Involvement of Executive Functions in Children Metamemory

Marie Geurten, Corinne Catale, & Thierry Meulemans

Department of Psychology: Cognition and Behavior, Neuropsychology Unit, University of Liège, Belgium

Corresponding author:

Marie Geurten
Department of Psychology: Cognition and Behavior
Neuropsychology Unit
University of Liège
Boulevard du Rectorat – B33
Sart Tilman, 4000 Liège
BELGIUM

Email: mgeurten@ulg.ac.be

Phone: +3243665943

Abstract

This experiment examined how knowledge of memory strategies and of memory functioning improves during childhood and what variables are involved in this development. Three main aspects of metamemory were assessed based on the performance of a group of 100 children (aged 4, 6, 9, and 11) on a battery of executive tasks. At the same time, the influence of variables such as intelligence, vocabulary and parental education level was also investigated. Results of mediation analyses reveal that the relation between children's age and internal strategy knowledge was partially mediated by working memory skills, but that executive functions did not mediate the impact of chronological age on children's knowledge of external strategies or of memory functioning. Additionally, verbal fluency predicted internal and external strategy knowledge. Implications for general learning theories in childhood are discussed.

Keywords: Metamemory, Executive functions, Working memory, Children

Introduction

Over the past few decades, many studies on episodic memory have focused on the mechanisms and variables that increase memory performance. One of the best-supported findings in this area involves the positive influence of metamemory skills. Specifically, several studies have shown that knowledge of memory functioning (i.e., metamemory) can improve prospective and retrospective memory performance by causing people to implement appropriate strategies (DeMarie, Miller, Ferron, & Cunningham, 2004; Geurten, Catale, & Meulemans, 2015; Geurten, Lejeune, & Meulemans, 2015; Grammer, Purtell, Coffman, & Ornstein, 2011; Hutchens et al., 2012).

According to Schneider (2008), metamemory comprises knowledge of strategies, including both internal (e.g., mental imagery) and external strategies (e.g., shopping lists), and general knowledge of memory functioning (e.g., delay effect). As mentioned above, metamemory has consistently been shown to be involved in the implementation of appropriate memory strategies by adults (Hutchens et al., 2012) and children (Geurten, Lejeune et al., 2015). In their longitudinal study, for example, Grammer et al. (2011) established that 6-year-old children's use of organizational strategies (e.g., conceptual sorting and clustering) on a classical sort-recall memory task at a specific time point was predicted by their explicit knowledge of these strategies three months earlier.

From a developmental point of view, much of the research on metamemory shows that 4-year-old children already have some basic knowledge of memory functioning (e.g., Justice, 1989; O'Sullivan, 1993; Wellman, 1978) and that this knowledge improves significantly during childhood: moderately between the ages of 4 and 6 years, then more dramatically between 6 and 12 years of age (Antshel & Nastasi, 2008; Fritz, Howie, & Kleitman, 2010; Geurten, Catale et al., 2015; Joyner & Kurtz-Costes, 1997; Kreutzer, Leonard, & Flavell, 1975). Some authors have recently postulated that certain high-level cognitive functions may be involved in the development of knowledge of memory functioning (Antshel & Nastasi, 2008; Fernandez-Duque, Baird, & Posner, 2000; Grammer et al., 2011). Antshel and Nastasi (2008), for instance, who studied the development of metamemory in preschool children with Attention Deficit Hyperactivity Disorder (ADHD), showed that, at age 4, children with ADHD had comparable metamemory skills to control children. At the one-year follow-up, however, the control participants demonstrated strong gains in metamemory, but the children with ADHD did not show any significant improvements in their metamemory performance. Interestingly, in that study, data analyses revealed that metamemory scores tended to be related to children's level of executive functioning at both assessment points.

Similarly, Benson, Sabbagh, Carlson, and Zelazo (2013) postulated that some processes associated with executive functions could play a critical role in learning from environmental experience. In particular, executive functions allow people to (a) identify relevant variables and situations (Diamond, Barnett, Thomas, & Munro, 2007); (b) notice discrepancies between expectations and outcomes (i.e., error monitoring; Zelazo, Carlson, & Kesek, 2008); and (c) flexibly update prior knowledge based on new evidence. In sum, it would appear that the development of metamemory depends on the executive ability to detect relevant information from environmental experience and then update the metamemory repertoire by deleting outdated beliefs when necessary (see also Fernandez-Duque et al., 2000). To our knowledge, however, no previous study has been carried out to confirm this hypothesis and examine the relations between metamemory and executive functions with a data set covering a long period of childhood. To date, researchers studying the relationships between metamemory and executive functions have mostly focused on the ability to assess memory states and regulate memory performance (a component of metamemory called “procedural metamemory”; see Schneider, 2008). However, the relationship between knowledge of memory functioning and executive functions is still relatively unexplored.

In this context, the main aim of this study is to investigate whether the well-established influence of chronological age on different categories of metamemory knowledge could be mediated by children’s executive functioning. More specifically, we hypothesized that the strongest link between executive functions and metamemory involves aspects related to knowledge of internal strategies. For one thing, internal strategies do not need concrete, environmental aid to be applied (Intons-Peterson & Fournier, 1986). Furthermore, they are rarely verbalized by adults (Coffman, Ornstein, McCall, & Curran, 2008). This makes them relatively hard-to-observe behaviors, which presumably require more effort, more commitment, and more monitoring to be learned. Therefore, we assumed that they should be more dependent on high-level cognitive functions.

In contrast, executive functions should be less involved in the learning of external strategies. Intrinsically, these strategies are easily observable; at least, the external instruments that support them are (Lovelace & Twohig, 1990; Schryer & Ross, 2013). Furthermore, the utilization of strategies requiring external aid is frequently encouraged – and thus explained – by parents (e.g., “put your bag in the car so you don’t forget it tomorrow morning”) or by teachers (e.g., “write in your diary that you have to ask your mother to sign this paper so you’ll be sure to remember it"). Consequently, we hypothesized that external strategies depend more on the accessibility of metamemory experience than on cognitive influences. In this context, executive functions would play a smaller role in their improvement with age.

Along the same lines, general knowledge of memory functioning is not usually considered to be related to executive functions. This knowledge, which concerns, for example, the effects of delay or interference on memory performance, is the early basis for metamemory (e.g., Johnson & Wellman, 1980; Schneider, 2008) and is usually demonstrated to be related to variables such as socioeconomic status (Pears & Moses, 2003), maternal education (Grammer et al., 2011), and verbal ability (Cutting & Dunn, 1999), all of which are associated with parent-child talks about metacognitive states. But these demographic variables do not tell us anything about the specific cognitive mechanisms that underlie the development of metamemory knowledge.

Nevertheless, the finding that executive functions are not related to metamemory at a given point in children's development does not mean that they never will be. Indeed, although executive functions are demonstrated to emerge as early as 2.5 years old (e.g., Garon, Bryson, & Smith, 2008), most researchers agree that major changes in executive functioning occur between 4 and 6 years old and are followed by continued refinement throughout childhood and adolescence (for a review, see Best & Miller, 2010). The relative immaturity of executive functions implies that they might have no major or significant relationship with metamemory before the age of 6. However, at age 6 and later, a more visible link should appear between high-level cognitive functions and certain metamemory factors.

For this reason, in our study, a large battery of executive tasks measuring inhibition, planning, working memory, and verbal fluency abilities was given to four groups of children aged 4, 6, 9 and 11 years old, respectively (for studies that establish the importance of these four ages in children's metamemory development, see Antshel & Nastasi, 2008; Fritz et al., 2010; Geurten, Catale et al., 2015). At the same time, a three-factor metamemory scale assessing knowledge of internal and external strategies and of general memory functioning was administered to each child. In line with the work of Benson et al. (2013; see also Fernandez-Duque et al., 2000), the main goal of the present research was to examine the influence of executive functions on different components of children's metamemory (i.e., internal strategy knowledge, external strategy knowledge, and general knowledge of memory functioning). In a more exploratory way, the relations between specific metamemory factors and variables such as intelligence, vocabulary and parental education level were also investigated.

Method

Participants

The participants were 100 typically developing unilingual children aged 4, 6, 9, and 11 years old. The demographic characteristics of each age group and the whole sample are summarized in Table 1. As Table 1 shows, the proportion of girls and boys was roughly equivalent in each age group, $\chi^2(3) = .52$, $p = .91$. Similarly, no age group difference was found in terms of parental education level, $F(3,96) = 0.67$, $p = .57$, assessed by means of both parents' years of education; reasoning intelligence, $F(3,96) = 1.19$, $p = .32$; and verbal ability, $F(3,96) = 2.52$, $p = .06$. Children were recruited from French-speaking kindergartens and elementary schools in the province of Liège, Belgium.

< Table 1 >

Materials

Metamemory scale.

Five subtests inspired by Kreutzer et al.'s (1975) interview were used to measure metamemory. These five subtests (Preparation Object, Retrieval Event, Immediate Delay, Retroactive Interference, and Rote Paraphrase) were adapted for French-speaking children and modified to assess three main components of metamemory: knowledge of internal strategies, knowledge of external strategies, and knowledge of general memory functioning (for a study demonstrating the good psychometric properties of this scale, see Geurten, Catale et al., 2015). Basically, participants were presented with a variety of vignettes and, depending on the scenario, were asked either to list as many applicable strategies as possible or to select from two alternative responses (forced-choice) and justify their answer. Only responses relevant to the scenario were scored as correct. In preparation for the task, children were given a practice scenario to ensure that they understood the instructions. Corrective feedback was provided at the end of it. Compared with the English versions of the scale, the length of the scenarios and the vocabulary used to describe them to participants were simplified, some of the situations presented in the scenario were revised so that European children could understand them more easily, and illustrations were provided for each scene in order to lighten subjects' memory load. For every vignette, separate scores were calculated each time internal strategy, external strategy, or general memory functioning answers were provided. Ten scores were obtained for the five subtests; the maximum score was 6 marks for internal and external strategy factors and

7 marks for the general memory knowledge factor. Information on scenarios, allowable responses, and scoring criteria is given in Table 2.

< Table 2 >

Intelligence assessment tasks.

Peabody Picture Vocabulary Test. The French version of the Peabody Picture Vocabulary Test (PPVT-R; Dunn, Thériault-Whalen, & Dunn, 1993) is a measure of receptive vocabulary that requires children to choose which one of four pictures best illustrates a word. The 170 items are ordered based on their difficulty. The raw score is calculated by subtracting from the ceiling item (last item administered) the total number of errors made after the basal item (eighth item in succession answered correctly).

Matrix Reasoning. Matrix Reasoning is a subtest of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2005) and of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III; Wechsler, 2004) and is traditionally used to evaluate nonverbal “fluid” intelligence (Tamm & Juranek, 2012). In this study, the 4-year-old children were given the WPPSI subtest while the three older groups were given the WISC subtest. The dependent variable was the standard score for the number of correct solutions provided in the task.

Cognitive tasks.

***Fruit Stroop*.** Like many Stroop-type tasks, the Fruit Stroop assesses individuals’ ability to inhibit dominant verbal responses. Developed by Santostefano (1988) and adapted for children by Archibald and Kerns (1999), this task – used by Wright, Waterman, Prescott, and Murdoch-Eaton (2003) with participants aged from 3 to 16 – has the advantage of enabling non-readers to perform as well as readers do. The task has been adapted many times as a result of past studies. Here, we chose to employ a computerized version adapted from Catale, Lejeune, Schmitz, and Meulemans (2014). Specifically, three sections were created. In the first one, 48 colored squares (blue, green, red, and yellow) appeared successively on the computer screen. Participants were asked to press the answer key (indicated by a colored sticker) corresponding to the color of the squares as quickly as possible. The second section presented uncolored fruits (banana, strawberry, and pear). Children were instructed to name the colors that the fruits should have by pressing the appropriate answer key. In the third section, participants were shown 48 wrongly colored fruits (e.g., red banana, blue strawberry, and yellow pear) and, once again, were required to press, as quickly as possible, the key corresponding to the color that the fruits should have. For each section, reaction times and numbers of errors were recorded. An interference score was then calculated (interference index; see Meulemans, 2008). This score was obtained by subtracting the median reaction time in the first section (colored squares) from the median reaction time in the final section (incorrectly colored fruits). The same procedure was applied to errors. In both cases, low values indicated better inhibition control.

Go/No-Go. The Go/No-Go task is a commonly used computerized measure of motor inhibition administered to preschoolers and adults without demonstrating either floor or ceiling effects (Drewe, 1975; Raaijmakers et al., 2008). Participants were required to respond as quickly as possible by pressing a response key (in this case, the spacebar) each time that a preselected target (the “Go stimulus”: a red cat) appeared. Responding to a distractor (the “No-Go stimulus”: a black cat) was recorded as a Commission error. Not responding to a target was recorded as an Omission error. Stimuli (50% of targets) are presented in random order. Each stimulus was presented for 350 ms, with variable interstimulus intervals ranging from 1900 to

4100 ms. An initial practice block of 8 trials preceded the experimental block of 40 trials. Scoring was based on (a) total Commission and Omission errors and (b) median reaction time to the “Go stimuli.”

Self-Ordered Pointing. The Self-Ordered Pointing Test (SOPT), originally described by Petrides and Milner (1982), is a working memory task designed to appraise executive monitoring skills, that is, the ability to generate and monitor a sequence of responses. Over time and across studies, the task has been considerably adapted – mainly to be useable with children as young as 4 without demonstrating floor effects (Cragg & Nation, 2007) – but the general principle has remained the same. To perform well on the task, subjects have to keep the previously chosen item in mind and use this information to guide subsequent responses. In this study, a computerized version of a verbal form of the SOPT was administered. The task had the appearance of a book, divided into sections composed of pages. Every page in the book contained a set of drawings of common objects. The same pictures were presented on each page of a section, but in a different spatial location each time. Children were instructed to touch a picture on the screen and then a new one on each page until they had pointed to all the pictures in the section. Repeating a choice was scored as an error. Specifically, in this experiment, after a practice trial, participants viewed five series of colored pictures containing 4, 5, 6, 8, and 10 concrete nameable objects, respectively. These pictures were taken from the standardized set developed by Rossion and Pourtois (2004). To prevent subjects from always pointing to the same location on the screen, drawings were randomly arranged on each page. Each series was presented twice. The second time a given series was administered, children were asked to begin by choosing a different picture than in the previous trial. The total number of errors in both parts of the task was used as dependent variable.

Tower of London. Planning ability was investigated using a computerized version of the Tower of London (ToL). Procedures for administering and scoring the test were taken from Lussier, Guerin, Dufresne, and Lassonde (1998). Originally designed to appraise planning abilities in children aged 6 to 12 years old, this task has been used with children as young as 3 (Klenberg, Korkman, & Lahti-Nuuttila, 2001). In this study, pictures of the traditional pegs of different lengths attached to a strip and the three colored balls were presented on the computer touch screen. Children were asked to move the balls from a prearranged model to a new one by making no more than a specified limited number of movements. Before the beginning of the test, a practice problem was presented to familiarize children with the task and the touch screen's functioning. Twelve problems of increasing difficulty were then administered. The problems' difficulty was determined according to their complexity and the number of moves (from 2 to 5) permitted. A maximum of six trials was allowed to complete each level. The mean of the total number of trials required to solve the 12 problems was used as dependent variable.

Verbal fluency. Although they have little cognitive specificity, verbal fluency tasks have been shown to be sensitive to prefrontal cortex functioning, which is known to be related to executive skills (Phelps, Hyder, Blamire, & Shulman, 1997). In their various forms, these tasks assess the ability to generate an original strategy for conducting an organized search in the internal semantic network (Welsh, Pennington, & Groisser, 1991). In this study, children were asked to name as many examples as possible from two specific semantic categories within a 60-

second time frame. “Animals” and “things that can be eaten or drunk” were the two selected categories. Items named more than once or words that fell outside the above-mentioned categories were scored as incorrect. The dependent measure for this task was the total number of correct examples across both categories.

Procedure

The consent of the parents and of the school principals was obtained before the study started. Children were tested individually in a quiet room in their school, using a touch screen computer. Each child participated in two 45-minute sessions approximately one week apart. In session 1, half the participants were given the Matrix subtest, the metamemory scale, the Go/No-Go, and the PPVT-R; the remaining tasks were presented in session 2. The other half of the participants completed the sessions in the opposite order. The order of the tests was counterbalanced within sessions. Analyses indicated no effect of order of presentation on performance of any of these tests.

Results

Data Analysis

The involvement of chronological age and executive functions in children’s metamemory performance was investigated. At the same time, the influence of variables such as intelligence, vocabulary and parental education level was also examined. To do so, correlation and mediation analyses were carried out to determine how these variables interacted to influence children’s metamemory skills. All results reported in the present section were considered significant when the exceedance probability was lower than .05. One of the critical requirements for the use of a mediation analysis is that significant linear associations are highlighted between all the independent and dependent variables included in the model before testing for a mediated effect (Preacher & Hayes, 2008). Thus, in the following section, mediation analyses were not conducted when this prerequisite was not fulfilled.

< Table 3 >

Preliminary Analyses

As mentioned above, a large battery of cognitive tasks was administered in this study. These tasks were selected to be applicable to every age group in our sample without demonstrating either floor or ceiling effects. Levene’s tests were carried out to ensure that each variable included in the analyses showed homogeneity of variance. Only the interference index computed for reaction times in the Fruit Stroop task and the internal strategy factor of the metamemory scale revealed an unequal variability between age groups ($p = .005$ and .001, respectively). Descriptive statistics for all the independent and dependent variables are presented in Table 3, and a matrix of correlations for all the cognitive and demographic measures included in this study is displayed in Table 4. We should also note that the significant correlations between reaction times ($r = .55$, $p < .001$) and number of errors ($r = .31$, $p = .002$) on the two inhibition tasks led us to calculate composite scores regrouping these measures. Reaction times and number of errors on the Go/No-Go and Fruit Stroop (interference scores) tasks were standardized and averaged, respectively, to form two separate composite scores labeled as (a) inhibition (RT) and (b) inhibition (Errors).

< Table 4 >

Finally, the internal reliability of the three factors of the metamemory scale was also inspected using Cronbach’s α. The coefficient was .87 for the whole scale and .77, .71 and .69, respectively, for the internal strategy, external strategy and general memory functioning factors. These scores indicated acceptable to good internal reliability for each of the values (Schmitt, 1996).

Correlation Analyses

As can be seen in Table 3, the results of the one-way analyses of variance (ANOVAs) revealed a significant difference between age groups for the total metamemory scale, $F(3, 96) = 102.16$, $p < .001$, $n^2_p = .76$; the internal strategy factor, $F(3, 96) = 62.40$, $p < .001$, $n^2_p = .66$; the external strategy factor, $F(3, 96) = 24.85$, $p < .001$, $n^2_p = .44$; and the general memory functioning factor, $F(3, 96) = 56.42$, $p < .001$, $n^2_p = .64$. For this reason, separate correlation analyses were conducted to determine which variables are related to these metamemory scores in each of the age groups included in our sample. As Table 5 reveals, significant correlations were highlighted between the working memory measure (i.e., the total number of errors in the SOPT), and both the total score and the internal strategy score of the metamemory scale for 6-, 9-, and 11-year-old children. A statistically significant link was also found between the planning measure (i.e., the mean of the total number of trials in the ToL) and the latter two metamemory scores for 11-year-old children. In addition, correlations were observed between the verbal fluency score and the total metamemory scale, the internal strategy factor, and the external strategy factor for the three older groups of children. However, neither cognitive nor demographic variables were found to correlate with the general memory functioning factor of the metamemory scale. Similarly, no variable was shown to be related to 4-year-old children’s metamemory scores.

Overall, the links between the metamemory factors and the executive tasks tended to be small. However, some significant correlations of medium and large effect sizes were highlighted for certain specific metamemory scores, suggesting that not all types of executive skills are involved in children's knowledge of memory functioning. The relationships between these cognitive and metamemory scores are further examined in the next section.

<Table 5>

Mediation Analyses

The primary aim of this study was to investigate whether and how executive functions affected metamemory performance. 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 executive functions on the relation between chronological age and metamemory performance. In this section, we use the standard nomenclature proposed by Preacher and Hayes (2008) to report the results of the mediation analyses. Using this codification, the [a] coefficient estimates the strength of the direct link between the independent variable and the mediator. The [b] coefficient estimates the strength of the direct link between the mediator and the dependent variable. The [c] coefficient estimates the strength of the direct link between the independent and dependent variables. The [ab] coefficient estimates the indirect effect of the independent variable on the dependent variable. Finally, the [c'] coefficient estimates the direct effect of the independent variable on the dependent variable when the mediator's influence is taken into account. The analyses were conducted first on the total score of the metamemory scale, and then on the three metamemory subscales.

Total metamemory score. The mediation model and the significant path coefficients are shown in Figure 1. The results revealed a significant effect of chronological age on the metamemory score (path [c]), as well as on all cognitive measures (path [a]), confirming that both metamemory and executive performance improve with age. Furthermore, the results also showed a significant effect of two cognitive measures (i.e., working memory and verbal fluency scores) on metamemory performance (path [b]), suggesting that participants with better high-level cognitive abilities demonstrated better metamemory performance. On the whole, each of the three predictors included in the model added significantly to the total amount of variance explained, $R^2 = .80$, $F(3,96) = 125.00$, $p < .001$. A bias-corrected bootstrap confidence interval for the indirect effect (path [ab]) based on 1,000 bootstrap samples was entirely above zero for the working memory (95% CI [0.001, 0.019]) and verbal fluency (95% CI [0.021, 0.069]) scores, suggesting that the influence of children's age on metamemory performance was mediated by working memory and verbal fluency skills. Specifically, because the working memory task employed in the present study (the SOPT) was designed to appraise children's monitoring abilities (Cragg & Nation, 2007), the latter results seem to indicate that executive monitoring processes mediate the effect of age on children's metamemory. However, this mediation effect was only partial. In fact, evidence was found that chronological age still affected metamemory independently of its effect on the presumed mediated influence (path [c']).

< Figure 1 >

Internal strategy score. The mediating influence of executive functions on the relation between chronological age and internal strategy knowledge was investigated. The mediation model and path coefficients are shown in Figure 2. The results showed a significant effect of chronological age on the metamemory score (path [c]) and on each of the cognitive measures (path [a]). Data analyses also revealed a significant effect of working memory and verbal fluency on internal strategy knowledge (path [b]). Once again, the three variables included in the model (i.e., chronological age, verbal fluency, and working memory) added significantly to the total amount of variance explained, $R^2 = .67$, $F(3,96) = 64.24$, $p < .001$. A bias-corrected bootstrap confidence interval for the indirect effect (path [ab]) based on 1,000 bootstrap samples was entirely above zero for the working memory (95% CI [0.002, 0.003]) and verbal fluency (95% CI [0.003, 0.012]) scores, indicating that the influence of children's age on internal strategy knowledge was mediated by working memory (i.e., monitoring skills) and verbal fluency abilities. However, as with the total score on the metamemory scale, the mediation effect was only partial. Indeed, the results revealed that chronological age still affected metamemory performance independently of its effect on the presumed mediated influence (path [c']).

< Figure 2 >

External strategy score. The influence of executive functions on the relation between chronological age and external strategy knowledge was examined. The mediation model and path coefficients are shown in Figure 3. Once again, the results revealed a significant effect of children's age on metamemory (path [c]) and all cognitive (path [a]) scores. Furthermore, the results also showed a significant relation between chronological age and verbal fluency (path [b]). The global model also appeared to be significant, $R^2 = .47$, $F(2,97) = 42.78$, $p < .001$. A bias-corrected bootstrap confidence interval for the indirect effect (path [ab]) based on 1,000 bootstrap samples was entirely above zero (95% CI [0.007, 0.028]), demonstrating that the influence of the children’s age on external strategy knowledge was mediated by verbal fluency skills. Furthermore, there was no evidence that chronological age still affected children’s level of external strategy knowledge independently of its effect on verbal fluency (path [c']).

< Figure 3 >

General memory functioning score. Finally, the mediating influence of executive functions on the relation between chronological age and the general memory functioning factor of the metamemory scale was explored. A significant effect of children’s age on the general memory functioning subscale was highlighted, $\beta = .78$, $p < .001$, $R^2 = .60$. However, no significant relation was found between the executive variables included in our analyses and the metamemory score, ruling out the use of a mediation analysis.

Discussion

The principal aim of this study was to examine whether executive functions are involved in the improvement of three main categories of metamemory knowledge – internal strategy knowledge, external strategy knowledge and general memory knowledge – during childhood. The results demonstrate that individual differences in some specific executive functions mediate the influence of chronological age on some components of metamemory. As hypothesized, of the three assessed metamemory factors, internal strategy knowledge was the most sensitive to executive abilities. In particular, working memory skills were shown to be involved in the development of the internal strategy repertoire.

An explanation of this influence of working memory on internal strategy knowledge can be found in Benson et al.’s (2013) study of metacognitive beliefs. Extended to the field of strategic metamemory knowledge, these authors’ hypothesis seems to explain our findings quite adequately (see also Fernandez-Duque et al., 2000). Specifically, Benson et al. assume that to engage in effective experience-based learning, children have to monitor their behavior so they can notice discrepancies between expected outcomes and actual ones and then integrate the new information they have just learned into their repertoire of knowledge. Under such conditions, it is not surprising that working memory skills are found to be linked to internal strategy knowledge. Indeed, in the present study, working memory was assessed using a task specifically designed to appraise children's monitoring abilities (Cragg & Nation, 2007).

However, Benson et al.'s (2013) theory allows us to explain more than the development of internal strategy knowledge. In fact, their understanding of the learning-through-experience process can also be applied to explain why – with the exception of verbal fluency – no relationship was found between executive variables and external strategy knowledge. As Pintrich (2002) points out, although many children fail to acquire metamemory through day-to-day experience, some are actually able to learn quite effectively when metamemory is trained explicitly (see also Grammer et al., 2011; Kinsella et al., 2009; Troyer, Murphy, Anderson, Moscovitch, & Craik, 2008). Kurtz, Schneider, Carr, Borkowski, and Rellinger (1990) demonstrated that external strategies are frequently taught and their use is often encouraged by teachers. In parallel, the observation of external strategy execution is generally easier and less demanding in terms of cognitive resources since such strategies require a concrete instrument to be used. Consequently, children probably do not need to implement effortful processes to monitor the effectiveness of external strategies as they do for internal ones.

In fact, the results reveal that high-level cognitive functions affect the external strategy score only when an organized search in the semantic repertoire is required. Specifically, a link between internal and external strategy knowledge and verbal fluency abilities was highlighted. These findings were expected and can easily be explained. As was demonstrated by Hodzik and Lemaire's (2011) and Hutchens et al.'s (2012) studies of normal aging and amnesic mild cognitive impairment syndrome, respectively, poor access to the semantic repertoire due to a decrease in – or in the present case, the immaturity of – organized search abilities prevents participants from explicitly generating as many strategies as they actually know. On the contrary, better-organized search abilities are associated with higher metamemory scores which, in turn, are usually found to be associated with a higher probability of implementing appropriate mnemonic strategies as well as with better memory performance (Hutchens et al., 2012).

After explaining how experience and executive functions interact in the acquisition of internal and external strategy knowledge, it remains to be determined how more general knowledge about memory is learned. According to the literature, certain demographic characteristics are assumed to be involved in the development of such general memory knowledge (Cutting & Dunn, 1999; Pears & Moses, 2003), as well as in the development of metamemory knowledge of all kinds (Joyner & Kurtz-Costes, 1997). Nevertheless, contrary to this hypothesis, none of the cognitive or demographic variables included in the analyses explains the improvement in general memory knowledge with age.

One could argue that this unforeseen result stems from the way general knowledge of memory functioning was assessed in this study. In fact, four marks out of the seven allocated for the general knowledge factor were justification marks, that is, participants had to defend their forced-choice answers. This part of the task demands strong verbalization skills since children are required to explicitly put their thoughts into intelligible words. Thus, it is possible that the knowledge captured by the scale is not an accurate reflection of what children really know about memory functioning but only of what they are able to explicitly express. Consequently, the effect of demographic variables on metamemory knowledge may have been artificially underestimated because of the scale's lack of sensitivity. However, we choose to reject this assumption.

In fact, because the scale employed in this study has been shown to be more sensitive and less language-dependent than classical measures of metamemory knowledge (Geurten, Catale et al., 2015), it might be assumed that the link between demographic variables and general memory knowledge highlighted in previous studies (Fritz et al., 2010; Grammer et al., 2011; Joyner & Kurtz-Costes, 1997; Lockl & Schneider, 2006) is not a real effect but a statistical artifact due to the language contamination of the assessment tools used in those studies (see Bebko, McMorris, Metcalfe, Ricciuti, & Goldstein, 2014). But, if this postulate is confirmed and the effect of demographic characteristics on metamemory knowledge is shown to be a simple reflection of a methodological bias, how can the improvement in general memory knowledge with age be explained?

One answer to this question may be found in Goschke and Bolte's (2007) work on semantic knowledge acquisition. According to these authors, semantic learning occurs by means of an implicit process involving the detection of environmental regularities. And metamemory is nothing but complex semantic knowledge about memory (Hutchens et al., 2012). With this in mind, it could be hypothesized that some aspects of the metamemory development observed during childhood are due not to explicit but to implicit learning of memory functioning. None of the data collected in this study allow us to either confirm or refute this interpretation, but it opens up interesting prospects for future investigation.

Nevertheless, although the lack of results for general knowledge about memory functioning is quite surprising, it provides more than a few avenues for future research. The highlighted dissociation between the variables that influence the three factors of the metamemory scale has the benefit of demonstrating that different kinds of metamemory knowledge do not all improve through the same processes. Although the variables underlying general memory learning remain to be determined, this study has shed light on the development of strategy knowledge. Naturally, these findings must be confirmed in future investigations using a longitudinal approach, for example; among other things, this kind of approach would be most likely to control the mutual positive effect that strategy knowledge and executive performance can have on each other. (For a longitudinal study demonstrating the interrelation between executive abilities and theory of mind, for example, see Schneider, Lockl, & Fernandez, 2005.)

Conclusion

This study allowed us to show that executive functions – and, particularly, working memory skills – seem to be involved in the improvement of internal strategy knowledge during childhood. However, although this finding is quite interesting in itself and enhances our understanding of how executive functions and experience work together to influence the development of metamemory, some questions remain unanswered. In particular, it remains unclear how general knowledge about memory is learned from environmental experiences. Our assumption is that an implicit process may be involved, but at present we do not have sufficient data to confirm this hypothesis, which will be further explored in the future.

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Figure Captions

Figure 1. Unstandardized path coefficients of the mediation model including chronological age (in months) as independent variable, the total score for the metamemory scale as dependent variable, and verbal fluency and working memory measures as mediators.

Figure 2. Unstandardized path coefficients of the mediation model including chronological age (in months) as independent variable, the internal strategy factor as dependent variable, and verbal fluency and working memory measures as mediators.

Figure 3. Unstandardized path coefficients of the mediation model including chronological age as independent variable, external strategy factor as dependent variable, and verbal fluency as mediator.

Table 1

Participants' Characteristics (Means and Standard Deviations) by Age Group

	All (n = 100)	4 years (n = 24)	6 years (n = 28)	9 years (n = 20)	11 years (n = 28)
Female (No.)	55/100	12/24	16/28	12/20	15/28
Age (Months)	94.90 (32.91)	53.58 (3.55)	75.29 (3.43)	115.16 (3.95)	135.46 (3.65)
Parental Education Level	14.00 (2.04)	13.92 (2.10)	13.87 (2.15)	14.58 (2.06)	13.79 (1.93)
Intelligence (Matrix)	10.07 (2.85)	10.83 (2.46)	9.43 (2.61)	9.75 (3.88)	10.29 (2.49)
Vocabulary (PPVT-R)	110.65 (8.75)	107.00 (9.82)	110.07 (10.04)	112.85 (4.63)	112.78 (7.89)

Note. Matrix = Matrix Reasoning subtest of Wechsler Intelligence Scale for Children; PPVT-R = Peabody Picture Vocabulary Test

Table 2

Details of the Metamemory Scale

Scenarios	Allowable responses	Scoring
Preparation object 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. Manipulate the ball** **2. Write a note** **3. Recruit human assistance** *4. Use internal facilitation (e.g., rehearsal)*	*Internal strategy: MAX = 1* **External strategy: MAX = 3**
Immediate delay Imagine you are a treasure hunter and you have found a chest. But this chest is locked and only a code will unlock it. This code is "4729." What do you do first? Unlock the chest or take a minute to drink some water before that? Why? What could you do to remember a long set of numbers?	1. Open the chest first 2. Not forget the code *3. Rehearse*/**Write a note**	General knowledge: MAX = 2 *Internal strategy: MAX = 1* **External strategy: MAX = 1**
Retrieval event Imagine you have a friend who has a dog. You ask him when he got it. He says he got it as a puppy and he knows it was a Christmas gift, but he does not remember the year. What could he do to remember the year he got his dog?	**1. Look at some documents (e.g., birth certificate)** **2. Recruit human assistance** *3. Use mathematical reasoning (e.g., the current calendar year minus the dog's age)* *4. Associate other details of the relevant Christmas*	*Internal strategy: MAX = 2* **External strategy: MAX = 2**
Retroactive interference One day, two friends go to a party and meet 7 children they did not know before. After the party, one of the two friends comes back home while the other goes to play football. There, he meets 6 children he did not know before. In the evening, the children are asked by their parents for the names of all the children they met at the party. Who is going to remember better? The one who came straight home or the one who played football? Why?	1. The child who went back home 2.1. The one who played football met more children 2.2. He is more likely to mix up the children's names	General knowledge: MAX = 3
Rote paraphrase There is a boy. His teacher has asked him to listen to a story on a CD. He instructed him to pay attention to it because he will have to tell the whole story to the class later. How do you think it will be easier for the boy to tell the story later: word for word or in his own words? Why? What would you do if you wanted to learn a story word for word? What would you do if you wanted to learn a story in your own words?	1. In his own words 2. Learning something by heart without repetition is very hard. In our own words, we just have to remember the important events of the story. *3. Rehearse* *4. Remember key events*	General knowledge: MAX = 2 *Internal strategy: MAX = 2*

Table 3

Scores (Means and Standard Deviations) on the Executive Variables and the Metamemory Scores by Age Group

	4 years	6 years	9 years	11 years	F	p
Executive scores						
Fluency	14.12 (4.03)	20.21 (5.39)	32.35 (6.39)	37.14 (8.08)	75.57	<.001
Inhibition (GNG – Errors)	7.08 (3.89)	6.21 (3.94)	4.02 (2.96)	3.29 (2.34)	7.38	<.001
Inhibition (GNG – RT)	745.71 (142.74)	563.5 (104.36)	442.80 (72.70)	398.07 (105.65)	49.05	<.001
Inhibition (Stroop – Error Index)	1.34 (1.44)	1.23 (1.12)	0.098 (1.16)	0.48 (1.13)	3.25	.025
Inhibition (Stroop – RT index)	26.33 (13.74)	18.94 (10.97)	11.65 (4.14)	11.07 (6.10)	13.44	<.001
Planning (ToL)	5.57 (0.73)	5.02 (0.70)	4.87 (0.49)	4.40 (0.60)	16.06	<.001
Working Memory (SOPT)	4.03 (0.93)	3.27 (0.93)	2.58 (0.89)	2.53 (0.76)	15.80	<.001
Metamemory scores						
Total	4.33 (1.46)	7.04 (2.59)	10.85 (2.68)	14.86 (2.35)	102.16	<.001
Internal strategies	1.17 (0.56)	1.89 (0.96)	2.60 (1.19)	4.82 (1.25)	62.40	<.001
External strategies	1.25 (1.26)	2.79 (1.52)	3.21 (0.95)	4.29 (1.21)	24.85	<.001
General knowledge	1.92 (0.88)	2.43 (1.38)	5.05 (1.82)	5.85 (1.14)	56.42	<.001

Note. RT = Reaction Time; GNG = Go/No-Go; ToL = Tower of London; SOPT = Self-Ordered Pointing Test

Table 4

Partial Correlation Matrix for Cognitive and Demographic Variables, Controlling for Chronological Age

	Fluency	GNG-Errors	GNG-RT	Stroop-Errors	Stroop-RT	ToL	SOPT	Matrix	PPVT-R
Cognitive variables									
Fluency	/								
Inhibition (GNG – Errors)	–.21*	/							
Inhibition (GNG – RT)	–.19	.02	/						
Inhibition (Stroop – Error Index)	–.21*	.31*	.16	/					
Inhibition (Stroop – RT index)	–.15	.12	.55**	.18	/				
Planning (ToL)	–.28*	.14	.32**	.13	.17	/			
WM (SOPT)	–.20*	.14	.30*	.18	–.06	.24*	/		
Demographic variables									
Intelligence (Matrix)	.01	–.22*	–31*	.09	–.28*	–.29*	–.22*	/	
Vocabulary (PPVT-R)	.25*	–.25*	–08	–.10	–.06	–.01	–.11	.18	/
Parental Education Level	.27*	–.14	–13	–.21*	–.28*	–.14	–.18	.14	.31*

Note. RT = Reaction Time; WM = Working Memory; GNG = Go/No-Go; ToL = Tower of London; SOPT = Self-Ordered Pointing Test; Matrix = Matrix Reasoning subtest of Wechsler Intelligence Scale for Children; PPVT-R = Peabody Picture Vocabulary Test – Revised

*p < .05; **p < .001

Table 5

Correlations between Cognitive and Demographic Variables and Each of the Metamemory Scores by Age Group

	4 years				6 years				9 years				11 years			
	Tot	Int	Ext	Gen	Tot	Int	Ext	Gen	Tot	Int	Ext	Gen	Tot	Int	Ext	Gen
Cognitive variables																
Fluency	.04	–.26	.27	–.16	.44*	.34	.38*	.23	.67**	.50*	.52*	.39	.40*	.44*	.41*	–.07
Inhibition (Errors)	–.33	–.06	–.16	–.28	–.07	–.08	.01	–.08	–.37	–.38	.12	–.33	.13	.08	.09	.09
Inhibition (RT)	–.04	–.17	–.02	.07	.22	.07	.22	.12	–.14	–.41	.12	–.01	–.09	–.13	–.02	–.03
Planning (ToL)	.10	.15	–.21	.38	–.34	–.08	–.21	–.26	.24	.17	–.03	.26	–.54*	–.49*	–.32	–.26
WM (SOPT)	–.21	–.31	–.15	.05	–.23	–.43*	.06	–.18	–.63*	–.70**	–.07	–.42	–.20	–.42*	–.12	.15
Demographic variables																
Parental Education Level	.17	–.08	.22	.02	.30	.19	.24	.18	.30	.06	.06	.38	.02	.12	.23	–.32
Intelligence (Matrix)	–.04	–.14	–.10	.15	–.06	–.10	–.01	.07	.34	.35	–.11	.33	.21	.34	–.09	.17
Vocabulary (PPVT-R)	.11	.11	.09	–.03	.29	.05	.19	.23	.37	.32	.23	.21	.15	.21	.06	.03

Note. Tot = Total score for the metamemory scale; Int = Internal strategy score; Ext = External strategy score; Gen = General memory functioning score; RT = Reaction Time; WM = Working Memory; ToL = Tower of London; SOPT = Self-Ordered Pointing Test; Matrix = Matrix Reasoning subtest of Wechsler Intelligence Scale for Children; PPVT-R = Peabody Picture Vocabulary Test

*p < .05; **p < .001