Metamemory Following Childhood Brain Injury: A Consequence of Executive Impairment

Marie Geurten[1], Mathilde Chevignard[2], Bernadette Kerrouche[3], Anne Tiberghien[3], & Thierry Meulemans[1]

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

[2] Rehabilitation department for children with acquired neurological injury, Saint-Maurice Hospitals, Saint-Maurice, France; and Sorbonne Universities, UPMC Univ Paris 06, UMR 7371, UMR_S 1146, LIB, F-75005, Paris, France

[3] Outreach team for children and adolescents with acquired brain injury, Saint-Maurice Hospitals, Saint-Maurice, France

E-mail: Marie Geurten, mgeurten@ulg.ac.be;

Mathilde Chevignard, m.chevignard@hopitaux-st-maurice.fr;

Bernadette Kerrouche, b.kerrouche@hopitaux-st-maurice.fr;

Anne Tiberghien, a.tiberghien@hopitaux-st-maurice.fr;

Thierry Meulemans, thierry.meulemans@ulg.ac.be

Correspondence about this article should be addressed to Marie Geurten, Department of Psychology: Cognition and Behavior, Neuropsychology Unit, University of Liège, Boulevard du Rectorat, B33, 4000 Liège – Belgium; E-mail: mgeurten@ulg.ac.be; Phone number: +32 4 366 59 43

Abstract

In this study, we investigated the influence of children's level of executive functioning on two types of metamemory knowledge following a traumatic brain injury (TBI). For this purpose, 22 children (aged 7 to 14 years) who had sustained a moderate to severe TBI and 44 typically developing children were recruited. Children with TBI were divided into two groups according to the severity of their executive impairment. Injury severity was determined by the Glasgow Coma Scale (GCS) score on admission or by the duration of unconsciousness. All children were then tested on both their knowledge of general memory functioning and their level of memory self-awareness, respectively assessed using total number of correct responses on an adapted version of Kreutzer et al.'s metamemory interview and a self-other discrepancy score on a questionnaire evaluating everyday memory abilities. Data analyses revealed that participants with TBI who suffered impaired executive functions demonstrated less general metamemory knowledge, and underestimated the frequency of their memory problems, compared with children with TBI who had preserved executive functions and with control participants. Considering the well-established effect of metamemory knowledge on people's spontaneous implementation of strategies, the interest and the importance of these findings on both theoretical and clinical grounds are discussed.

Keywords: Metamemory; Self-awareness; Traumatic brain injury; Executive functions; Children

Learning and memory impairments are regularly reported as a consequence of severe and moderate traumatic brain injury (TBI) in adults (for selective reviews, see Tulving, 2002; Vakil, 2005) and in children (e.g., Catroppa & Anderson, 2007; Farmer et al., 1999; Mandalis, Kinsella, Ong, & Anderson, 2007). Such impairments have long-lasting negative consequences for everyday life (Anderson, Catroppa, Morse, & Haritou, 1999) and academic achievement (Miller & Donders, 2003). In rehabilitation, an approach frequently adopted to circumvent these memory problems involves the implementation of appropriate compensatory strategies (Cicerone et al., 2005; das Nair & Lincoln, 2012; Fleming, Shum, Strong, & Lightbody, 2005; Kaschel et al., 2002; Wilson, 1992). For instance, Kaschel et al. (2002) demonstrated that mental imagery training improved the memory performance of patients with TBI more than other standard rehabilitation methods (e.g., practical guidelines to improve memory), and that these improvements were accompanied by positive changes in relatives' ratings of patients' memory functioning at the three-month follow-up.

For this reason, research on episodic memory has long emphasized the study of processes and variables that could favor the spontaneous use of compensatory strategies in daily life. One of the best-supported findings in this field involves the positive influence of metamemory knowledge (DeMarie, Miller, Ferron, & Cunningham, 2004; Geurten, Lejeune, & Meulemans, 2015; Grammer, Purtell, Coffman, & Ornstein, 2011; Hutchens et al., 2012; Lachman & Andreoletti, 2006; Ownsworth, McFarland, & Young, 2002). Traditionally, metamemory knowledge is supposed to comprise semantic knowledge of memory tasks and strategies, including knowledge of internal (e.g., mental imagery) and external strategies (e.g., shopping lists), as well as knowledge about task characteristics (e.g., delay effect), and people's representations of their own memory functioning (i.e., memory self-awareness), including individuals' perception and understanding of their own memory strengths and limitations (Flavell, 1979; Kennedy & Coelho, 2005; Morris & Mograbi, 2013; Schneider, 2008; Toglia & Kirk, 2000). Knowledge of memory tasks and strategies is usually assessed with structured interviews composed of several scenarios designed to tap into semantic knowledge of memory functioning in different areas (e.g., Kreutzer, Leonard, & Flavell, 1975; Troyer & Rich, 2002), awareness of personal memory characteristics is assessed by comparing the patient's scores on a deficit rating scale with those of a clinician or family member (for a review, see Fleming, Strong, & Ashton, 1996; see also Bogod, Mateer, & Macdonald, 2003; Sherer et al., 2003; Smith & Arnett, 2010).

As mentioned above, these two types of knowledge have been shown to be involved in the implementation of appropriate memory strategies. 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 is predicted by their explicit knowledge of these strategies three months earlier. (For a study demonstrating the influence of metamemory knowledge on strategy use in adults, see Hutchens et al., 2012.) Similarly, Ownsworth et al. (2002) highlighted a significant correlation among measures of self-awareness and strategy use in a population of adults with acquired brain injury, demonstrating that participants with higher levels of self-awareness were more likely to make use of strategies in day-to-day life.

From a developmental point of view, much of the research on metamemory has shown that both types of explicit metamemory knowledge (i.e., knowledge of tasks and strategies vs.

self-awareness) improve significantly during childhood – particularly between the age of 6 and 12 years – and continue to develop more subtly throughout adolescence and adulthood (Fritz, Howie, & Kleitman, 2010; Kreutzer et al., 1975; Pressley & Schneider, 1997; Shin, Bjorklund, & Beck, 2007). Interestingly, some authors have recently postulated that certain high-level cognitive functions are involved in the development of the two classes of metamemory knowledge (Antshel & Nastasi, 2008; Fernandez-Duque, Baird, & Posner, 2000; Grammer et al., 2011). This hypothesis is supported by several neuropsychological studies carried out on adult patients with TBI that highlighted significant (negative) correlations between patients' level of executive functioning and both types of metamemory measures. Specifically, the results of these studies indicated that patients with poor executive functioning underestimate the frequency of their deficits and demonstrate less general knowledge of memory tasks and strategies than patients with good executive functioning (Bivona et al., 2008; Bogod et al., 2003; Ciurli et al., 2010; Morton & Barker, 2010; Ownsworth et al., 2002).

Surprisingly however, despite the obvious clinical and theoretical value of this "executive" hypothesis and the fact that its corroboration could improve memory rehabilitation programs, few studies have examined this question from a developmental perspective. Moreover, to our knowledge, this hypothesis has never been tested in a population of children who had sustained a TBI. Although Hanten et al. (2004; see also Crowther et al., 2011) studied the effects of TBI severity on children's ability to predict their own memory performance, no study seems to have examined the influence of executive impairments on both memory self-awareness and knowledge of memory tasks and strategies after childhood brain injury. The present research is thus an attempt to fill this gap.

In this context, the primary aim of this study was to investigate whether children with TBI who suffer significant executive impairment demonstrate poorer explicit knowledge of external strategies, internal strategies, and task characteristics than children with TBI who have no executive impairment. To this end, two groups of children with TBI, differing only in the severity of their executive impairment, were recruited and tested on their general metamemory knowledge. In parallel, the metamemory scores of each TBI participant were also compared to the metamemory scores of two matched controls. The first control participant was the same age as the TBI participant at the time of the assessment. The second control participant was the same age as the TBI participant at the time of the injury. Our goal in using this procedure was to determine whether an executive impairment following a TBI simply slows down children's acquisition of new metamemory knowledge, or whether it also has a negative effect on knowledge that should already have been acquired at the time of the injury.

The second aim of this research was more exploratory: to examine the influence of executive impairments on children's memory self-awareness. In agreement with previous findings presented in the literature on adults (e.g., Morton & Barker, 2010), we expected children with TBI with poor executive functioning to underestimate the magnitude of their memory problems, compared to those with good executive functioning. Furthermore, we also hypothesized that TBI participants with executive impairment would be less accurate than age-matched control participants when they had to estimate the frequency of their memory problems.

In sum, the two main goals of this study were (a) to demonstrate the influence of executive functions on children's knowledge of memory tasks and strategies by comparing two groups of TBI participants who differed according to the severity of their executive deficits, and (b) to explore whether the level of the children's executive impairment could also explain the accuracy of their representations of their own memory functioning.

Methods

Participants

A total of 22 French-speaking children (11 females) who had sustained moderate (n = 6) to severe TBI (n = 16) from closed head trauma participated in this study. They were recruited from the University Hospital (n = 5) and the Regional Hospital (n = 4) in Liège, Belgium, the University Hospital (n = 1) and the William-Lennox Healthcare Center (n = 5) in Brussels, Belgium, and the Saint-Maurice Hospitals (n = 5) in Saint-Maurice, France. All children were older than 6 at the time of injury and were between 7 and 14 years of age at the time of assessment. Injury severity was determined by the Glasgow Coma Scale score (GCS; Teasdale & Jennett, 1974) on admission (severe ≤ 8; moderate > 8 and < 13) or by the duration of unconsciousness (severe > 6 hours; moderate < 6 hours and > 1 hour). Participants were a minimum of 6 months post-injury to allow for post-acute spontaneous functional recovery. Exclusion criteria included a history of psychiatric disorder (e.g., depression), an established diagnosis of developmental disability (e.g., dyslexia) or mental deficiency, a brain injury resulting of child abuse, and a pre-trauma history of neurologic disorder (e.g., epilepsy). A sample of 44 typically developing children was also recruited from primary and secondary schools in Belgium, and was matched as closely as possible to the TBI participants for age, parental education level, verbal ability, and fluid intelligence. The latter three variables were assessed using the two parents' years of education and standard scores on the vocabulary test and the matrix reasoning test of the Wechsler Intelligence Scale for Children (WISC-IV; Wechsler, 2005), respectively. Demographic and neuropsychological data on the TBI and control groups are displayed in Table 1. Both patients and control children were enrolled and tested following written informed consent from their parents and with the agreement of the ethics committees of the participating institutions.

< Table 1 about here >

Material

Neuropsychological measures. All participants underwent a neuropsychological examination that assessed both their memory and executive functioning. Long-term memory abilities were appraised using the story recall test from the French version of the Children's Memory Scale (CMS; Cohen, 1997), which requires children to retell two simple stories, one after another, directly after hearing them and after a 25-minute delay. The outcome measures were the standard scores for the total number of items recalled across the two stories for the immediate and delayed recall. Short-term memory capacities were assessed using a non-word repetition task (Poncelet & Van der Linden, 2003). The standard score for the total number of items correctly repeated was used as an outcome measure in our analyses. Executive functions were assessed with the self-ordered pointing test (SOPT), which evaluates the executive ability to monitor a sequence of responses (Cragg & Nation, 2007); a go/no-go test of response inhibition (Raaijmakers et al., 2008); and the dragons' house test of flexibility from the attentional test battery for children (KiTAP; Zimmermann, Gondan, & Fimm, 2005). The numbers of errors on the three tasks were recorded.

Knowledge of tasks and strategies measure. Five subtests inspired by Kreutzer et al.'s (1975) classical interview were used to measure knowledge of memory tasks and strategies. These five subtests (Preparation Object, Retrieval Event, Immediate Delay, Retroactive Interference, and Rote Paraphrase) were adapted to assess three main components of metamemory knowledge: knowledge of internal strategies, knowledge of external strategies, and knowledge of task characteristics (for a study demonstrating the good psychometric properties of this scale, see Geurten, Catale, & Meulemans, 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 (e.g., "Could you give me all the ways that you could solve this problem?") or to select one of two alternative responses and to justify their answer (e.g., "Why do you think choice X would be better than choice Y?"). In other words, the metamemory scale was designed to assess whether children know *what* strategies can be used to solve a specific memory task and *when* these strategies can be used, but did not examine *how* children actually use these strategies to solve their problems. For every scenario, separate scores were calculated each time answers related to internal strategy, external strategy, or task characteristics were provided. The maximum score was 19 points for the whole scale: 6 points each for internal and external strategy factors, and 7 points for the task characteristics factor. Examples of scenarios, corrected responses, and scoring criteria can be found in Appendix A.

Memory self-awareness measure. As we are not aware of any existing instrument to assess children's knowledge of their own everyday memory functioning, a new self-other rating scale was used in this research. The scale comes in both a self-rating and an other-rating form and contains 40 easily understandable items that are rated on a 4-point Likert scale indicating frequency of occurrence ranging from 1 (“not at all”) to 4 (“very often”). Prior to this study, 75 typically developing children (age range = 6–14) and their significant others (parents) answered the questionnaire. Data analyses revealed good internal consistency (α = .93 and .95 for the self-rating and other-rating versions, respectively) and a good correlation between the two forms of the questionnaire (r = .50, $p < .001$). Item response theory analyses indicated that the items did not differ in terms of difficulty (1.06 < item difficulty < 1.84) or discrimination (0.33 < item discrimination < 0.71). A paper reporting the results of the full validation study of this scale is currently in preparation in our lab. In accordance with previous studies (e.g., Fleming et al., 1996; Sherer et al., 2003; Smith & Arnett, 2010), participants’ level of awareness was computed by subtracting parents’ ratings from children’s ratings to produce a self-other discrepancy score (–120 to +120). A negative score indicated that children underestimated the frequency of their memory problems. We chose parents instead of clinicians as significant other raters because we expected them to be in the best position to judge children’s memory abilities in day-to-day life. Examples of items from the memory questionnaire can be found in Appendix B.

Procedure

Children with TBI were tested individually at home (n = 16) or in the hospital where they were recruited (n = 6). Control children were tested alone in a quiet room at their school. Each child participated in a 60-minute session during which half the participants were given the tasks in the following order: (1) the non-words repetition task, (2) the vocabulary subtest, (3) the story recall task (immediate recall), (4) the matrix subtest, (5) the dragons’ house task, (6) the go/no-go test, (7) the story recall task (delayed recall), (8) the metamemory scale, (9) the SOPT, and (10) the memory questionnaire. The other half of the participants completed the tasks in the opposite order (except for the immediate and delayed recall components of the story recall task, whose order could not logically be reversed).

At the end of the recruitment process, TBI participants were divided into two groups according to their level of executive functioning. Specifically, their scores for the three executive tasks assessing inhibition (go/no-go), flexibility (dragons' house), and working memory (SOPT) skills were compared with a normative sample composed of 325 children (aged 4 to 14 years) as a function of their gender and chronological age. Children for whom two out of the three executive scores were more than one standard deviation from the mean of the normative sample were included in the low executive group ("TBI-Low"; n = 11). The remaining children were included in the high executive group ("TBI-High"; n = 11). In parallel, the same procedure was applied to control participants. However, as control participants were not expected to demonstrate executive impairments, a much less stringent criterion was employed to divide them into groups. Specifically, children for whom two out the three executive scores were lower than the mean of the normative sample were included in the low executive group ("Control-Low"; n = 15). The remaining participants were included in the high executive group (Control-High"; n = 29). As Table 2 shows, the two TBI groups and the two control groups differed significantly for each score on the three executive tasks. On the other hand, the two TBI groups and the two control groups were equivalent for all of the demographic, clinical, and neuropsychological variables.

< Table 2 about here >

Finally, regardless of executive group, each patient was carefully matched with two control participants for age, parental education level, verbal ability, and fluid intelligence. The first control participant was the same age as the TBI participant at the time of the assessment ("Control 1"). The second control participant was the same age as the TBI participant at the time of the injury ("Control 2"). As Table 1 reveals, the TBI and control groups were equivalent on each of the matching variables, but were significantly different for some of the memory and executive scores.

Data Analyses

The primary goal of this study was to determine whether children with TBI who had severe executive impairment demonstrated less explicit knowledge of memory functioning than children with TBI who had no executive impairment. In light of our small sample size, regression analyses could not be used to properly test this hypothesis (for a discussion of the required sample size as a function of different effect size parameters for regression analyses, see Maxwell, 2000). In this context, we chose to compare the metamemory scores of these two groups (TBI-Low vs. TBI-High) using analyses of variance (ANOVAs), where the different scores for the metamemory scale were included as dependent measures. The second aim of the study was to examine whether the accuracy with which children with TBI grasped the frequency of their memory problems (memory self-awareness) was also influenced by the seriousness of their executive impairment. For this purpose, an ANOVA was carried out to compare the self-other discrepancy score for the memory questionnaire in the two TBI groups.

All results reported in this section were considered significant when the exceedance probability was lower than .05, unless otherwise noted. Effect sizes were calculated using η^2_p for ANOVAs. Preliminary analyses indicated homogeneity of variance between the two TBI groups and revealed no gender or order effect on any of the dependent variables. Similarly, homogeneity of variance was observed between the TBI participants and their two control groups, except for the discrepancy score of the memory questionnaire. A logarithmic transformation was therefore applied on the latter variable.

Results

Knowledge of Memory Tasks and Strategies

TBI-High vs. TBI-Low. To test the hypothesis that an executive impairment might affect children's general metamemory knowledge, the two TBI groups were compared on the four scores of the metamemory scale (total, internal strategy factor, external strategy factor, and task characteristics factor). The results of the ANOVA revealed a significant difference between the TBI-High and TBI-Low groups for the total scale, $F(1, 20) = 5.12$; $p = .035$; $\eta^2_p = .20$, and the internal strategy factor, $F(1, 20) = 4.86$; $p = .039$; $\eta^2_p = .20$. However, no difference was found between the two TBI groups for the external strategy factor, $F(1, 20) = 1.18$; $p = .29$, and the task characteristics factor, $F(1, 20) = 3.27$; $p = .09$.

Control-High vs. Control-Low. To examine whether the influence of executive group on metamemory knowledge can also be seen in a sample of typically developing children, the two control groups were compared on the four scores of the metamemory scale. As with the TBI groups, the results of the ANOVA revealed a significant difference between the Control-High and Control-Low groups for the total scale, $F(1, 42) = 8.80$; $p = .005$; $\eta^2_p = .17$, and the internal strategy factor, $F(1, 42) = 7.91$; $p = .01$; $\eta^2_p = .16$. However, no difference was found between the two control groups for the other two factors of the scale, *Fs* < 3.

TBI-High vs. control groups. As a significant difference was highlighted between the two TBI groups for the total score and the internal strategy score of the metamemory scale, separate analyses were carried out to determine whether each TBI group differed significantly on these two variables from (a) the control group matched for age at the time of assessment, and (b) the control group matched for age at the time of injury. The analyses conducted on the TBI-High group are presented in this section and those conducted on the TBI-Low group are presented in the following one.

As Table 3 shows, the results of the one-way ANOVAs revealed no significant difference between the TBI-High and the Control 1 groups, neither for the whole metamemory scale, $F(2, 60) = 2.62$; $p = .12$, nor for the internal strategy factor, $F(2, 60) = 0.13$; $p = .72$. Similarly, no difference was found between the TBI-High and the Control 2 groups for the latter variables, $F < 1$. On the whole, these results seem to indicate that children with TBI who demonstrated no executive impairment were equivalent to their control groups in terms of general metamemory knowledge.

TBI-Low vs. control groups. Analyses were conducted to compare the metamemory scores of the children with TBI who demonstrated significant executive impairments with the metamemory scores of their two control groups. According to our hypotheses, we expected TBI participants to differ only from the control participants who were matched for age at the time of assessment, but to be equal to the control participants who were matched for age at the time of injury. To confirm this view, two linear contrasts were carried out to compare (a) the two metamemory scores for the TBI-Low and the Control 1 groups and (b) the two metamemory scores for the TBI-Low and Control 2 groups. Once the Bonferroni correction was applied, statistical tests were considered significant when the p value was lower than .025. For the total metamemory scale, the results showed that the TBI-Low group scored lower than both the Control 1, $F(1, 60) = 17.88$, $p < .001$, $\eta^2_p = .47$, and Control 2, $F(1, 60) = 5.72$, $p = .02$, $\eta^2_p = .22$, groups. However, for the internal strategy factor, planned comparisons revealed a significant difference between the TBI and Control 1 groups, $F(1, 60) = 8.90$, $p = .01$, $\eta^2_p = .27$, but not between the TBI and Control 2 groups, $F(1, 60) = 0.50$, $p = .49$ (see Table 3). As a whole, these findings tend to indicate that children with executive impairment show less metamemory knowledge than would be expected for children of their age at the time of assessment. To some extent, however, they also demonstrate less metamemory knowledge than would be anticipated for children of their age at the time of injury.

< Table 3 about here >

Memory Self-Awareness

TBI-High vs. TBI-Low. In accordance with previous findings in adults (e.g., Ciurli et al., 2010; Morton & Barker, 2010), the second aim of this research was to explore whether differences in executive impairment can influence the accuracy of the representations that children have of their own memory functioning after a TBI. For this purpose, a one-way ANOVA was carried out to compare the two TBI groups (TBI-High vs. TBI-Low) on the self-other discrepancy score for the memory questionnaire. Three participants had to be excluded from the analysis because they did not answer all the items of the questionnaire (1 TBI-High and 2 TBI-Low). The results revealed a significant difference between the two TBI groups, $F(1, 17) = 6.55$; $p = .020$; $\eta^2_p = .28$, for the self-awareness score. Specifically, as Figure 1 shows, children with executive impairment were found to underestimate the frequency of their memory problems compared to those with no executive impairment.

Control-High vs. Control-Low. To determine whether differences between the two executive groups of tipically developing children would be revealed by the memory self-awareness score, a one-way ANOVA was carried out to compare the two control groups (Control-High vs. Control-Low) on the self-other discrepancy score on the memory questionnaire. Six participants had to be excluded from the analysis because they did not answer all of the items of the questionnaire (4 TBI-High and 2 TBI-Low). The results revealed a trend toward a significant difference between the two groups, $F(1, 36) = 3.69$; $p = .06$; $\eta^2_p = .10$.

TBI-High vs. control group. As a significant difference was found between the two TBI groups for the self-awareness measure, separate analyses were conducted to compare the score of each of these clinical groups with the score of their control group matched for age at the time of assessment. The results for the TBI-High group are discussed in the present section while the results for the TBI-Low group are presented in the next section. As Figure 1 illustrates, results on the one-way ANOVA demonstrated no difference between the TBI-High group and its control group, $F(1, 33) = 0.70$; $p = .42$, suggesting that children with TBI who have no executive impairment understand the frequency of their memory problems as well as age-matched typically developing children.

< Figure 1 about here >

TBI-Low vs. control group. The results of the one-way ANOVA revealed a main effect of group (TBI-Low vs. Control 1) on the self-other discrepancy score, $F(1, 33) = 8.18$; $p = .01$; $\eta^2_p = .32$, which indicates that children with impaired executive functions underestimate the frequency of occurrence of their everyday memory failures compared to typically developing children of the same age (see Figure 1).

Discussion

The primary focus of this study was to investigate the involvement of children's level of executive functioning in the development of two types of metamemory knowledge following a TBI (i.e., knowledge of memory tasks and strategies vs. memory self-awareness). For this purpose, two groups of children who had sustained a TBI, who were equivalent for all clinical, demographic, and neuropsychological variables except for the severity of their executive deficit, were compared on their scores for both classes of metamemory knowledge measures. Although the small sample size means that the results of our statistical analyses must be interpreted with caution, some interesting findings were highlighted which seem to confirm our hypotheses.

Specifically, one of the main findings of this research was that children with TBI with executive impairment (TBI-Low) tend to demonstrate less knowledge of memory tasks and strategies than those with no executive impairment (TBI-High). Furthermore, statistical analyses also revealed that the latter children's metamemory scores did not differ from those of their controls. In contrast, children with executive impairment performed worse than their age-matched controls, demonstrating a lower level of metamemory knowledge than is expected for children of their age. Overall, these results seem to corroborate the findings of previous developmental studies hypothesizing that high-level cognitive functions are involved in the development of children's general knowledge of memory functioning (e.g., Fernandez-Duque et al., 2000; Grammer et al., 2011).

More unexpectedly, however, comparisons with control groups for the total score on the metamemory scale revealed that children with executive impairment perform worse than both controls matched for age at the time of assessment and controls matched for age at the time of injury, indicating that these children demonstrate less knowledge of general memory functioning than they were supposed to have achieved before being injured. There are at least two possible explanations for this result. First, newly acquired metamemory knowledge that was not consolidated at the time of injury could simply have been lost as a result of the TBI (Brown, 2002; Meeter & Murre, 2004; Nadel & Bohbot, 2001). Second, the decrease in the efficiency of executive processes following the TBI could have reduced the children's ability to switch from one kind of metamemory knowledge to another. This could have prevented participants from producing several reliable responses for each scenario when the semantic associations between the information contained within their metamemory network were not sufficiently strong to allow them to respond without using effortful processes (for similar reasoning on strategy selection in aging, see Hodzik & Lemaire, 2011; Lemaire, 2010). From a clinical point of view, the corroboration of one of these hypotheses, combined with the invalidation of the other, would have certain implications. Rehabilitation programs will not be the same when metamemory knowledge is demonstrated to be lost after a TBI as they are if this knowledge can be retrieved when participants are placed in situations that are less demanding in terms of cognitive resources (e.g., when directive cues are provide to help children use their metacognitive skills; see Barnes & Dennis, 2001). Unfortunately, none of our findings allow us to determine to what extent each of these explanations might apply. Additional research should therefore be carried out to further investigate these hypotheses.

The second aim of the present study was to explore whether differences in the severity of the executive impairment could explain the accuracy of children's knowledge of their own memory functioning. In accordance with previous findings in adults (e.g., Bogod et al., 2003; Ciurli et al., 2010; Morton & Barker, 2010), statistical analyses carried out on the memory self-awareness measure indicate that children with TBI who have a reduced level of executive functioning seem to underestimate the frequency of their memory problems (impaired self-awareness), while those with preserved executive functions appear to understand their own memory functioning as accurately as control children. As with knowledge of memory tasks and strategies, our results seem to confirm that high-level cognitive functions are involved in children's perception and understanding of their own memory strengths and limitations.

From a theoretical point of view, our findings could have important implications. Indeed, this study is the first to demonstrate the influence of executive functions on children's level of both classes of metamemory knowledge (knowledge of memory tasks and strategies vs. memory self-awareness) following a TBI. Overall, these results strengthen the hypothesis that high-level cognitive functions contribute to the acquisition of several types of metamemory knowledge during childhood (Fernandez-Duque et al., 2000; Grammer et al., 2011). Furthermore, to our knowledge, this research is also the first to provide evidence of the involvement of executive functions in the impairment of children's memory self-awareness after a TBI.

From a clinical perspective, the finding that impaired metamemory knowledge may be reported as a consequence of executive deficits following a moderate or severe TBI is interesting, particularly considering the well-established effect of this knowledge on people's spontaneous implementation of strategies and, consequently, on their memory performance (e.g., DeMarie et al., 2004; Grammer et al., 2011; Hutchens et al., 2012; Ownsworth et al., 2002). Moreover, our results also provide some possible avenues to explain the memory problems that are sometimes observed several years after the TBI among children who exhibited no such (severe) impairment at the time of injury. Indeed, consequences of a reduced level of metamemory knowledge may only become visible after a long delay, when memory abilities alone become insufficient to perform memory tasks without using complex mnemonic strategies that have to be selected from a set of metamemory knowledge.

Conclusion

Metamemory knowledge has long been established to have a positive effect on strategy use and memory performance (e.g., DeMarie et al., 2004; Grammer et al., 2011; Hutchens et al., 2012). In this study, we determined that the level of executive functioning seems to be involved in children's acquisition of both memory self-awareness and knowledge of memory tasks and strategies. Specifically, our results revealed that children with impaired executive functions demonstrated less knowledge of general memory functioning and poorer memory self-awareness than those with preserved executive functions. These findings must, of course, be replicated using other types of metamemory measures (e.g., the memory self-awareness questionnaire used here still needs to be validated and family members' ratings can be unreliable due to the high stress levels resulting from caregivers' long-term efforts to cope with TBI patients; see Fleming et al., 1996) and generalized to a larger sample of participants. However, considering the substantial contribution that metamemory knowledge makes in helping people to handle their memory problems, this question is of great interest on clinical grounds, and thus ought to be examined in depth in future neuropsychological and developmental studies of metamemory.

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Appendix A

Examples of Two Scenarios Included in the General Metamemory Interview

Scenarios	Correct 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	External strategy
	2. Write a note	External strategy
	3. Recruit human assistance	External strategy
	4. Internal facilitation (e.g., rehearsal)	Internal strategy
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	Task characteristics
	2. Not forget the code	Task characteristics
	3. Rehearse	Internal strategy
	4. Write a note	External strategy

Appendix B

Examples of Items Included in the Memory Questionnaire

Items
Finds it hard to describe what he/she did during the day (he/she keeps to general statements such as "On Tuesday, I go to the pool, like every Tuesday.").
Has difficulties memorizing something alone and without help from the people around him/her (e.g., teachers, parents).
Asks the same questions several times (in less than two minutes).
Fails a test (in which he/she has to recapitulate memorized information) even though he/she studied hard at home.
Experiences difficulties remembering certain important events from his/her own past.
Isn't able to remember a series of instructions (e.g., "Take down the laundry and go and get a carton of milk and two boxes of cookies.").
Forgets what is planned for the day if it differs from routine (e.g., school field trip).
Forgets what he/she just said.
Loses or doesn't remember where he/she left his/her belongings (e.g., pen, class diary, schoolbag, toys).
Has difficulties telling a story he/she heard or the plot of a movie he/she saw a few days/weeks ago, because he/she doesn't remember it.
Has difficulties answering questions about a passage/story he/she just heard.
Has difficulties talking about an episode from his/her life (e.g., accident, family weekend) that strongly affected him/her.

Table 1

Demographic and Neuropsychological Data (Means and Standard Deviations) for Control and TBI Participants

	TBI (n = 22)	Con 1 (n = 22)	Con 2 (n = 22)	p	η^2_p
Demographic data					
Age – assessment (months)	133.32 (26.32)	134.50 (26.21)	/	.88	.00
Age – injury (months)	115.81 (23.72)	/	114.95 (22.79)	.89	.00
SES	13.36 (2.44)	14.07 (2.08)	13.97 (1.71)	.48	.02
Intellectual skills					
Matrix (WISC)	8.59 (3.30)	9.64 (3.06)	10.45 (1.95)	.10	.07
Vocabulary (WISC)	10.05 (3.23)	12.00 (2.64)	11.09 (2.18)	.08	.08
Memory skills					
Non-word repetition	–1.22 (1.03)	–0.81 (0.86)	–1.06 (0.77)	.32	.04
Story recall (immediate)	8.23 (2.76)	11.32 (2.53)	10.36 (2.32)	< .001	.21
Story recall (delayed)	7.82 (3.13)	11.32 (2.78)	10.72 (2.39)	< .001	.24
Executive skills					
Go/no-go (RT)	474.55 (49.20)	426.48 (74.38)	441.64 (96.14)	.10	.07
Go/no-go (Errors)	3.82 (3.85)	3.05 (2.80)	4.23 (3.74)	.52	.02
Flexibility (RT)	1228.18 (998.22)	819.09 (367.04)	894.17 (366.78)	.09	.07
Flexibility (Errors)	8.55 (6.91)	5.00 (3.99)	6.91 (3.74)	.08	.08
SOPT (Errors)	18.96 (10.27)	11.68 (9.80)	10.04 (6.45)	.004	.16

Note. TBI = traumatic brain injury; Con 1 = controls matched for age at the time of assessment; Con 2 = controls matched for age at the time of injury; SES = socioeconomic status; WISC = Wechsler Intelligence Scale for Children; RT = reaction time; SOPT = Self-Ordered Pointing Test

Table 2

Distribution of Clinical, Demographic, and Neuropsychological Data (Means and Standard Deviations) for the Two TBI Groups (TBI-High vs. TBI-Low)

	TBI-High (n = 11)	TBI-Low (n = 11)	p	η^2_p
Demographic				
Sex (No. of females)	7	4	.20	
Age	137.45 (27.05)	129.18 (26.20)	.47	.03
SES	13.31 (2.48)	13.41 (2.51)	.93	.00
Clinical				
GCS	9.45 (3.83)	9.73 (3.82)	.87	.00
Length of coma (days)	2.73 (2.87)	6.27 (6.45)	.11	.12
Months since injury	14.81 (12.92)	22.09 (22.28)	.36	.04
Type of injury (No. of participants)			.53	
RTA	9	10		
Fall	2	1		
Intellectual skills				
Matrix (WISC)	9.00 (2.93)	8.18 (3.74)	.57	.02
Vocabulary (WISC)	10.18 (2.48)	9.91 (3.96)	.84	.00
Memory skills				
Non-word repetition	–1.24 (0.82)	–1.19 (1.25)	.91	.00
Story recall (immediate)	9.18 (1.78)	7.27 (3.29)	.11	.13
Story recall (delayed)	8.81 (2.48)	6.82 (3.48)	.14	.11
Executive skills				
Go/no-go (Errors)	2.09 (2.17)	5.54 (4.46)	.032	.21
Flexibility (Errors)	4.00 (3.22)	13.09 (6.66)	< .001	.45
SOPT (Errors)	13.00 (8.20)	24.91 (8.72)	.004	.35

Note. TBI = traumatic brain injury; SES = socioeconomic status; CGS = Glasgow Coma Scale; RTA = Road traffic accident; WISC = Wechsler Intelligence Scale for Children; RT = reaction time; SOPT = Self-Ordered Pointing Test

Table 3

Scores (Means and Standard Deviations) on the General Metamemory Knowledge Measures by Group

Group	Variable	TBI	Con 1	Con 2
TBI-High	Total score	12.45 (2.70)	14.36 (2.84)	12.36 (1.63)
	Internal strategy	3.00 (1.00)	3.18 (1.33)	2.82 (0.87)
	External strategy	4.09 (1.04)	4.73 (1.19)	3.91 (0.70)
	Task characteristics	5.36 (1.91)	6.45 (1.37)	5.64 (0.67)
TBI-Low	Total score	9.45 (3.47)	14.55 (1.97)	12.45 (2.30)
	Internal strategy	1.91 (1.30)	3.18 (0.87)	2.27 (1.10)
	External strategy	3.56 (1.29)	4.55 (0.93)	4.27 (1.49)
	Task characteristics	4.00 (1.61)	6.82 (1.47)	5.90 (1.64)

Note. TBI = traumatic brain injury; Con 1 = controls matched for age at the time of assessment; Con 2 = controls matched for age at the time of injury

Figure Captions

Fig. 1. *Mean self-other discrepancy score on the self-awareness measure for traumatic brain injury (TBI) and control groups as a function of the patients' level of executive impairment (TBI-High vs. TBI-Low). TBI and control groups were matched for age at the time of assessment.*