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Feeling-of-Knowing in Episodic Memory following Moderate-to-Severe Closed-head Injury

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Abstract

The ability to accurately monitor one's memory is a metacognitive process that is important in everyday life. In this study, we examined episodic memory feeling-of-knowing (FOK) ratings in 21 moderate-to-severe closed-head injury (CHI) participants (> 1 year post injury) and 21 controls. Participants studied 36 critical cue-target word pairs. Following a brief delay, they were asked to recall the target that corresponded to a given cue. Confidence ratings were made for recalled words and FOK judgments were made for non-recalled words in terms of the likelihood of recognizing the target word on a subsequent recognition test. We found that CHI participants demonstrated less accurate recall but accurate ability to judge their recall performance (retrospective memory monitoring). CHI participants also demonstrated intact feeling-of-knowing judgments when providing binary judgments, but demonstrated difficulties making finer discriminations on an ordinal scale (prospective memory monitoring). These findings suggest that memory monitoring is not a unitary construct. It is proposed that CHI participants may display intact memory monitoring when predictions are based on familiarity assessment but not when continued probing for additional episodic information is required.

Keywords

traumatic brain injury; memory monitoring; metamemory; metacognition

Our ability to accurately monitor information stored in memory is a metacognitive ability that has considerable importance in everyday life. For example, faced with failure when attempting to recall information from memory, we must decide the extent to which the information seems readily accessible and, consequently, whether we should continue an effort to retrieve it (Koriat, 2000). Within the closed-head injury (CHI) literature, although deficits in episodic memory have been well documented (e.g., Knight, Harnett, & Titov, 2005; Levin, 1988; Vanderploeg, Crowell, & Curtiss, 2001), few studies have evaluated the cognitive mechanisms by which metamemory judgments are made. This is an important area of study as it has been suggested that inaccurate metamemory can impede a person's ability to benefit from rehabilitation

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(Herbert & Powell, 1989; Lam, McMahon, Prickly, & Gehred-Schulz, 1988). In addition, several case studies have shown that by providing feedback and review about memory performance the metamemory accuracy of individuals with CHI can be improved (Giacino, & Cicerone, 1998; Schlund, 1999). In this study, we used a feeling-of-knowing (FOK) paradigm and confidence level ratings to investigate the prospective and retrospective memory monitoring abilities of moderate-to-severe CHI participants at the time of retrieval.

Early studies investigating metamemory accuracy following CHI generally suggest that CHI individuals tend to overestimate their memory abilities (Boake et al., 1995; Port, Willmott, & Charlton, 2002; Roche, Fleming, & Shum, 2002; Sbordone, Seyranian, & Ruff, 1998). However, several variables appear to moderate this outcome, as a less severe head injury (Leathem, Murphy, & Flett, 1998; Sherer et al., 1998), a greater time since injury (Allen & Ruff, 1990; Sunderland, Harris, & Baddeley, 1983), and a nondepressed mood state (Boake et al., 1995) have all been found to lead to better memory self-awareness following CHI. In these early studies, metamemory accuracy was most commonly investigated by contrasting CHI patients' self-ratings of their memory functioning with objective test findings or with ratings made by family members and rehabilitation staff (Flemming, Strong, & Ashton, 1996). More recently, metamemory abilities following CHI have been investigated using experimental techniques that require participants to make estimates about their memory performance in close temporal proximity to the memory task (e.g., Kennedy, 2004; Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000; Schmitter-Edgecombe & Woo, 2004). Such measurement techniques include eliciting global predictions, in which judgments are made about how many items from a study list will subsequently be recalled, and item-by-item predictions, in which predictions are made about the likelihood of subsequent recall for individual items.

In a recent study that elicited global memory predictions, Schmitter-Edgecombe and Woo (2004) found that metamemory was better preserved than actual memory performance in participants who suffered a severe CHI. In that study, participants with severe CHI (> 1 year post injury) and controls predicted their recall for verbal and visual material both prior to and following experience with the memory tasks. Although CHI participants exhibited poorer recall than controls, this study found that both groups were equally self-aware of how differing task demands influenced their recall. That is, both CHI and control participants predicted better recall for material presented multiple times as opposed to on a single occasion and for material that would be recalled immediately as opposed to after a delay. Both groups also successfully modified their predictions following task exposure, indicating that the CHI participants were able to self-monitor their performances and use experience to derive more accurate memory performance expectations.

The results of a series of studies conducted by Kennedy and colleagues (Kennedy, 2001; Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000) also suggest that moderate-to-severe CHI individuals maintain the ability to accurately monitor episodic information during learning. These studies used the judgment-of-learning (JOL) procedure which required participants, at the end of a learning trial or after a short delay, to make item-by-item judgments regarding the likelihood that they would remember specific learned information on a subsequent memory test. Kennedy & Nawrocki (2003) found that when making delayed JOL predictions about subsequent recall for acquired narrative information (i.e., two minutes after narrative presentation), both the CHI and control groups were more accurate in predicting recall for stated information than for implied information. Furthermore, Kennedy and Yorkston (2000) showed that CHI and control participants were very accurate in making delayed JOL predictions (i.e., two to four minutes after presentation) about their ability to later recall word pairs but inaccurate when making predictions immediately after studying the word pairs. These findings suggest that, similar to controls, participants with CHI are able to benefit from the opportunity to self-monitor items successfully stored in memory at the time of learning.

The present study expands previous item-by-item memory monitoring research in the CHI population by investigating memory monitoring at the time of retrieval using a feeling-of-knowing (FOK) paradigm. In the typical FOK procedure (Hart, 1965), participants are asked to estimate the likelihood that they will subsequently recognize a piece of information that they had failed to recall either from semantic memory or from recently learned episodic memory (e.g., Nelson & Narens, 1990; Souchay, Isingrini, & Espagnet, 2000). To evaluate FOK accuracy as an expression of the participants' actual metamemorial knowledge, FOK ratings are compared with success or failure on a recognition test. Unlike JOLs that are made during the study phase and are thought to rely heavily on the participants' prior knowledge of variables that will influence their memory performance, FOKs are made after the recall attempt and are thought to reflect the participants' capacity to monitor their performance by generating and using feedback from their memory performance (Bieman-Copland & Charness, 1994). Consequently, FOK judgments have been viewed as involving a computation process in which the byproduct of the retrieval process is used to evaluate the ease of future access to the answer (Koriat & Levy-Sadot, 2001; Souchay, et al., 2000, Souchay & Isingrini, 2004).

In the present study, moderate-to-severe CHI and control participants learned cue-target word pairs. Following a distracter task, they were then presented with the cue words and asked to recall the target words. For those items they were unable to recall, they were asked to provide a FOK judgment about the likelihood that they would be able to recognize the correct answer among a number of alternatives. For those items in which they produced an answer, participants provided a confidence level rating about their recall attempt (Costermans, Lories, & Ansay, 1992). The confidence level ratings represent a retrospective judgment about whether a provided answer has been correctly recalled from memory (Costermans et al., 1992; Marquié & Huet, 2000). The FOK ratings, on the other hand, represent a prospective judgment about whether the participant will later recognize a studied target item that could not be brought to consciousness at that moment. By obtaining confidence level ratings in addition to FOK judgments, we were able to examine both retrospective and prospective memory monitoring accuracy. Previous research has demonstrated dissociations between retrospective and prospective monitoring accuracy, with intact recall confidence and impaired prospective memory monitoring being found in both Alzheimer's disease (AD) patients and patients with lesions in the frontal lobe (Pappas et al., 1992; Schnyer et al., 2004). Consistent with previous literature (e.g., Schmitter-Edgecombe, Marks, Wright, & Ventura, 2004; Vanderploeg et al., 2001), we expect that participants with CHI will perform more poorly than controls on the episodic recall and recognition tasks. Prior research suggests that moderate-to-severe CHI participants can successfully self-monitor their performances at the time of learning (Kennedy & Yorkston, 2000; Schmitter-Edgecombe & Woo, 2004) and that they can demonstrate intact recall confidence accuracy for newly learned episodic information (Kennedy, 2001). The purpose of this study was to investigate whether moderate-to-severe CHI participants would also exhibit intact prospective memory as well as retrospective memory monitoring abilities at the time of retrieval.

As a secondary aim of this study, we also investigated the relation between episodic memory FOK, retrospective memory monitoring, executive-frontal functions and medial-temporal functions. Prior research suggests that frontal cortical structures are involved in predictions about episodic memory retrieval in the FOK paradigm (Janowsky, Shimamura, & Squire, 1989; Souchay, et al., 2000; Schnyer et al., 2004; Schnyer, Nicholls, & Verfaellie, 2005). For example, the results of FOK judgment research with brain injured patients (Janowsky et al., 1989) and a recent functional magnetic resonance imaging study (Schnyer et al., 2005) suggest that the prefrontal cortex plays an important role in monitoring the contents of memory. Souchay et al. (2000) also showed that age-related decline in episodic memory FOK accuracy could partially be accounted for by a composite score of various tests of executive abilities. In addition to executive-frontal functions, research conducted with individuals with focal

temporal lobe epilepsy suggests that medial temporal lobe dysfunction can impact FOK accuracy (Prevey, Delaney, & Mattson, 1988; Prevey, Delaney, Mattson & Tice, 1991). Consistent with this notion, Souchay et al. (2002) recently found that episodic memory deficits were a more important factor than executive functions in explaining the FOK inaccuracy found in AD patients. In cases of moderate-to-severe CHI, both the prefrontal cortex and the temporal lobe area have a higher probability of being damaged compared to other areas of the cortex (Adams et al., 1989; Schneibel & Levin, 1997; Wilson et al., 1995). By examining the pattern of associations among FOK accuracy, retrospective memory monitoring, and neuropsychological tests sensitive to executive-frontal functions and medial-temporal functions, we may uncover information about those factors that contribute to metamemorial judgments following moderate-to-severe CHI.

Method

Participants

Twenty-one individuals (6 female, 15 males) who had suffered a moderate-to-severe CHI and 21 neurologically normal controls (9 female, 12 male) were the participants in this study. The majority of participants with CHI were identified through patient records obtained from a regional traumatic brain injury rehabilitation program in Spokane, WA. Others were recruited through presentations made at several head injury support groups. This experiment was completed as part of a larger test battery that included standardized neuropsychological tests and other experimental measures (see Schmitter-Edgecombe & Bales, 2005; Schmitter-Edgecombe & Kayne, in press). The participants with CHI received feedback regarding their cognitive functioning in return for their time.

Participants were considered to have suffered a moderate-to-severe CHI if review of medical records indicated that (a) depth of coma, as assessed by the Glasgow Coma Scale (Teasdale & Jennett, 1974), was 12 or less ($N = 13$); or (b) duration of coma was greater than 2 hours ($N = 5$). In the three cases where we were unable to obtain medical records, both the participant and a significant other reported a coma duration of 5 days or greater. In addition, duration of post-traumatic amnesia (PTA), assessed retrospectively by careful clinical questioning of the participant, was 7 days or longer for all CHI participants ($M = 90$; $SD = 111$; $range = 7-390$ days); 76% of participants reported PTAs of more than two weeks, and 67% of more than four weeks.

All participants with CHI were assessed at least one-year following injury ($M = 6.92$ years; $SD = 6.72$, $range = 1-22$) and were experiencing residual cognitive deficits; 71% were more than two years post-injury and 33% were more than six years post-injury. The majority of participants with CHI suffered their head injuries as a result of a motor vehicle or motorcycle accident ($N = 17$), with the remaining 4 injuries resulting either from a fall of greater than 10 feet ($N = 3$) or a bicycle accident ($N = 1$). To minimize possible developmental effects on performance, CHI participants were at least 16 years old at the time of injury ($range = 17-50$ years) and less than 55 years old at testing ($range = 18-52$ years). Participants were excluded from the study if they had a pre-existing neurological, psychiatric, or developmental disorder (s) other than a CHI, a history of treatment for substance abuse, or a history of multiple head injuries. All participants demonstrated adequate visual acuity as indicated by a Snellen ratio of at least 0.50 at a distance of 41 cm.

Six of the control participants were neurologically normal undergraduate students participating as a requirement for course credit. The remaining 15 control participants were recruited from the community through the use of advertisement. In return for their participation, they received monetary compensation. To increase the likelihood that the CHI participants' premorbid abilities were roughly equivalent to those of the controls, the age ($M = 33.14$; $SD = 10.51$) and

educational level ($M = 13.14$; $SD = 1.62$) of the CHI participants was closely matched to the age ($M = 29.58$; $SD = 10.75$) and educational level ($M = 13.76$; $SD = 1.81$) of the control participants, $t's < 1.2$. In addition, an estimate of premorbid Wechsler Adult Intelligence Scale-Revised (WAIS-R) Full Scale Intelligence Quotient (FSIQ) derived from the Barona Index equation (Barona, Reynolds, & Chastain, 1984), which takes into account six demographic variables (i.e., age, sex, race, education, occupation, and region), revealed that the CHI ($M = 106.50$; $SD = 4.77$) and control ($M = 105.36$; $SD = 7.53$) groups did not differ significantly in premorbid abilities, $t(40) = .56$. At the time of study, the WAIS-R FSIQ estimate derived from participants' scores on the Shipley Institute of Living Scale (Zachary, 1991), revealed slightly poorer performance by the CHI group ($M = 98.90$, $SD = 8.61$) compared to the control group ($M = 105.10$, $SD = 6.66$), $t(40) = 2.59$, $p < .05$.

To characterize the CHI population and highlight those areas in which the CHI group was experiencing residual cognitive difficulties, a battery of neuropsychological tests was administered to all participants. As can be seen in Table 1, consistent with the typical cognitive sequelae of a moderate-to-severe CHI, the CHI participants performed more poorly than the controls on tests assessing attention and speeded processing [Symbol Digit Modalities Test (SDMT), Smith, 1991; Trail Making Test, Part A, Reitan, 1958], immediate and delayed verbal memory [California Verbal Learning Test (CVLT), Delis, Kramer, Kaplan, & Ober, 1987; Wechsler Memory Scale-III (WMS-III), Wechsler, 1997], and executive functioning [Trail Making Test, Part B, Reitan, 1958; Letter Number Sequencing subtest from the WAIS-III, Wechsler, 1997; Controlled Oral Word Association Test (COWAT), Benton & Hamsher, 1976]. In contrast to the above performances, the groups did not differ significantly on a confrontation naming test [Test of Adolescent/Adult Word Finding (TAWF), German, 1990] or in perseverative responding on an executive functioning task [Wisconsin Card Sorting Test (WCST), Heaton, 1981].

Stimuli—Two sets of cue-target word pair stimuli were constructed. Each stimulus set contained the same 36 cue words but a different target word. The target words were low associates to the cue words. The target words were balanced across stimulus sets in terms of cue-to-target strength (Set A: .011–.019; Set B: .011–.019), word frequency (Set A: 1–72 per million; Set B: 1–82 per million) and concreteness (Set A: 5.05–6.76; Set B: 5.13–6.96; Nelson, McEvoy & Schreiber, 1998). The target words from both stimulus sets were used in the recognition test along with four other distracter words that were also low associates to each cue word (cue-to-target strength = .011–.22). During study, each cue word was presented in black lowercase letters in 36 pt Times font on 8.5 in by 5.5 in paper. Each target word was presented directly below the cue word in black uppercase 36 pt Times font. A total of eight additional cue-target word pairs were created; four pairs were added to the beginning and end of each stimulus set to minimize primacy and recency effects. These cue-target buffer pairs remained constant across each stimulus set. Assignment to stimulus set was counterbalanced within each group.

Procedure—Each participant completed a study phase and a test phase. For the study phase, participants were told that they would be presented with cue-target word pairs and their task was to learn the target words. They were told to use the cue word (printed in lower case letters) to help them learn the corresponding target word (printed in uppercase letters) because the memory test would involve presenting them with the cue word and asking for the corresponding target word. Each cue-target word pair was presented for 6 seconds. The cue-target word pairs were presented in the same order for all participants.

Following the study phase, participants completed the Symbol Digit Modalities Test, which took approximately 8 minutes to administer. For the test phase, participants were first presented one-by-one with the cue word in the same type font as during study and given 15 seconds to

produce the corresponding target word. Whenever a potential target word was produced, participants were asked to make a level of confidence rating about the correctness of their answer using a 7-point rating scale (1 = 'I am not at all sure that my answer is correct' to 7 = 'I am absolutely sure that my answer is correct'). Whenever participants were unable to think of the target word, they were asked to make a FOK judgment about their ability to correctly recognize the target word from among six words when presented with the cue word. FOK ratings were also made on a 7-point Likert scale ranging from '1' ('I am absolutely sure that I will not recognize the correct answer') to '7' ('I am absolutely sure that I will recognize the correct answer'). The testing phase did not begin until the experimenter was sure that the participants understood what they were supposed to do. The second part of the test phase involved having participants complete the recognition test for all 36 items, not just the subset of items for which they made FOK judgments. Participants were given a sheet of paper with the cue words in the left hand column and they were asked to circle the corresponding target word for each cue word. The cue words for the recall and recognition test were presented in the same order.

Results

Episodic Memory Performance

Recall and recognition performance—Before comparing the recall and recognition performances of the CHI and control groups, raw data were converted to mean proportional data. As expected, the data revealed poorer recall and recognition performance by the CHI participants. The mean proportion of answers provided during the cued recall task was significantly greater for the control group ($M = .66$, $SD = .20$) compared to the CHI group ($M = .46$, $SD = .21$), $t(40) = 3.13$, $p < .005$. Of the answers provided, the mean proportion of successfully recalled target words was also significantly greater for the controls ($M = .80$, $SD = .20$) compared to the CHI participants ($M = .62$, $SD = .32$), $t(40) = 2.13$, $p < .05$. The proportion of correct answers on the recognition task similarly differed between the groups, with the CHI group ($M = .68$, $SD = .24$) recognizing proportionally fewer of the target words than the control group ($M = .85$, $SD = .14$), $t(40) = 2.84$, $p < .01$. Furthermore, the CHI group ($M = .59$, $SD = .26$) recognized proportionally fewer items that they provided FOK judgments for than the control group ($M = .73$, $SD = .20$), $t(40) = 1.96$, $p < .05$. In contrast, for those target items that were unsuccessfully recalled, both groups showed proportionally similar levels of recognition (CHI $M = .67$, $SD = .33$; Control $M = .65$, $SD = .32$).

Retrospective Memory Monitoring

Confidence Ratings—Before comparing the CL judgments of the CHI and control group, we evaluated whether the two groups used the CL rating scale in a similar fashion. The percentages of ratings falling into the different categories were entered into a 2 (group: CHI or control) $\times$ 7 (rating: 1, 2, 3, 4, 5, 6, and 7) mixed-model ANOVA. The analysis revealed a main effect for ratings, $F(6, 240) = 39.73$, $MSe = 259.61$, $p < .001$. Tests of simple effects indicated a greater use of the 'I am absolutely sure that my answer is correct' category ($M = 48\%$) compared to all other categories ($ps < .001$). In addition, the category ratings for 'My answer is most likely correct' ($M = 16\%$), 'My answer might be correct' ($M = 13\%$), and 'My answer is just as likely to be correct as incorrect' ($M = 10\%$) were used more often than the category ratings for 'My answer might be incorrect' ($M = 6\%$), 'My answer is most likely incorrect' ($M = 3\%$) and 'I am not at all sure that my answer is correct' ($M = 4\%$), $ps < .05$. There was no significant main effect of group, $F < 1$, or group by rating interaction, $F < 1$, indicating that the CHI and control groups used the CL rating scale in a qualitatively similar way.

Since the CHI and control group distributed their ratings across the CL scale in a similar way, we then determined whether participants assigned higher CL ratings to words that they correctly recalled as compared to incorrectly recalled. Five control participants and two CHI participants who never produced an incorrect target word could not be included in this analysis. The group (CHI or control) by recall (correct or incorrect) mixed-model ANOVA revealed that the mean CL rating assigned to target words that were correctly recalled ($M = 6.17$, $SD = .12$) was significantly higher than the mean CL rating assigned to incorrectly recalled target words ($M = 4.56$, $SD = .25$), $F(1, 33) = 41.84$, $MSe = 1.08$, $p < .001$. There was no significant main effect of group, $F < 1$. In addition, there was no significant interaction between group and recall, $F < 1$, as the discrepancy between mean ratings for correctly and incorrectly recalled target words was similar for the CHI (difference = 1.82) and control (difference = 1.40) group. These findings indicate that both groups were able to show discrimination between successfully recalled and unsuccessfully recalled target words.

Measures of association and agreement accuracy—Consistent with recent metacognitive literature (e.g., Souchay et al., 2002; 2004), to determine both degree of association (i.e., the degree to which levels of one variable covary with levels of a second variable) and relative accuracy (i.e., the degree to which judgments match correct and incorrect performance) between CL ratings and recall performance, we calculated the Goodman-Kruskal gamma correlation and the Hamann coefficient, respectively (see Nelson, 1984; Schraw, 1995). Both the gamma and Hamann coefficients are nonparametric correlation measures that range from -1 to 1 where 0 corresponds to no association (gamma) or chance levels of accuracy (Hamann).

For the gamma calculation, the original CL rating values were used. That is, since confidence judgments were rated on a seven-point scale, gamma was calculated by casting the frequency of responses into a 2 (recall: correct or incorrect) by 7 (ratings: 1, 2, 3, 4, 5, 6, and 7) contingency table. The cell frequencies, or number of cases per each cell of the 2×7 table, were then entered as a weight variable, and gamma was calculated through the Crosstabs option of SPSS 12.01 (SPSS Base 9.0 User's Guide, 1999). Due to limitations of the gamma statistic (Schraw, 1995), participants who used only one or two of the ratings cells were eliminated from the analysis. Therefore, five controls and three CHI participants could not be included in the group comparison of the gamma statistic. An Independent-samples t -test conducted on the gamma coefficient revealed that the CHI group ($M = 0.64$, $SD = .56$) and the control group ($M = .75$, $SD = .35$) did not differ significantly in the level of association between CL ratings and recall performance, $t < 1$ (see Table 2). In addition, the gamma correlations for both groups indicated a strong association between recall performance and CL judgments, with the gamma index being significantly above zero for both the CHI group, $t(17) = 4.87$, $p < .001$, and the control group, $t(15) = 8.64$, $p < .001$.

Unlike the gamma coefficient, which assesses the joint probability of judgments and memory performance, the Hamann coefficient requires each of the ratings and memory performances to be treated as mutually exclusive probabilities and provides a measure of agreement accuracy between ratings and memory performance (Schraw, 1995). Because of the need for binary data to compute this statistic, CL ratings were clustered, with ratings 1–4 considered 'not-confident' and 5–7 considered 'confident'. Because of the additive function of this statistic, all 21 participants could be used in the analysis. Evaluation of the Hamann coefficient revealed that the CHI group ($M = .53$, $SD = .39$) did not differ significantly from the control group ($M = .69$, $SD = .27$) in the accuracy of their retrospective judgment. The Hamann index was also greater than chance for both the CHI, $t(20) = 6.30$, $p < .001$, and control, $t(20) = 11.62$, $p < .001$, groups. These findings indicate that, similar to controls, the CHI participants were able to reliably identify those target words that they had successfully recalled from those that they had unsuccessfully recalled.

Prospective Memory Monitoring

FOK Ratings—Similar to the procedure used with the CL ratings, the percentages of FOK ratings falling into the different categories were entered into a 2 (group: CHI or control) by 7 (ratings: 1, 2, 3, 4, 5, 6, and 7) mixed model ANOVA to determine whether the CHI and control groups utilized the FOK scale in a similar manner. Results indicated a main effect for ratings, $F(6, 240) = 7.85$, $MSe = 470.25$, $p < .001$. Follow-up tests of simple effects indicated a greater use of the ‘I might recognize the correct answer’ category ($M = 33\%$) than all other categories, $ps < .01$. In addition, the category ratings for ‘I will most likely recognize the correct answer’ ($M = 20\%$), ‘I am just as likely to recognize as to not recognize the correct answer’ ($M = 15\%$) and ‘I might not recognize the correct answer’ ($M = 12\%$) were used more than category ratings ‘I am absolutely sure that I will recognize the correct answer’ ($M = 8\%$), ‘I will most likely not recognize the correct answer’ ($M = 8\%$), and ‘I am absolutely sure that I will not recognize the correct answer’ ($M = 4\%$), $ps < .05$. Importantly, there was no significant main effect of group, $F < 1$, or indication of a group by rating interaction, $F < 1$. This suggests that both groups used the FOK rating scale in a qualitatively similar way.

A mixed model ANOVA was then used to determine whether participants assigned higher FOK ratings to words they later successfully recognized. Four control participants and three CHI participants could not be included in this analysis because they either successfully recognized, or did not recognize (CHI = 1), all target words for which they had made an FOK judgment. The group (CHI or control) by recognition (correct or incorrect) analysis revealed a significant main effect of recognition, $F(1, 33) = 15.37$, $MSe = .14$, $p < .001$, that was modified by a significant group by recognition interaction, $F(1, 33) = 5.89$, $MSe = .14$, $p < .05$. Evaluation of the interaction revealed that the control participants made higher FOK ratings for target words that they later correctly recognized ($M = 4.86$, $SD = .98$) compared to those they incorrectly recognized ($M = 4.33$, $SD = .94$), $t(16) = 3.78$, $p < .005$. In contrast, CHI participants did not show a significant difference in their FOK ratings for correctly recognized ($M = 4.48$, $SD = 1.41$) and incorrectly recognized ($M = 4.10$, $SD = .94$) target words, $t(17) = 1.33$, $p > .20$. There was no significant main effect of group, $F = 1.22$. This index of prospective memory monitoring indicates that the CHI group experienced more difficulty than the control group correctly predicting those target words that they would later successfully recognize.

Measures of association and agreement accuracy—Similar to the procedure followed for retrospective memory monitoring, we calculated the gamma and Hamann statistics to determine the degree of association and relative accuracy between FOK ratings and recognition performance. Again, due to the limitations of the gamma coefficient, a gamma index could not be computed for four controls and four CHI participants. All 21 participants were used in the calculation of the Hamann index.

An Independent-samples t -tests of the gamma coefficient for prospective memory monitoring revealed that control participants’ overall gamma coefficient ($M = .48$, $SD = .38$) showed a significantly higher level of association between FOK judgments and recognition performance than that of the CHI participants (CHI $M = .19$, $SD = .44$), $t(32) = 2.07$, $p < .05$. In addition, while the level of association between FOK judgments and recognition was significantly above chance for the control participants, $t(16) = 5.20$, $p < .001$, the level of association did not differ significantly from ‘zero’ or ‘no association’ for the CHI participants, $t = 1.80$. To compute the Hamann coefficient, ratings were again clustered, with FOK ratings 1–4 coded as not-likely-to-be-recognized and FOK ratings 5–7 coded as likely-to-be-recognized. In contrast to the gamma index, the Hamann coefficient did not indicate a significant difference between the CHI ($M = .20$, $SD = .41$) and control ($M = .26$, $SD = .46$) groups in the accuracy of FOK judgments, $t < 1$. In addition, the Hamann coefficients were significantly above chance for both the CHI group, $t(20) = 2.21$, $p < .05$, and the control group, $t(20) = 2.54$, $p < .05$. These findings

suggest that the CHI participants showed adequate accuracy in FOK judgments concerning whether they would successfully recognize a target, but demonstrated difficulties discriminating their ratings along an ordinal scale. Furthermore, correlational analyses revealed that FOK gamma and FOK Hamann were not significantly related for the CHI participants ($r = .23$). For the control group, FOK Hamann and gamma were significantly correlated ($r = .69, p < .005$).

Correlations with neuropsychological variables

Correlations were calculated to examine the relationship between retrospective and prospective memory monitoring ability and the memory and executive measures shown in Table 3. The analyses were first conducted for the CHI participants, and then, to maximize the statistical power of our analyses, for both the CHI and control participants. Because the measures represented raw scores, we attempted to reduce the confounding effects of age by partialling out age all the correlational analyses conducted. For the CHI participants, a significant correlation was observed between the CL Index and Trails B ($r = -.56, p < .05$). Significant correlations were also observed between the FOK Hamann index and Logical Memory II ($r = .48, p < .05$) and WCST perseverative errors ($r = -.55, p < .05$). No other correlations were significant ($r_s = -.24$ to $.32$). For the CHI and control participants combined, the CL Hamann index correlated significantly with all four of the memory measures ($r_s = .34$ to $.41, p_s < .05$) and with Trails B ($r = -.48, p < .01$) and Letter-Number Sequencing ($r = .38, p < .05$). The FOK gamma index also correlated significantly with all four of the memory measures ($r_s = .34$ to $.39, p_s < .05$). In addition, significant correlations were observed between the FOK Hamann index and Logical Memory II ($r = .33, p < .05$) and WCST perseverative errors ($r = -.36, p < .05$). No other correlations were significant ($r_s = -.31$ to $.32$).

We then examined the roles of memory and executive functioning as mediators of memory monitoring ability. The neuropsychological tests sensitive to frontal-executive (Trails B time, WAIS-III Letter-Number Sequencing, COWA Total # Words, and WCST-64 Perseverative Responses) and memory functioning (CVLT Total Recalled Trials 1–5, CVLT Long-Delay Free Recall, WMS-III Logical Memory I, and WMS-III Logical Memory II) were converted to z scores and then averaged. The four measures of memory ($r_s = .69$ to $.92$) and of executive functioning ($r_s = .45$ to $.69$) were well correlated. All composite measures were scaled so that better performance was reflected by higher values. For the CHI participants, the composite measure of executive functioning correlated with the CL Hamann index ($r = .45, p < .05$). No other correlations reached significance for either the executive functioning composite ($r_s = .01$ to $.33$) or the memory composite ($r_s = -.01$ to $.37$). For both groups combined, significant correlations were observed between the CL Hamann index and both the memory ($r = .40, p < .01$) and executive functioning ($r = .45, p < .01$) composites. A significant correlation was also observed between the FOK gamma index and the memory composite ($r = .40, p < .05$). No other correlations reached significance for either the executive functioning composite ($r_s = .09$ to $.30$) or the memory composite ($r_s = .02$ to $.29$).

Because the memory score appeared to be a reliable predictor of FOK gamma performance, which was the one measure in which the CHI participants performed more poorly than the controls, we attempted to evaluate the role of memory as a mediator of metamemory monitoring differences between the CHI and control participants. To do this, we used an analysis of covariance. If memory capacity mediates the CHI effect on FOK gamma, removing the composite memory score should reduce the CHI effect on FOK gamma. The analysis revealed that, when the memory composite score was controlled for, the difference between the CHI and control groups was no longer significant, $F(1, 31) = .65, p > .40$. The adjusted means of FOK gamma for the CHI and control groups were .27 and .41, respectively.

Correlations with injury characteristics

Correlations were also conducted for the CHI participants between the prospective (FOK gamma and Hamann) and retrospective (CL gamma and Hamann) measures of memory monitoring and injury characteristics (i.e., time since injury and severity of injury). No significant correlations emerged between the memory monitoring measures and either time since injury ($r_s = -.31$ to $.30$) or injury severity as assessed by self-reported length of PTA ($r_s = -.22$ to $-.10$). In addition, no significant correlations were found between the neuropsychological tests sensitive to memory and either time since injury ($r_s = .03$ to $.29$) or PTA ($r_s = -.17$ to $.38$).

Discussion

This study expands previous research by investigating, at the time of memory retrieval, both retrospective and prospective memory monitoring abilities in a CHI population. The CHI participants in this study all suffered moderate-to-severe brain injuries, were greater than one-year post injury, and were exhibiting residual neuropsychological impairments at the time of testing. The CHI and control participants learned cue-target word pairs and, after a distracter task, were asked to recall each target word when presented with the corresponding cue word. Whenever participants produced an answer to a cue word, they were asked to provide a confidence rating about their memory performance. This confidence rating, which reflected participants' judgment about whether the retrieved word was the correct target word, served as our measure of retrospective memory monitoring. If participants did not provide a recall, they made a FOK judgment about whether they believed they would be able to recognize the target word from amongst a group of distracter items. FOKs reflect judgments about whether sought after information is still in memory even though it cannot be retrieved at the moment, and the FOK judgment served as our measure of prospective memory monitoring.

In line with past research, the CHI group's recall and recognition for the studied material was poorer than that of the control group. Despite demonstrating impairment in episodic memory, the CHI participants did not differ significantly from controls in their ability to assign confidence ratings to their recall performance. That is, the CHI and control groups demonstrated similar levels of judgment accuracy and association between recall performance and CL judgments, and both groups assigned higher CL ratings to correct as compared to incorrect recall attempts. In addition, for both groups, the measures assessing memory monitoring accuracy (i.e., CL Hamann) and association (i.e., CL gamma) were well above chance, and participants were highly confident in the ratings given to correctly recalled targets (i.e., 'My answer is most likely correct'). These findings demonstrate that despite impairments in episodic memory, participants with moderate-to-severe CHIs were able to show accurate retrospective memory monitoring abilities for retrieved items.

In regards to prospective memory monitoring ability, we found that when assessing the relative accuracy of predictions (i.e., Hamann index), CHI participants' FOK judgments about their future memory performance did not differ from controls. That is, the degree to which FOK judgments, when dichotomized into 'likely-to-be-recognized' (ratings 5–7) and 'not-likely-to-be-recognized' (ratings 1–4), matched subsequent correct and incorrect recognition performance was above chance and similar for the CHI and control participants. In contrast, analysis of the degree of covariation between FOK judgments and recognition performance revealed a lower level of association for the CHI participants compared to controls. Furthermore, unlike for controls, the CHI participants' gamma coefficient was no better than chance indicating 'no association' between FOK judgments and recognition performance. In addition, unlike the controls, the CHI participants did not assign higher FOK ratings to target words that were later correctly as compared to incorrectly recognized. Computed from an ordinal scale, the gamma statistic is more sensitive than the Hamann index to the distribution

of scores. These findings indicate that while chronic (>1 year postinjury), moderate-to-severe CHI participants showed adequate accuracy in FOK judgments concerning whether they would successfully recognize a target, they demonstrated difficulties discriminating their ratings along an ordinal scale.

Consistent with other studies which have shown dissociations between retrospective and prospective memory monitoring abilities in clinical populations (e.g., Pannu, Kaszniak, & Rapsak, 2005; Pappas et al., 1992; Schnyer, 2004), these data indicate that memory monitoring is not a unitary function. These data further suggest that FOK decisions are based, in part, on some abilities that are not tapped by simple recall confidence. Koriat and Levy-Sadot (2001) proposed that accurate FOK retrieval predictions involve a cascading two-step process beginning with assessment of the relative familiarity of the cue (Metcalf, 1993; Reder & Ritter, 1992) and ending with an effortful accessibility assessment (Koriat, 1993, 1997). In the first step, if cue familiarity is low, then a fast “don’t know” response may be initiated (Klin, Guzman, & Levine, 1997); the target is discounted (i.e., feeling of not knowing) and memory search is discontinued. In contrast, if the cue elicits partial familiarity about the target, memory interrogation is initiated (Reder, 1987). This second step is hypothesized to involve a deliberate search process during which a relative sense of the accessibility of the memory is evaluated based upon the amount of ease and access to partial clues (e.g., fragments of the target, semantic and episodic attributes), regardless of whether the clues are correct. According to Koriat and Levy-Sadot (2001), cue familiarity and accessibility may contribute to FOK judgments either independently or interchangeably.

In terms of abilities involved in recall confidence ratings, Costerman et al. (1992) hypothesized that because CL judgments are required only when a tentative target word is produced, participants may use the strength of the link between the cue and target to generate a CL estimate. However, this option does not exist for FOK ratings. Schnyer et al. (2004) recently suggested that the initial stage of FOK judgments may tap processes similar to those involved in confidence ratings. That is, these authors hypothesized that the ability to evaluate cue-familiarity may be functionally similar to the ease-of-generation assessment proposed as the basis of confidence ratings. Based on their finding of intact confidence judgments and impaired FOK ratings in frontal lobe patients, Schnyer et al. (2004) proposed that frontal lobe patients may display an intact ability to monitor recall accuracy and retrieval predictions based on familiarity assessment, but they fail when monitoring requires continued probing for additional episodic information. If this model is correct, then similar to frontal lobe patients, our data suggest that CHI participants may experience greater monitoring difficulty than controls when memory monitoring involves evaluating the ease of future accessibility to an answer.

Similar to the retrospective confidence levels employed in the present study, Kennedy and Yorkston (2000) found that CHI and control participants did not differ in their memory accuracy predictions when predicting memory performance following retrieval attempts. Using the JOL procedure, Kennedy and colleagues (Kennedy, 2001; Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000) have also consistently shown that moderate-to-severe CHI individuals maintain the ability to accurately monitor episodic information during learning. The current data extends this previous research by showing that participants with CHI may experience prospective memory monitoring difficulties when making judgments at the time of retrieval. Unlike FOK judgments, which are believed to begin with the assessment of the cue, and then if there is a sufficient degree of familiarity shifts to an accessibility assessment of memory (Koriat & Levy-Sadot, 2001), JOL predictions are thought to be best accommodated by cue-familiarity theory (Koriat, 1997). Therefore, the overall pattern of findings in the CHI metamemorial judgment literature is consistent with the idea that CHI participants may experience difficulties when monitoring requires continued probing for additional episodic

information, but not when recall accuracy and retrieval predictions are based on familiarity assessment.

Our data are also consistent with Schraw's (1995) suggestion that the gamma and Hamann index do not measure exactly the same phenomenon, and that both should be examined in FOK research. More specifically, we found that the CHI and control groups' prospective memory monitoring performance differed significantly when measured with the gamma index but not the Hamann coefficient. In addition, no significant correlation between the gamma and Hamann indices were found for the CHI participants. According to Schraw (1995), the Hamann index is a more appropriate measure of judgment accuracy while the gamma index is more appropriate for capturing the degree of covariation between recognition performance and FOK judgments. Thus, it appears that while the CHI participants in this study were able to determine at a gross level whether they would be able to correctly recognize the answer at a future time point (perhaps by relying on cue-familiarity), they had difficulty making finer discriminations about the accuracy of subsequent memory retrieval along an ordinal rating scale.

Recently, Souchay et al. (2004) suggested that the Hamann index can be taken as a more sensitive measure of FOK judgments than the gamma statistic. They based this conclusion on their finding that the Hamann coefficient was more highly correlated with executive functioning in older adults than the gamma index. Although we found no significant association between our frontal-executive composite and either the FOK gamma or Hamann indices, we did find for the CHI group that perseverative errors on the WCST correlated significantly with the Hamann measure. This may suggest that perseverative responding may be more highly related to poorer metamemory abilities than other components of frontal lobe functioning. However, we also found that the correlation coefficient involving the frontal-executive composite was substantially higher for FOK Hamann ($r = .33$) than FOK gamma ($r = .16$). This may suggest that executive functioning deficits play a more prominent role in explaining FOK inaccuracy than in capturing the degree of covariation between recognition performance and FOK judgments. Consistent with this notion, for the CHI and control participants combined, we found that our memory composite measure and all four of our measures of episodic memory ability correlated significantly with the FOK gamma index but not the FOK Hamann index. Furthermore, after we covaried out the memory composite measure (Schnyer et al. 2004), the CHI group's gamma index was above chance and did not differ from that of the control group. These findings suggest that for episodic memory FOK tasks, the FOK gamma measure may be partially mediated by episodic memory performance in moderate-to-severe CHI participants.

The study data also appear to suggest that the requirements involved in making subtle distinctions along an ordinal scale are more influenced by episodic memory abilities than those involved in making binary yes/no distinctions. This may be because the ability to make finer discriminations regarding the likelihood that a solicited target is retained in memory and will be recognized at a later time requires greater reliance on the ability to conduct an effortful, deliberate search of clues available in memory. As Koriat (1993, 1997) suggested, FOK predictions can be conceptualized as being based on a partial product of retrieval memory operations. Given that participants had only 15 seconds to produce a corresponding target word, it could be that the CHI participants prospective monitoring performance was limited by the amount of partial clues that could be brought to mind during that limited time frame and/or by the use of less efficient strategic retrieval strategies. Both of these possibilities would limit the amount of information that may be needed to accurately capture the degree of covariation between recognition performance and FOK judgments. The role that memory difficulties may play in metamemory performance is currently in need of further exploration. In an early study, Janowsky et al. (1989) found that patients with Korsakoff's syndrome were unable to make accurate FOK judgments about newly learned sentences following a 5 minute delay, whereas

participants with frontal lobe lesions were impaired only after a 1–3 day delay when the memory trace was weakened. These authors hypothesized that frontal lobe lesions and memory impairment together may result in more severe metamemory difficulties than frontal lobe lesions alone. Consistent with this hypothesis, in a recent comprehensive review of metamemory experiments in neurological populations, Pannu & Kaszniak (2005) found that the patient groups that had memory loss in addition to frontal dysfunction (e.g., Alzheimer's dementia, Korsakoff's syndrome) performed the most poorly on metamemory tasks.

The participants with CHI in this study all experienced diffuse brain damage as a result of a moderate-to-severe CHI in young-to-middle adulthood. In addition, they all were Caucasian individuals who were more than one year post-injury and had recovered to a cognitive level that allowed for semi-independent to independent living. Furthermore, none of the participants were in the demented range of functioning. Participants were also recruited retrospectively from a rehabilitation center and from support groups. Therefore, generalizability may not extend well to individuals with CHI who experience focal frontal lobe lesions or for those whose cognitive deficits are so severe that they are unable to integrate and maintain knowledge regarding their own functioning. In addition, in the present study we investigated FOK accuracy on an episodic memory task that involved recognition predictions about newly learned information. Given that episodic FOK accuracy and semantic FOK accuracy (i.e., predictions about information already stored in memory) have been found to dissociate in some clinical populations (e.g., Brandt, 1985; Janowsky et al., 1989; Souchay, et al., 2002) and have been hypothesized to depend differentially on frontal functions (Souchay et al., 2002; Souchay, Bacon, & Danion, 2006), future studies are needed to investigate semantic FOK and/or directly contrast semantic and episodic FOK accuracy following moderate-to-severe CHI. Furthermore, because this research was conducted in a laboratory setting and involved item-by-item predictions for cue-target word pairs, the generalizability of these findings to real world situations that involve retrospective and prospective memory monitoring, remains to be explored. Given the impact that inaccurate metamemory can have on a person's ability to benefit from rehabilitation, future studies are needed to better understand issues related to metamemory following brain injury, especially in the early phases of recovery.

In conclusion, we used an FOK procedure and CL ratings to investigate prospective and retrospective memory monitoring abilities in a moderate-to-severe CHI population that was more than one year post-injury. We found that despite impaired episodic memory performance, the CHI participants demonstrated accurate retrospective memory monitoring abilities for recalled items. Prospective memory monitoring abilities were found to be intact when assessed by binary judgments about whether or not an item that could not be retrieved would be recognized, but not when finer discriminations were required on an ordinal scale. These findings indicate that the difficulties the moderate-to-severe CHI participants experienced with prospective memory monitoring are not part of a more global monitoring deficit and that FOK predictions are influenced by abilities that are not tapped by simple recall confidence. To account for the pattern of study findings, it was hypothesized that CHI participants were functionally similar to controls when making accurate monitoring judgments based on either the strength of the link between cue and retrieved target or on cue-familiarity, but appeared to deteriorate when prospective monitoring judgments required continued probing for additional episodic information. Future research will be needed to further evaluate the plausibility of this hypothesis and the role that memory loss plays in metamemory performance.

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Table 1
Demographic Data and Mean Summary Data for the Closed-head Injury (CHI) and Control Groups

Test Variable	Mean		SD		N		Cohen's d
	CHI	Con	CHI	Con	CHI	Con	
Demographics							
Age	33.14	29.58	10.51	10.75	21	21	-.34
Education	13.14	13.76	1.62	1.81	21	21	.37
Gender	6F,15M	9F,12M					
Estimated Premorbid FSIQ ^a	105.36	106.50	4.77	7.53	21	21	.18
Intellectual Ability/Word-finding							
WAIS-R estimated FSIQ ^b	98.90	105.10 *	8.61	6.66	21	21	.83
TAWF Total Correct	33.55	34.48	3.20	1.72	21	21	.37
Attention/Speeded Processing							
SDMT Total Oral Correct	54.53	69.00 **	17.27	14.80	20	20	.94
SDMT Total Written Correct	47.30	59.95 **	13.48	11.83	21	20	1.01
Trails A (time)	34.62	22.24 *	23.01	6.46	21	21	-.75
Verbal Memory							
CVLT Trials 1-5	40.14	55.71 ***	15.87	9.20	21	21	1.23
CVLT LD Free Recall	7.65	12.33 ***	4.49	2.33	21	21	1.35
WMS-III Logical Memory I	35.90	45.38 **	10.46	9.43	21	21	.97
WMS-III Logical Memory II	19.43	28.81 ***	9.22	6.70	21	21	1.19
Executive Functioning							
Trails B (time)	82.50	49.33 **	51.49	17.62	21	21	-.89
WAIS-III L-N Sequencing	9.48	12.10 **	3.46	2.34	21	21	.91
COWAT Total Correct	32.95	41.20 *	10.00	10.61	20	20	.82
WCST-64 Perseverative Resp	7.67	6.33	6.35	2.48	21	21	-.29

Notes: Unless otherwise indicated, mean scores are raw scores. CHI = Closed-head injury; Con = control; WAIS-R = Wechsler Adult Intelligence Scale-Revised; FSIQ = Full Scale Intelligence Quotient; TAWF = Test of Adult Word Finding; SDMT = Symbol Digit Modalities Test; CVLT = California Verbal Learning Test; WMS-III = Wechsler Memory Scale-Third Edition; WAIS-III = Wechsler Adult Intelligence Scale-Third Edition; L-N = Letter-Number; COWAT = Controlled Oral Word Association Test (PRW); WCST = Wisconsin Card Sorting Test.

^a Estimated Premorbid Wechsler Adult Intelligence Scale-Revised FSIQ based on the Barona Index equation (Barona, Reynolds, & Chastain, 1984), which takes into account the following six demographic variables: age, sex, race, education, occupation, and region.

^b Estimated Wechsler Adult Intelligence Scale-Revised FSIQ derived from participants' total score on the Shipley Institute of Living Scale (Zachary, 1991).

* $p < .05$,

** $p < .01$,

*** $p < .001$.

Table 2

Means for Confidence Levels and Feeling-of-knowing ratings and Gamma and Hamann Indexes for the Closed-head injury (CHI) and Control Groups

Test Variable	Mean		SD		N		Cohen's d	
	CHI	Con	CHI	Con	CHI	Con	CHI	Con
Confidence Level Ratings								
Correct Recall ^a	6.03	6.32	.87	.46	19	16		.41
Incorrect Recall ^a	4.63	4.50	1.67	1.35	19	16		.08
Gamma Index ^b	.64	.75	.56	.35	18	16		.25
95% Confidence Interval	.39–.89	.59–.91						
Hamann Index	.53	.69	.39	.27	21	21		.49
95% Confidence Interval	.40–.76	.59–.89						
Feeling-of-knowing Ratings								
Correct Recognition ^a	4.48	4.86	1.41	.98	18	17		.31
Incorrect Recognition ^a	4.10	4.33	1.17	.94	18	17		.21
Gamma Index ^b	.19	.48*	.44	.38	17	17		.73
95% Confidence Interval	-.01–.39	.31–.65						
Hamann Index	.20	.26	.41	.46	21	21		.14
95% Confidence Interval	.01–.39	.05–.47						

^a Participants who never produced an incorrect target word were removed.^b Due to limitations of the gamma statistic (Schraw, 1995), gamma coefficients could not be computed for participants who used only one or two of the ratings cells.^c Participants who either successfully recognized, or did not recognize (CHI = 1), all target words for which they had made an FOK judgment were removed.* $p < .05$

Table 3

Correlations Among the Neuropsychological Tests Sensitive to Memory and Executive Functioning and the Gamma and Hamann Coefficients for the Closed-head Injury (CHI) Group and the CHI and Control Group Combined.

Test Variable	CHI			CHI and Controls		
	CL		FOK	CL		FOK
	Gamma	Hamann	Gamma	Hamann	Gamma	Hamann
Verbal Memory						
CVLT Trials 1–5	.13	.24	.32	.31	.25	.34*
CVLT LD Free Recall	–.04	.38	.27	.38	.03	.39*
WMS-III Logical Memory I	.14	.38	.28	.25	.10	.41*
WMS-III Logical Memory II	–.07	.39	.30	.48*	.08	.31*
Composite Score	.04	.35	.33	.37	.13	.39*
Executive Functioning						.40*
Trails B (time)	–.24	–.56*	–.20	–.18	–.31	–.48**
WAIS-III L-N Sequencing	.04	.36	.09	.01	.09	.33
COWA Total Correct	–.23	.07	.27	.08	.04	.21
WCST-64 Perseverative Resp	–.06	–.28	–.02	–.55*	–.17	–.24
Composite Score	.08	.45*	.16	.33	.20	.30

Notes. CHI = Closed-head injury; Con = control; CVLT = California Verbal Learning Test; WMS-III = Wechsler Memory Scale-Third Edition; L-N = Letter-Number; COWAT = Controlled Oral Word Association Test (PRW); WCST = Wisconsin Card Sorting Test. Partial Correlations controlling for age.

* $p < .05$;

 $p < .01$