of memory functioning and (b) memory capacity. However, the strategies employed to carry out PM tasks are not based on the same mechanisms as the strategies that are used to perform RM tasks. Indeed, unlike RM strategies, which rely on memory stores (i.e., RM tasks usually require participants to keep several past events in mind at the same time), PM strategies are not so demanding in terms of memory capacity (i.e., PM tasks usually require participants to perform only one future action at a time). However, the latter have been proven to consume more executive resources. In point of fact, numerous studies indicate that PM tasks typically require participants to inhibit ongoing actions in order to be able to switch from one task to another (Mackinlay et al., 2009; Mahy et al., 2014; Shum, Cross, Ford, & Ownsworth, 2008; Ward, Shum, McKinlay, Baker-Tweney, & Wallace, 2005). Thus, following Mäntylä et al. (2007), who demonstrated that children's time monitoring strategy is predicted by their level of executive skills, it can be assumed that, where PM tasks are concerned, children's strategic behaviors are more likely to be related to their level of executive functioning than to their memory capacity.

For these reasons, the primary aim of the present study was to investigate whether and how time monitoring, metamemory knowledge, and executive functions interact to influence time-based memory performance, depending on the ongoing task's difficulty, in three groups of children aged 4, 6, and 9 years old (for studies that establish the importance of these three ages in children's PM development, see Kretschmer et al., 2013; Voigt et al., 2011; Yang, Chan, & Shum, 2011; T. D. Zimmermann & Meier, 2006). To this end, an original time-based PM paradigm was employed to control the cognitive demand of the ongoing activity not by varying the task difficulty in itself – as is usually done in PM studies – but by varying the children's level of expertise for the task. More specifically, participants in this study were given a perceptuomotor procedural memory task as the ongoing activity. The rationale for this choice was that performance of the procedural task can easily be improved by appropriate training that, once completed, allows participants to carry out the task without calling much on their executive resources, whereas this is not the case for participants who did not receive the preliminary training.

In this context and in accordance with the work of DeMarie et al. (2004) and Mäntylä et al. (2007), the two main goals of the present study were (a) to examine whether the influence of metamemory knowledge on PM performance is truly mediated by the use of a time monitoring strategy; and (b) to explore whether this indirect relation between metamemory knowledge, strategic time monitoring and PM performance depends on the amount of executive resources children must invest in order to perform the ongoing procedural activity.

Methods

Participants

Participants were 72 typically developing children aged 4 (Mean = 54.08, SD = 2.44), 6 (Mean = 78.88, SD = 3.01), and 9 years old (Mean = 113.75, SD = 2.85). There were 24 participants per group. The proportion of girls and boys was strictly equivalent in each group. No group difference was found in terms of parental education level ($F(2,69) = 0.63$, $p = .53$), verbal ability ($F(2,69) = 1.08$, $p = .34$), and nonverbal intelligence ($F(2,69) = 0.90$, $p = .41$), assessed using the two parents' years of education, scores on the Peabody Picture Vocabulary Test (PPVT-R; Dunn, Thériault-Whalen, & Dunn, 1993) and scores on the Matrix Reasoning test (Wechsler, 2004, 2005), respectively. The sample was recruited from French-speaking kindergartens and elementary schools in the province of Liège, Belgium.

Materials

PM paradigm. As a PM paradigm, children completed an original computerized game composed of both a time-based memory task and an ongoing activity. The details of this new paradigm are described below.

Ongoing task. The ongoing task included in this paradigm was a perceptuomotor procedural test adapted from Lejeune, Catale, Schmitz, Quertemont, and Meulemans (2013): the inverted mouse task. To thwart the ceiling effect that was detected at pretest, two versions of the task were presented to children depending on their chronological age. The 4- and 6-year-old children received an easier version of the inverted mouse task while the 9-year-old children were given a more challenging version. Children were given only the version of the ongoing task that was adapted to their age.

In the "easy" version, a stimulus (a cartoon character) appeared on the screen and children were instructed to use the computer mouse, in inverted mode (i.e., the mouse is positioned upside down), to "catch" the stimulus and put it in a basket located at the bottom of the screen as quickly as possible. The number of stimuli that the children were able to put in the basket before the end of the PM task served as an indicator of their ongoing task performance. In the "hard" version, participants were required to trace the contour (i.e., two black lines spaced 1.7 cm apart) of a triangular shape with the inverted mouse. Specifically, the instruction was to trace the outline of the figure as quickly and accurately as possible in order to "catch" various toys appearing on the screen (inside the contour) without going outside the parallel lines. When the cursor moved outside the contour, participants had to reposition it at the place where they left the path before being allowed to continue the task. The number of whole figures children were able to trace before the end of the PM task was used to assess their ongoing task performance.

Time-based memory task. In parallel with this ongoing activity, a time-based memory task involving a small cartoon character that climbed a ladder had to be carried out. Unlike event-based tasks that involve the detection and the recognition of an external cue as a reminder of the necessity to perform an action, time-based tasks generally require participants to execute an action after a predetermined period of time has elapsed. In the present case, children had to remember to press a response key (Enter key) each time the character reached a red area on the top of the ladder; when the response key was pressed at the right time, the character was taken back to the bottom of the ladder. The character reached the red area exactly 105 seconds after it started climbing. Once it reached the red area, the children had a 30-second time window (target time) to press the response key. If they did not press the key before the end of the time window, the character was automatically taken back to the bottom of the ladder without any signal to indicate that a failure had occurred. Task duration was 14 minutes and included 7 target times (i.e., the interval between each pair of target times was 2 min ± 15 s). Not responding to a target time was recorded as an omission error. The dependent variable for the task was the total number of omission errors made for the 7 target times. Thus, scores ranged from 0 to 7, with higher scores indicating poorer PM performance.

Moreover, the ladder served as an equivalent to a clock, enabling participants to check how much time was left until the character had to be taken back to the bottom of the ladder. The character's position on the ladder (as well as the ladder itself) was concealed during the time-based memory task. However, participants could check it as often as they wanted by pressing a specific key on the keyboard (Space key). When this key was pressed, the character and the ladder appeared for 2 s on the left side of the screen. The number of time checks during the first half of each 2-minute trial was subtracted from the number of time checks during the second half of each 2-minute trial. This figure was then divided by the total number of time checks during each 2-minute trial to obtain a proportion, given that some children made many more time checks than others. The resulting score was used as a measure of strategic time monitoring.

Once the task was completed, participants were asked questions about what they were instructed to do during the PM paradigm. Questions were asked about both general (about the task's aims) and specific (about the response keys) instructions. The rationale for these inquiries was to ensure that children's PM performance were not affected by failures in the RM component of the task (Mattli, Schnitzspahn, Studerus-Germann, Brehmer, & Zöllig, 2013). Every child in our sample was shown to be able to satisfactorily recall all the task instructions.

Training task. As previously mentioned, one of the main goals of this study was to examine whether the factors involved in PM performance varied as a function of the participants' level of expertise in the ongoing task. To this end, the children in our sample were divided into two groups of equal size: (a) an expert group, which was trained in the ongoing perceptuomotor procedural task (session 1) before being exposed to the PM paradigm (session 2); and (b) a novice group, which did not learn the ongoing task before being presented with the PM paradigm but was given a filler task. The modalities of the training task depended on the version of the inverted mouse task that was administered to participants. For the easy version, the task consisted of six blocks of seven trials (a trial = one stimulus put in the basket), while, in the hard version, the task consisted of six blocks of one trial (a trial = one figure entirely traced). A pretest carried out in a group of 36 participants was used to determine how many blocks and trials should be included in each version of the training task to induce sufficient procedural learning. The time (in seconds) taken to complete each block was used to assess children's procedural training performance.

Time estimation task. Several authors have assumed that time-based memory performance may rely on participants' ability to estimate time durations (e.g., Mackinlay et al., 2009). To control for this possible effect, a computerized time estimation task adapted from our time-based memory paradigm was administered to each child. Specifically, the task used in this experiment comprised two phases: (a) an observation phase and (b) an estimation phase. In the first phase, children were instructed to watch a character climbing a ladder and to press a response key when it reached the top. They were informed that the character would reach the top of the ladder in 2 minutes. Then, once they had experienced this specific length of time, participants were required to estimate the same duration themselves by pressing a response key when they thought that 2 minutes had elapsed. Finally, after receiving feedback about the duration they had just estimated, participants performed a second trial. The dependent variable was the averaged estimated time (in seconds) of the two trials composing the estimation phase.

Metamemory scale. Two subtests inspired by the French metamemory scale for children (Geurten, Catale, & Meulemans, 2013) were administered to assess metamemory knowledge. For each subtest, children were presented with a scenario constructed to appraise their knowledge of PM strategies. Specifically, after they were presented with a scenario, participants had to generate as many relevant strategies as possible that could be used to increase the likelihood of remembering the action to be performed. Only responses relevant to the scenario were scored as correct. The maximum score was 8 marks (four strategies per subtest). In preparation for the task, children were given a practice scenario to ensure that they understood the instructions. A description of the two subtests can be found in Table 1.

< Table 1 >

Executive tasks. Children's executive abilities were also investigated. Participants were given nonverbal cognitive tasks such as the abstract self-ordered pointing test (SOPT) to assess the executive ability to generate and monitor a sequence of responses (e.g., Cragg & Nation, 2007), a go/no-go test of response inhibition (e.g., Raaijmakers et al., 2008), and the Dragons' House test of flexibility from the attentional test battery for children (P. Zimmermann, Gondan, & Fimm, 2005). Two executive scores amalgamating the participants' results for the three executive tasks were computed. Specifically, the reaction times (RT) on the Dragons' House and go/no-go tasks, on one hand, and the number of errors made on the SOPT, Dragons' House, and go/no-go tasks, on the other hand, were standardized and averaged, respectively, to form two separate executive composite scores labeled EF (RT) and EF (Errors).

Procedure

Children were tested individually in a quiet room in their school, using a laptop computer equipped with Toolbook and E-prime software. Each child participated in two 60-minute sessions one week apart. In session 1, participants were given the Matrix subtest, the training/filler task, the time estimation task, and the PPVT-R. In session 2, they were presented with the metamemory scale, the go/no-go task, the time-based memory task, the Dragons' House test, and the SOPT. In session 1, children in the novice group performed a filler task (i.e., a naming task) instead of the training task so that the session's duration would be approximately equivalent in both experimental groups. The order of the tests was counterbalanced within sessions. Analyses indicated no effect of presentation order on performance of any of these tests.

The study was approved by the local ethics committee. Written consent was obtained from the parents before the study began.

Results

Data Analyses

One of the main goals of this study was to determine whether PM performance is influenced by the cognitive demand associated with the ongoing task. For this purpose, time-based memory scores for the expert and novice groups were compared. Specifically, statistical analyses were conducted with a 3 (age group: 4-, 6-, or 9-year-olds) X 2 (expertise: expert or novice) between-subjects design. After that, the involvement of executive functions, time monitoring strategy, and metamemory knowledge in children's PM performance was also investigated. To do so, forward stepwise regression analyses and mediation analyses were carried out to determine how these variables interacted to influence time-based memory skills. All results reported in this section were considered significant when the exceedance probability was lower than .05. Effect sizes were calculated using R^2 for regression analyses and η^2_p for analyses of variance (ANOVAs).

Preliminary Analyses

Preliminary analyses were conducted to ensure the relevance of our experimental procedure. More specifically, repeated measures and between-subjects ANOVAs were conducted to determine whether children in the expert group improved their performance of the inverted mouse task between the beginning and end of the training task and outperformed children in the novice group when the perceptuomotor procedural task was presented simultaneously with the time-based memory test. The results of the repeated measures ANOVA revealed a significant increase in children's performance between the first and last blocks of the inverted mouse training task for the total sample ($F(1,35) = 40.65$, $p < .001$, $\eta^2_p = .54$) as well as for the 4-year-old ($F(1,11) = 14.92$, $p = .003$, $\eta^2_p = .58$), 6-year-old ($F(1,11) = 13.31$, $p = .004$, η^2_p

= .55), and 9-year-old ($F(1,11) = 19.17$, $p = .001$, $\eta^2_p = .63$) groups of children. Similarly, the results of the one-way ANOVA showed a significant difference between the performance of the expert and novice groups for the whole sample ($F(1,70) = 36.31$, $p < .001$, $\eta^2_p = .34$) as well as for children aged 4 ($F(1,22) = 55.18$, $p < .001$, $\eta^2_p = .71$), 6 ($F(1,22) = 20.20$, $p < .001$, $\eta^2_p = .48$), and 9 years old ($F(2,69) = 27.40$, $p < .001$, $\eta^2_p = .55$). Taken together, these results indicate that the children in the expert group learned the procedural skill at the training session, which enabled them to better perform the inverted mouse task at test.

Prospective Memory and Metamemory

Children's PM performance is commonly supposed to vary with age (Kretschmer et al., 2013; Voigt et al., 2011; Yang et al., 2011; T. D. Zimmermann & Meier, 2006) as well as with the cognitive demand of the ongoing task (Ward et al., 2007). To confirm these hypotheses, the effects of age and expertise on the number of omission errors for the time-based memory task were examined. The results of the two-way ANOVA revealed a significant main effect of age ($F(2,66) = 17.79$, $p < .001$, $\eta^2_p = .35$) and of expertise ($F(1,66) = 7.35$, $p = .008$, $\eta^2_p = .10$) on PM performance. Post hoc analyses (Newman Keuls test) highlighted a significant difference between all age groups for the PM task ($p < .05$). Moreover, no interaction effect was found between the two variables ($F(2,66) = 1.61$, $p = .20$, $\eta^2_p = .05$), indicating that the effect of level of expertise on time-based memory performance was roughly comparable in all three age groups.

Expert group. The primary aim of this study was to investigate whether and how metamemory knowledge, executive functions, and time monitoring strategy affected PM performance depending on the participants' level of expertise in the ongoing task. For this reason, separate analyses were carried out to determine which variables influence PM scores in the two experimental groups (expert and novice). The analyses conducted on the expert group are presented in this section while the analyses conducted on the novice group are presented in the following one.

Stepwise analyses. A forward stepwise linear regression analysis was carried out to determine the best predictors of the children's PM score. In agreement with previous studies, the variables included in the analysis were (a) chronological age; (b) composite scores for executive functions – EF (Errors) and EF (RT); (c) ongoing task score; (d) time monitoring rate; (e) metamemory score; and (f) time estimation score. As shown in Table 2, the results revealed that time-based memory performance in the expert group was predicted by children's strategic time monitoring ($R^2 = .11$, $\beta = -.36$, $p = .02$) and metamemory knowledge ($R^2 = .38$, $\beta = -.41$, $p = .007$). Each predictor added significantly to the total amount of variance explained ($R^2 = .48$, $F(2,33) = 15.31$, $p < .001$). Moreover, since the use of an appropriate time monitoring strategy was demonstrated to be one of the best predictors of the PM score, a second stepwise regression analysis was conducted to explore the variables involved in the children's time monitoring rate. Once again, the variables included in the analysis were (a) chronological age; (b) composite scores for executive functions – EF (Errors) and EF (RT); (c) ongoing task score; (d) metamemory score; and (e) time estimation score. The results showed that only metamemory knowledge accounted for the children's time monitoring rate ($R^2 = .30$, $\beta = .54$, $p < .001$).

Mediation analysis. In view of the results presented above, we chose to use a mediation analysis with bootstrapping (Preacher & Hayes, 2008) to explore the mediating influence of strategic time monitoring on the relation between metamemory knowledge and PM performance. The mediation model and the path coefficients are shown in Figure 1. Like the regression analyses, the results revealed a significant effect of metamemory score on both PM (path [c]) and time monitoring (path [a]) scores, suggesting that participants with higher metamemory knowledge were better at strategic time monitoring and PM performance. Furthermore, the results also showed a significant effect of time monitoring on PM score (path [b]), confirming that participants with better time monitoring skills demonstrated better PM performance. A bias-corrected bootstrap confidence interval for the indirect effect (path [ab]) based on 1,000 bootstrap samples was entirely below zero (95% CI [–0.73, –0.01]), indicating that the influence of metamemory knowledge on PM performance was mediated by the use of an appropriate time monitoring strategy. However, this mediation effect was only partial. In fact, evidence was found that metamemory knowledge still affected PM performance independently of its effect on presumed mediated influence (path [c']).

< Figure 1 >

Novice group.

Stepwise analyses. Following the procedure employed for the expert group, a forward stepwise linear regression analysis was carried out to determine the best predictors of the children's PM score in the novice group. As can be seen in Table 2, the results revealed that time-based memory performance was predicted by chronological age ($R^2 = .32$, $\beta = –.46$, $p = .004$) and time monitoring ($R^2 = .09$, $\beta = –.31$, $p = .044$). Each predictor added significantly to the total amount of variance explained ($R^2 = .41$, $F(2,32) = 11.01$, $p < .001$). Once again, since strategic time monitoring was demonstrated to predict PM score, a second stepwise regression analysis was conducted to determine which variables accounted for this variable. Its results revealed that time monitoring was predicted by the composite score of executive functions labeled EF (Errors) ($R^2 = .16$, $\beta = –.40$, $p = .018$).

< Table 2 >

Mediation analysis. Considering these findings, the mediating influence of strategic time monitoring on the relation between executive functions – EF (Errors) – and PM performance was examined. The mediation model and path coefficients are shown in Figure 2. The results revealed a significant effect of executive functions on both PM (path [c]) and time monitoring (path [a]) scores, suggesting that participants with higher executive functions had better time monitoring skills and higher PM scores. Furthermore, the results also showed a significant relation between time monitoring and PM performance (path [b]), confirming that participants with better strategic time monitoring demonstrated better PM performance. A bias-corrected bootstrap confidence interval for the indirect effect (path [ab]) based on 1,000 bootstrap samples was entirely above zero (95% CI [0.01, 1.00]), demonstrating that the influence of the executive functions on PM performance was mediated by time monitoring. Furthermore, there was no evidence that executive functions still affected PM performance independently of their effect on strategic time monitoring (path [c’]).

< Figure 2 >

Discussion

The primary focus of this study was to determine whether the indirect influence of metamemory knowledge on memory performance that is commonly observed in RM tasks would also be found when PM tasks are employed. In this experiment, a number of interesting results were obtained that confirm several previous findings and provide some promising possible avenues to explain how metamemory knowledge, strategy use, and executive functions interact to improve PM performance in childhood.

In agreement with previous studies, our results confirm that children’s PM performance improves with age and varies as a function of the cognitive demand of the ongoing activity

(Kretschmer et al., 2013; Voigt et al., 2011; Ward et al., 2007; Yang et al., 2011; T. D. Zimmermann & Meier, 2006). In the present research, the low or high level of cognitive demand associated with the ongoing task did not depend upon the task features in themselves, but rather on the participants' level of expertise with the task. Specifically, our results indicate that children who were trained to perform the ongoing procedural task before being presented with the PM paradigm (expert group) showed better time-based memory performance at test than children who were not trained to do the ongoing procedure (novice group). Additionally, the absence of any interaction between the participants' age and their level of expertise with the procedural task seems to confirm that, although it affects PM performance, the cognitive demand associated with the ongoing activity does not totally account for the improvement observed in time-based memory abilities with age. Moreover, stepwise regression analyses also revealed the expected positive relation between the score for strategic time monitoring and PM performance in both experimental groups (expert and novice), indicating that the use of an appropriate strategy seems to improve children's PM performance even when their resources are engaged in a cognitively demanding ongoing task (Costa et al., 2010; Mäntylä et al., 2007; Voigt et al., 2011; Voigt et al., 2014; Zinke et al., 2010).

However, although interesting, the aforementioned results simply replicate – using an original procedure – the results of several previous studies in the past few years. The main novelty of this experiment was that it determined which specific variables were involved in the children's implementation of effective time monitoring strategies. More specifically, our hypotheses were based on DeMarie et al.'s (2004) model of RM strategy use by children. According to those authors, the ability to use appropriate strategic memory behaviors is related to metamemory knowledge as well as to the participants' level of cognitive resources. In that light, the central finding of our research is that we demonstrated the validity of this RM model to explain how metamemory knowledge and strategy use interact to improve PM performance.

The results of the stepwise and mediation analyses carried out in our experiment reveal that the effect of children's strategic time monitoring on PM performance is predicted by metamemory knowledge in the expert group and executive functions in the novice group. More specifically, the results of this study tend to indicate that knowledge of memory functioning predicts PM performance through the implementation of an appropriate time monitoring strategy only when participants have been previously trained in the ongoing task and can therefore allocate most of their cognitive resources to the execution of the PM task. In addition, statistical analyses reveal that the mediation effect of time monitoring obtained between metamemory and PM scores is only partial (i.e., the effect of metamemory knowledge on PM performance remains significant even when the influence of time monitoring is taken into account). This result may indicate that children in the expert group – who have more available cognitive resources since they do not have to allocate them to the ongoing task – apply their metamemory knowledge to implement some supplementary memory strategies in addition to the one assessed in the present study and that the use of these supplementary strategies improves their memory performance (for studies that demonstrate the positive effect of multiple strategy use on memory performance, see Coyle, 2001).

Conversely, the stepwise analyses reveal that the use of strategic time monitoring by participants who were not trained in the procedural task before the PM test (novice group) is predicted by their executive functioning level. In other words, when the ongoing activity prevents children from using their cognitive resources to perform the time-based memory task, the implementation of a time monitoring strategy depends on their executive level rather than on their metamemory knowledge. Moreover, the statistical analysis shows that the effect of executive functions on PM performance is totally mediated by the use of the time monitoring strategy, indicating that the influence of working memory, inhibition, and flexibility skills, which are regularly identified in PM tasks (e.g., Costa et al., 2010; Kretschmer et al., 2013; Mahy et al., 2014), may be explained by the effect of these high-level functions on strategic time monitoring.

Taken as a whole, our results are consistent with DeMarie et al.'s (2004) model of RM strategy use, which assumes that strategic metamemory knowledge is useless when children do not have enough cognitive resources to use it appropriately. These findings are particularly interesting since they contribute to increase our understanding of how knowledge of memory functioning can influence memory performance in childhood. Specifically, this research has demonstrated that the positive effect of implementing strategic behaviors during a PM task can be predicted by both children's knowledge of memory functioning and their executive functions, and that the predominance of one of these variables over the other depends on the cognitive resources that must be allocated to the ongoing activity. From a developmental perspective, however, further studies still have to be carried out to determine whether this theory is valid at all times during children's cognitive development. Similarly, our results must also be replicated with a more restrictive time-based procedure. The 30-s time window used in this experiment is quite generous and, thus, could have made it more likely that children who lacked strategies could still succeed, or could even have prevented some participants from implementing an appropriate monitoring behavior due to the perceived ease of the task. From a metamemory point of view, the latter hypothesis is particularly interesting since it raises the question of whether children's assessments and beliefs about the difficulty of the PM task may influence their use of strategic metamemory knowledge.

Conclusion

The positive impact of metamemory knowledge on RM performance has long been established to be mediated by strategy use (DeMarie et al., 2004; Hutchens et al., 2012; Kron-Sperl et al., 2008). In this study, we determined that the indirect effect of metamemory on memory performance is not restricted to RM abilities but is also relevant in explaining PM performance. Specifically, the results of the present experiment revealed that children's knowledge of memory functioning improves PM performance through the implementation of appropriate strategic behavior, but only when cognitive resources are not entirely allocated to the ongoing activity. Overall, these findings extend DeMarie et al.'s (2004) model of RM to prospective tasks. That model assumes that the influence of strategy use on children's memory performance depends on both metamemory knowledge and cognitive resources. These results must, of course, be generalized to other sorts of PM paradigms. However, considering the substantial contribution PM problems make to everyday memory failures (Kliegel & Martin, 2003), the question has great practical value and thus should be carefully investigated in future metamemory research.

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Table 1

Details of the Metamemory Subtests

Screenplays	Expected responses	Sample responses
Subtest 1 You have to bring a ball to school tomorrow so you can play with your friends. What could you do so you won't forget to take it with you when you leave for school tomorrow morning?	1. Handle the ball 2. Write a note 3. Recruit human assistance 4. Use internal facilitation	1. I put the ball in the car 2. I write it on my hand 3. I ask mum to remind me to take it 4. I repeat it in my mind
Subtest 2 Imagine you have to take a cake out of an oven in a quarter of an hour. You must not take it out before this time because it would not be baked; neither must you take it out after this time because it would be burned. What could you do to remember to remove the cake from the oven at the proper time?	1. Recruit human assistance 2. Use external aids (e.g., timer) 3. Check the clock regularly 4. Use Internal facilitation	1. I ask mum to remind me to remove it 2. I make my phone ring 3. I watch the time closely 4. I repeat the word "cake"

Table 2

Stepwise Regressions Accounting for Prospective Memory and Time Monitoring Scores in Each Group (Expert vs. Novice)

Groups	Predictors	B	SEb	β	t	p	R^2
	PM						
	Step 1: Metamemory	–0.97	0.34	–.43	2.85	.007	.38
Expert	Step 2: Time Monitoring	–2.42	0.99	–.36	2.44	.020	.11
	Time Monitoring						
	Step 1: Metamemory	0.18	0.05	.54	3.77	<.001	.30
	PM						
	Step 1: Age (months)	–0.04	0.01	–.46	3.12	.004	.32
Novice	Step 2: Time Monitoring	–1.72	0.82	–.31	2.09	.044	.09
	Time Monitoring						
	Step 1: EF (Errors)	–0.19	0.08	–.40	–2.49	.018	.16

Figure Captions

Figure 1. Path coefficients of the mediation model for the expert group including metamemory knowledge as independent variable, time-based PM as dependent variable, and strategic time monitoring as mediator.

Figure 2. Path coefficients of the mediation model for the novice group including executive functions (composite errors score) as independent variable, time-based PM as dependent variable, and strategic time monitoring as mediator.