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Predictions of Episodic Memory following Moderate to Severe Traumatic Brain Injury During Inpatient Rehabilitation

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Abstract

We examined memory self-awareness and memory self-monitoring abilities during inpatient rehabilitation in participants with moderate to severe traumatic brain injury (TBI). Twenty-nine participants with moderate to severe TBI and 29 controls matched on age, gender, and education completed a performance prediction paradigm. To assess memory self-awareness, participants predicted the amount of information they would remember before completing list-learning and visual-spatial memory tasks. Memory self-monitoring was assessed by participants' ability to increase accuracy of their predictions after experience with the tests. Although the TBI participants performed more poorly than controls on both episodic memory tasks, no significant group differences emerged in memory self-awareness or memory self-monitoring. The TBI participants predicted that their memory performances would be poorer than that of controls, accurately adjusted their predictions in accordance with the demands of the tasks, and successfully modified their predictions following experience with the tasks. The results indicate that moderate to severe TBI individuals in the early stages of recovery can competently assess the demands of externally-driven metamemorial situations and utilize experience with task to accurately update their knowledge of memory abilities.

Keywords

traumatic brain injury; memory awareness; memory monitoring; metamemory; metacognition

Accurate self-awareness and self-monitoring of memory abilities are important to everyday memory functioning. Individuals are more likely to successfully learn and retain information if they can accurately assess the demands of metamemorial situations. For example, if an individual is aware that they may experience difficulty learning important information, compensatory strategies can be initiated to help aid learning (Kennedy, 2004). After studying the material, the individual can also monitor their memory to determine whether the material was successfully learned or additional study time is needed. While memory self-awareness involves having accurate knowledge about one's memory abilities (Fleming, Strong, & Ashton, 1995), memory self-monitoring involves attending to and having an understanding about the

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accessibility of information stored in memory (Hertzog, Saylor, Fleece, & Dixon, 1994; Koriat, 2000).

A growing body of literature suggests that individuals with traumatic brain injury (TBI) who are more than one year post injury demonstrate accurate memory self-awareness and memory self-monitoring abilities (e.g., Kennedy, 2004; Schmitter-Edgecombe & Anderson, 2007; Schmitter-Edgecombe & Woo, 2004). However, few studies have explored impairment of metamemorial abilities during the early stages of recovery from TBI. This is an important area of study because, as past research has suggested, the more individuals with TBI are aware of deficits, the more they benefit from rehabilitation following injury (Lam, McMahon, Priddy, & Gehred-Schulz, 1988). In this study, we used a performance prediction paradigm to investigate memory self-awareness and memory self-monitoring abilities in the early-stage of recovery from moderate to severe TBI.

Several early studies examined patient awareness of episodic memory abilities (i.e., memory for personally experienced events occurring in specifiable temporal and spatial contexts) by comparing patient self-ratings of memory to ratings completed by knowledgeable informants, such as a patient's family member or a rehabilitation staff member. Studies utilizing this strategy found that persons who sustained TBIs tended to underestimate their memory difficulties, especially during the early stages of recovery (Boake et al., 1995; Port, Willmott, & Charlton, 2002; Roche, Fleming, & Shum, 2002; Sbordone, Seyranian, & Ruff, 1998). More recently, studies investigating metamemorial abilities have relied on methodologies that require participants to make predictions about their memory performance on specific memory tasks in close temporal proximity to the memory tests. These assessment techniques include gross predictions, such as performance predictions (e.g., Schmitter-Edgecombe & Woo, 2004), and item-by-item predictions, such as judgment of learning (JOL; e.g., Kennedy, 2004; Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000) and feeling-of-knowing (FOK; e.g., Schmitter-Edgecombe & Anderson, 2007). These techniques have the advantage of allowing for investigation of the self-monitoring aspect of metamemory that occur during learning (i.e., the ability to update memory self-awareness) in addition to memory self-awareness.

Utilizing a gross prediction strategy, Schmitter-Edgecombe and Woo (2004) found preserved metamemorial abilities in individuals with severe TBI who were more than one year post injury. These authors had participants estimate the amount of verbal and visual information they would recall before and after receiving experience with the memory tasks. Although participants with TBI performed more poorly than controls on the verbal and visual memory tasks, the TBI participants were equally aware of how the memory demands of different tasks would impact recall performance prior to receiving experience with the tasks. In addition, both groups adjusted their memory predictions so that they were more accurate after receiving experience with the tasks. These results revealed accurate memory self-awareness and memory self-monitoring abilities in individuals with severe TBI who exhibited memory difficulties more than one year after injury.

In a sequence of studies that investigated memory self-monitoring abilities at the time of learning, Kennedy and colleagues also found that individuals with TBI who were in the later stages of recovery exhibited intact metamemorial abilities (Kennedy, 2001; Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000). Using an item-by-item strategy, participants made predictions about their recall of individual items both immediately after a learning trial or following a delay (i.e., at least 2 minutes). The findings revealed that when participants were allowed time to monitor information in episodic memory, the TBI group was as accurate as the control group in predicting their memory performance (Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000). In addition, both groups were equally less accurate when they made predictions immediately following learning. These findings indicate that, similar to controls, persons who are in the later stages of recovery following a TBI can accurately predict their memory performance when allowed time to self-monitor episodic memory during learning.

In a recent study investigating memory self-monitoring abilities at the time of retrieval, Schmitter-Edgecombe and Anderson (2007) found that TBI participants had impaired episodic memory but grossly intact self-monitoring abilities. Utilizing an item-by-item strategy, retrospective and prospective memory self-monitoring abilities were investigated in individuals with moderate to severe TBI who were more than one year post injury. Retrospective memory monitoring was assessed by having participants provide confidence levels (CL) for recalled information. To assess prospective memory monitoring, participants provided FOK judgments for material unsuccessfully recalled. That is, participants predicted the likelihood that the material not recalled would later be recognized. While TBI participants were accurate estimating their past memory performance, they demonstrated some difficulties predicting future memory performance during retrieval. Specifically, TBI participants were less accurate making predictions along an ordinal scale. However, when FOK ratings were clustered into ‘not-likely-to-be-recognized’ and ‘likely-to-be-recognized’, TBI participants' ratings were similar to controls. It was argued that individuals with TBI can make accurate predictions about future memory performance based on a familiarity assessment (Koriat & Levy-Sadot, 2001), but this ability breaks down when monitoring abilities are forced to rely on a continual search of episodic memory.

The basic finding of each of the aforementioned studies has been that persons in the later stages of recovery following a TBI maintain accurate knowledge of memory abilities. However, earlier studies comparing patient ratings of memory ability with ratings from others have suggested that TBI individuals in the early stages of recovery demonstrate impaired memory self-awareness (Boake et al., 1995; Port et al., 2002; Roche et al., 2002; Sbordone et al., 1998). The present study expands upon these past studies by utilizing a performance prediction paradigm to investigate both self-awareness and self-monitoring of memory abilities during the early stage of recovery from TBI (i.e., during inpatient rehabilitation).

Within two months following emergence from posttraumatic amnesia (PTA), TBI participants were asked to make memory performance predictions on list-learning and visual-spatial learning tests. To assess memory self-awareness, participants provided a prediction of their performance *before* completing the memory tests (i.e., pre-experience predictions). We were interested in whether individuals with TBI would demonstrate awareness of memory deficits and set accurate goals for future memory performance prior to receiving experience with the tasks. More accurate memory predictions are thought to reflect greater knowledge of personal memory abilities and of the influence of task difficulty on recall (Fleming et al., 1995). To assess memory self-monitoring, participants provided a second set of performance predictions *after* receiving experience with the memory tasks, (i.e., post-experience predictions). We were interested in whether individuals with TBI would positively benefit from experience with the tasks and thereby adjust their estimates to be more accurate. On the basis of prior research, we expected that TBI participants would perform more poorly on the memory tasks (e.g., Schmitter-Edgecombe et al., 2004; Vanderploeg et al., 2001), as well as demonstrate less accurate memory self-awareness than controls (e.g., Boake et al., 1995; Port et al., 2002; Roche et al., 2002; Sbordone et al., 1998). Findings from several studies, however, suggest that individuals in the early stages of recovery following TBI can improve their understanding of memory abilities when provided feedback (Giacino & Cicenrone, 1998; Schlund, 1999). Therefore, it was expected that TBI participants would benefit from experience with the memory tasks, accurately self-monitoring and adjusting post-experience memory estimates.

As a secondary goal of this study, we explored the relationship between participants' metamemory abilities and their performance on neuropsychological tests. Past research has been inconsistent about the cognitive abilities involved in metamemory, suggesting involvement of frontal abilities (Janowsky, Shimamura, & Squire, 1989; Kikyo, Ohki, & Miyashita, 2002; Vilkki, Surma-aho, & Servo, 1999), attention/speeded processing skills (Schmitter-Edgecombe & Woo, 2004), and medial-temporal functions (Schmitter-Edgecombe & Anderson, 2007). By conducting correlational analyses among memory predictions made both prior to and following experience with the memory tasks and neuropsychological tests, we expected to gather additional information about which cognitive skills may be related to metamemorial abilities.

Method

Participants

Twenty-nine individuals (8 females, 21 males) who had suffered a TBI and 29 neurologically normal controls (12 females, 17 males) participated in this study. The TBI participants were identified prospectively from admissions between January, 2004 and April, 2007 to a regional traumatic brain injury rehabilitation program in the Pacific Northwest. To be eligible to participate, individuals had to be between the ages of 15 and 55, and have no medical complications that would preclude their ability to be tested (e.g., dementia, aphasia). Participants were also excluded from this study if they had a history of substance abuse and/or a pre-existing neurological (including multiple head injuries), psychiatric, or developmental disorder(s) other than TBI (*n* = 26). Thirteen individuals declined to participate (*n* = 13) and two participants did not fully complete the memory predictions tasks (*n* = 2). TBI participants' data was also excluded from this study if a closely matched control in terms of age and education was not identified (*n* = 3). Control participants were recruited from the community through the use of advertisements and received monetary compensation in return for their time. TBI participants received feedback regarding their cognitive performances in return for their time.

Severe TBI was defined by a Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) score of 8 or less (*n* = 17) documented in medical records at the scene of the accident or in the emergency room. Moderate TBI was classified by a GCS between 9 and 12 (*n* = 5) or by a GCS of higher than 12 accompanied by positive neuroimaging findings and/or neurosurgery (*n* = 7; Dennis et al., 2001; Fletcher et al., 1990; Taylor et al., 2002; Williams, Levin, & Eisenberg, 1990). The majority of participants (*n* = 19) spent two hours or more in a coma as reported in medical records or by careful clinical questioning of the participant and/or knowledgeable informant, such as a family member (*M* = 72.52; *SD* = 188.55; *range* = 0 − 720 hours). All participants exhibited a period of PTA lasting 3 days or longer (*M* = 24.93; *SD* = 19.71; *range* = 3 − 90 days). Emergence from PTA was determined either by repeated administration of the Galveston Orientation and Amnesia Test (GOAT; *n* = 19; Levin, O'Donnell, & Grossman, 1979) or, if the participant with TBI had emerged from PTA prior to arriving at the rehabilitation institute, by asking the TBI participant to recall their memories until the examiner was satisfied that normal continuous memory was being described (*n* = 10, King et al, 1997; McMillan, Jongen, & Greenwood, 1996). All TBI participants were assessed within two months following emergence from post-traumatic amnesia (*M* = 18.31; *SD* = 14.79; *range* 0 − 49 days) and within three months from time of injury (*M* = 39.59, *SD* = 17.51; *range* = 13 − 78 days). The majority of TBI participants suffered their head injuries as a result of a motor vehicle or motorcycle accident (*n* = 20), with the remaining injuries resulting from a fall (*n* = 9). All participants demonstrated at least 20/60 visual acuity at a distance of 16 inches using both eyes as measured by a Snellen chart.

To increase the likelihood that the TBI participants' premorbid abilities were roughly equivalent to those of controls, the age (M = 28.28; SD = 12.78) and educational level (M = 12.69; SD = 2.12) of the TBI participants were closely matched to the age (M = 31.17; SD = 13.06) and educational level (M = 13.24; SD = 2.40) of controls, ts < 1.1. An estimate of participants' premorbid Wechsler Adult Intelligence Scale-Revised (WAIS-R) Verbal Intelligence Quotient derived from the Barona Index Equation (Barona, Reynolds, & Chastain, 1984), revealed that the TBI (M = 102.32; SD = 8.36) and control (M = 103.38; SD = 9.04) groups did not differ significantly in premorbid abilities, $t(56) = -0.47$.

To characterize the cognitive difficulties of the TBI participants, we administered a battery of neuropsychological tests. As can be seen in Table 1, the TBI 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], confrontation word naming [Test of Adolescent/Adult Word Finding (TAWF), German, 1990], visuospatial skills [Visual Form Discrimination test (VFD); Benton, Hamsher, & Sivan, 1994], executive functioning [Trail Making Test, Part B, Reitan, 1958; Controlled Oral Word Association test (COWA), Benton et al., 1994; 5-Point Test, Lee et al., 1997; Self Ordered Pointing Test (SOPT), Petrides & Milner, 1982], and word knowledge [Shipley Institute of Living Scale (SILS); Zachary, 1991]. In addition, there was a strong trend for poorer performance by the TBI participants on a verbal test of working memory [Letter-Number Sequencing subtest from the Wechsler Adult Intelligence Scale-III (WAIS-III), Wechsler, 1997], $t(56) = -1.83$, $p = .07$. In contrast to the above performances, the groups did not differ significantly on a test of everyday abstraction/problem-solving abilities [Problems of Everyday Living test (PEDL), Leckey & Beatty, 2002].

Materials

Participants were administered the Rey Auditory Verbal Learning Test (RAVLT; Majdan, Sziklas, & Jones-Gotman, 1996) and 7/24 Spatial Recall Test (Rao, Hammeke, & McQuillen, 1984). Both tests are standardized measures of memory functioning.

RAVLT (Majdan et al., 1996)—The RAVLT is a verbal list-learning test. Participants are presented with 15 words over five learning trials. The words are presented auditorially by the examiner at a rate of one word every two seconds with the instructions to repeat as many words as possible. Following the five learning trials, a 15-item interference list (i.e., list b) is presented. Short delay free recall for the original list (i.e., the list learned over the five learning trials) is tested immediately following presentation of the interference list. Long delay free recall is tested following a 20-minute delay filled with other activities.

7/24 Spatial Recall Test (Rao et al., 1984)—The 7/24 Spatial Recall Test is a visual-spatial memory test. Participants are shown a spatial array consisting of seven dots over five learning trials. During each learning trial, the spatial array is shown to the participant for 10 seconds, after which the participant is asked to reproduce the design by placing dots on a checkerboard. Following the five learning trials, an interference design is presented to the participant. Short delay free recall for the original design is tested immediately following presentation of the distracter design. Long delay free recall is tested following a 20-minute delay filled with other activities.

Procedure

This experiment was completed as part of a larger test battery that included standardized neuropsychological tests and other experimental measures (see Schmitter-Edgecombe & Rueda, 2008). All neuropsychological measures were administered in accordance with standardized instructions and collected across two days of testing. The memory predictions were collected on the first day of testing.

Before completing each of the memory tasks, the examiner presented the participants with a description of the task and asked the participants to make pre-experience predictions regarding their immediate and delayed recall performances (for task instructions, please see Addendum 1). Briefly, for the list learning test (i.e., RAVLT), participants were asked how many words from the 15-item list they thought they would recall after an initial learning trial, five learning trials, and a 20-minute delay. After administration of the learning trials (i.e., trials 1−5) and following the short-delay free recall trial, participants were asked to provide a post-experience prediction regarding the number of words they thought they would remember from the original 15-item word list after the 20-minute delay. Memory predictions for the visual-spatial learning task (i.e., 7/24 Spatial Recall test) were collected using a procedure similar to that of the verbal list learning test. More specifically, prior to experience with the task, participants were asked to estimate how many of the seven dots they thought they would recall after an initial learning trial, five learning trials, and a 20-minute delay. After administration of the short-delay free recall trial, participants made post-experience predictions about how many of the dots they thought they would recall after a 20-minute delay.

The memory tests were administered to each participant in the same order. That is, the list learning test (i.e., RAVLT) was administered to each participant first, followed by the visual-spatial learning task (i.e., 7/24 Spatial Recall Test). After completing the immediate memory trials, participants completed filler activities. Then, after the filler activities or as time dictated, participants completed the delayed memory trials of the RAVLT and 7/24 Spatial Recall Test. The 20 minutes of filler tests for the RAVLT consisted of the immediate memory trials of the 7/24 Spatial Recall test and the PEDL. The 20 minutes of filler tests for the 7/24 Spatial Recall test included the PEDL and the delayed memory trials of the RAVLT.

Results

To compare the actual recall performance of the TBI and control participants, a group (TBI vs. controls) by time of recall (trial 1 vs. trial 5 vs. long-delay) mixed model analysis of variance (ANOVA) was conducted separately for the list-learning and visual-spatial tasks. To examine memory self-awareness, similar group by time of recall ANOVAs were separately run for each memory task on participants' memory predictions data and on a memory prediction accuracy score, which represented the absolute difference between predicted and actual recall performance. Memory self-monitoring was then evaluated by comparing memory predictions for long delay free recall made prior to and following experience with each of the memory tasks. For analyses in which the condition of sphericity was not met, the Greenhouse-Geisser correction was used to make the F test more conservative (Tabachnick & Fidell, 2001). In all cases, the Greenhouse-Geisser adjustment factor was still significant suggesting no increased risk of type I error. Therefore, we report the standard univariate analysis data (Myers & Well, 2003).

Episodic Memory Performance

As seen in Table 2, for the list-learning task (i.e., RAVLT), the group (TBI vs. controls) by time of recall (trial 1 vs. trial 5 vs. long-delay) mixed model ANOVA revealed that the TBI group (M = 8.02) recalled less of the material than controls (M = 10.61), $F(1, 56) = 24.94$, $MSE = 11.67$, $p < .001$, $\eta^2 = .31$. As expected, a significant time of recall main effect, $F(2, 112) = 175.02$, $MSE = 3.13$, $p < .001$, $\eta^2 = .76$, showed that a greater number of list items were recalled after multiple learning trials [trial 1 M = 6.50; trial 5 M = 12.14, $F(1, 56) = 447.13$, $MSE = 2.06$, $p < .001$, $\eta^2 = .89$], followed by a significant reduction in retained list items after a 20-minute delay [M = 9.31, $F(1, 56) = 112.47$, $MSE = 2.06$, $p < .001$, $\eta^2 = .67$]. A significant

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interaction between group and time of recall, $F(2, 112) = 8.85$, $p < .001$, $\eta^2 = .14$, revealed that although TBI and control groups showed similar amounts of learning between trial 1 and trial 5 for the list-learning task (TBI = 47%, controls = 46%), $F = 3.51$, the TBI group lost more material between trial 5 and the 20-minute delayed recall than controls (TBI = 33%, controls = 16%), $F(1, 56) = 8.10$, $p < .01$, $\eta^2 = .13$.

For the visual-spatial test (i.e., 7/24 Spatial Recall Test), results from the 2 (group) by 3 (time of recall) mixed model ANOVA revealed that the participants with TBI ($M = 5.56$) recalled less of the visual-spatial material than controls ($M = 6.40$), $F(1, 56) = 11.36$, $MSE = 2.70$, $p < .001$, $\eta^2 = .17$. A significant time of recall main effect, $F(2, 112) = 16.49$, $MSE = 2.05$, $p < .001$, $\eta^2 = .23$, showed that a greater amount of the visual-spatial material was recalled after multiple learning trials [trial 1 $M = 5.43$; trial 5 $M = 6.74$, $F(1, 56) = 40.86$, $MSE = 1.22$, $p < .001$, $\eta^2 = .42$] followed by a significant reduction in recalled material after a 20-minute delay [$M = 5.78$, $F(1, 56) = 22.67$, $MSE = 1.19$, $p < .001$, $\eta^2 = .29$]. In contrast to results for the list-learning task, the TBI participants exhibited a greater degree of learning than the control group from trial 1 to trial 5 (TBI = 26%, controls = 13%), $F(1, 56) = 4.08$, $p < .05$, $\eta^2 = .07$. This finding, however, reflects the fact that both groups reached near ceiling performance on the visual-spatial memory task with no group difference in trial 5 performance (TBI: $M = 6.59$, controls: $M = 6.90$, $F = 2.32$). Therefore, because the control group's trial 1 visual-spatial task performance ($M = 6.00$) was better than that of the TBI group ($M = 4.86$), the control group had less room to improve their performance before reaching ceiling. Over a 20-minute delay, however, there was a strong trend indicating that the TBI group ($M = 5.24$) lost a greater amount of the material than controls ($M = 6.31$), $F(1, 56) = 3.50$, $p = .07$, $\eta^2 = .06$.

Summary

As expected, we found that participants with TBI demonstrated poorer recall of episodic information than controls. On the list-learning task, although the TBI participants exhibited similar amounts of learning across the multiple learning trials, their trial 1 and trial 5 recall of the word list was poorer than that of controls. In addition, they lost more of the word list items between trial 5 and the 20-minute delayed recall than the controls. On the visual-spatial task, both groups recalled similar amounts of material after multiple learning trials, although the TBI group retained less material after the long-delay.

Memory Self-Awareness

To assess memory self-awareness, we began by comparing memory predictions made by participants *before* they received experience with the memory tasks. We further evaluated the accuracy of memory predictions by calculating absolute difference scores between predicted and actual performance. We were particularly interested in whether TBI participants would be as accurate as controls in predicting their memory performance before receiving experience with the episodic memory tasks.

Memory Predictions—As seen in Table 2, the group (TBI vs. controls) by time of recall (trial 1 vs. trial 5 vs. pre-experience delayed recall) ANOVA revealed that the TBI participants ($M = 7.26$) predicted that they would perform more poorly than controls on the list-learning task ($M = 9.22$), $F(1, 56) = 11.40$, $MSE = 14.57$, $p < .001$, $\eta^2 = .17$. In addition, a main effect for time of recall, $F(2, 112) = 49.06$, $MSE = 4.45$, $p < .001$, $\eta^2 = .47$, revealed that both groups predicted that their performance would increase after multiple learning trials [trial 1 $M = 7.47$; trial 5 $M = 10.45$, $F(1, 56) = 101.97$, $MSE = 2.53$, $p < .001$, $\eta^2 = .65$] and decrease after a 20-minute delay [$M = 6.81$, $F(1, 56) = 62.16$, $MSE = 6.17$, $p < .001$, $\eta^2 = .53$]. The group by time of recall interaction was not significant, $F = 1.34$.

For the visual-spatial task, results from the group by time of recall ANOVA revealed that the TBI group (M = 5.02) predicted they would recall less material than controls (M = 5.60), $F(1, 56) = 4.37$, $MSE = 3.29$, $p < .05$, $\eta^2 = .07$. In addition, a significant main effect for time of recall, $F(2, 112) = 49.10$, $MSE = .87$, $p < .001$, $\eta^2 = .47$, revealed that participants predicted an increase in their learning from trial 1 (M = 4.98) to trial 5 (M = 6.26) and a decrease in their memory performance after a 20-minute delay (M = 4.69). The two-way interaction was not significant, $F = 1.14$.

Accuracy of Memory Predictions—The mixed model ANOVA conducted on the performance accuracy scores for the list-learning task revealed that TBI participants (M = 2.81) were as accurate in their performance predictions as controls (M = 2.75), $F < 1$. Participants' predictions for trial 1 (M = 2.00) and trial 5 (M = 2.52) were more accurate than their predictions for the long-delay (M = 3.81), $F(2, 112) = 10.53$, $MSE = 5.41$, $p < .001$, $\eta^2 = .16$. The two-way interaction between group and accuracy of prediction was not significant, $F < 1$.

Results from the mixed model ANOVA conducted on the performance accuracy scores for the visual-spatial learning test again revealed that TBI participants (M = 1.64) were as accurate as controls (M = 1.45), $F < 1$. A main effect for time of recall revealed that participants were more accurate for trial 5 (M = .76) than for trial 1 (M = 1.69) or the long-delay (M = 2.19), $F(2, 112) = 27.28$, $MSE = 1.15$, $p < .001$, $\eta^2 = .33$. The interaction involving group and time of recall was not significant, $F < 1$.

Summary—These data revealed accurate memory self-awareness abilities for individuals with moderate to severe TBI who were in the early stages of recovery. First, participants with TBI predicted that they would perform more poorly on the memory tasks than controls. They also predicted that their memory performance would increase across multiple learning trials and decrease after a 20-minute delay. In terms of prediction accuracy, the TBI participants were as accurate in their prediction estimates as controls. For both groups and both task types, prediction accuracy was greatest for trial 5 and poorest for the long delay free recall.

Memory Self-Monitoring

To evaluate memory self-monitoring abilities, analyses were conducted in three ways. First, we compared the long-delay memory predictions made *before* and *after* experience with the tasks. Second, we compared the accuracy of memory predictions made before and after experience with the memory tasks. Accuracy of memory predictions was assessed by calculating the absolute differences between predicted and actual long-delay recall performances. We were interested in whether TBI participants would adjust their long-delay performance predictions to be more accurate following task experience. Finally, to further assess accuracy of memory predictions, Pearson product-moment correlations were used to evaluate the relationship between memory predictions and actual recall performance in which stronger relationships suggested better accuracy.

Memory Predictions—For the list-learning task (see Table 3), a group (TBI vs. controls) by experience (pre-experience delayed recall vs. post-experience delayed recall) mixed model ANOVA revealed that the TBI group (M = 5.64) predicted they would recall less material than controls (M = 7.97), $F(1, 56) = 9.43$, $MSE = 16.66$, $p < .01$, $\eta^2 = .14$. Similarly, on the visual-spatial test, participants with TBI (M = 4.45) predicted they would recall less information than controls (M = 5.10), $F(1, 56) = 4.26$, $MSE = 2.92$, $p < .05$, $\eta^2 = .07$. There were no main effects of experience, Fs < 1, and no significant interactions, Fs < 1.

Accuracy of Memory Predictions—A 2 (group) by 2 (experience) ANOVA revealed that the TBI (M = 3.22) and control (M = 3.52) groups exhibited similar levels of prediction accuracy for the list-learning task, $F < 1$. As can be seen in Table 3, the post-experience predictions ($M = 2.93$) of both the TBI and control groups were more accurate than their pre-experience estimates ($M = 3.81$), $F(1, 56) = 4.67$, $MSE = 4.80$, $p < .05$, $\eta^2 = .08$. A similar analysis conducted for the visual-spatial memory task also revealed that the TBI group ($M = 2.00$) was as accurate as controls ($M = 1.83$) in predicting their memory performance, $F < 1$. A significant main effect for time of recall again revealed that both groups adjusted their post-experience predictions ($M = 1.64$) to be more accurate than their pre-experience predictions ($M = 2.19$), $F(1, 56) = 8.98$, $MSE = .98$, $p < .01$, $\eta^2 = .14$. For both tasks, the two-way interactions between group and time of recall were not significant, *F*s < 1.

Prediction-Performance Relationships—To further assess accuracy of memory predictions, Pearson product-moment correlations were computed. We examined differences between the pre-experience and post-experience correlations separately for each group and each memory test (Cohen & Cohen, 1983). For the TBI group, the post-experience correlation was statistically greater than the pre-experience correlation for both the list-learning task ($r = .10$ vs. $r = .68$), $t(28) = -3.02$, $p < .01$, and the visual-spatial memory task ($r = -.17$ vs. $r = .38$), $t(28) = -2.09$, $p < .05$. The initial pre-experience correlations for the TBI group were low with a negative correlation for the visual-spatial task becoming a statistically significant positive correlation following experience with the task. For the control group, an already statistically significant pre-experience correlation for the list-learning task trended towards becoming more significant following task experience ($r = .53$ vs. $r = .75$), $t(28) = -1.79$, $p = .08$. The pre-experience ($r = -.07$) and post-experience ($r = .06$) correlations for the visual-spatial task were both non-significant and low for the control group. Next, we examined differences between the TBI and control groups' correlations, both pre-experience and post-experience, using Fisher-*r*-to-*z* transformations. Although the control group ($r = .53$) exhibited a generally stronger pre-experience correlation for the list-learning task than the TBI group ($r = .10$), $z = -1.77$, $p = .08$, there was no group difference (TBI $r = .68$; controls $r = .75$) in the strength of the post-experience correlation, $z = -0.52$. Furthermore, the groups did not differ in the pre-experience correlation, $z = -0.37$, or the post-experience correlation, $z = 1.23$, for the visual-spatial memory test.

Summary—The results suggest that the TBI participants were able to successfully self-monitor their memory abilities, updating memory knowledge based on task experience. First, following experience with the memory tasks, both the TBI and control groups exhibited greater prediction accuracy. In addition, the absolute difference score revealed no difference between the TBI and control participants in overall prediction accuracy. Second, the pattern of performance-prediction correlations revealed that post-experience predictions were stronger predictors of actual recall than pre-experience predictions, suggesting that both groups benefited from experience with the tasks. Furthermore, following experience with the task, the strength of the correlation between actual and predicted performance did not differ between the TBI and control groups for either episodic memory task.

Correlations with Neuropsychological Variables

Correlations were conducted to examine the relationship between the accuracy of performance predictions and the cognitive tests assessing word-knowledge/word-finding, attention/speeded processing, visuospatial skills, and executive functioning listed in Table 1. We used the absolute difference scores as our measures of both pre-experience and post-experience prediction accuracy and we pooled the data across the list-learning and visual-spatial memory tasks to increase reliability. Because of the number of correlations conducted, we used a more stringent *p*-value of .01 for significance. For the TBI group, no statistically significant correlations between the neuropsychological measures and either pre-experience, r range $= -.34$ to $.27$, or post-experience, r range $= -.31$ to $.34$, prediction accuracy were found. For the control group, no significant correlations emerged for pre-experience prediction accuracy, $r = -.26$ to .43, or for post-experience prediction accuracy, $r = -.23$ to .38. The strongest relationship was between the Shipley word-knowledge test and pre-experience prediction accuracy for the control group, $r = .43$, $p = .02$, suggesting that those with better performance on the vocabulary test were less accurate predicting their memory performance before experience with the tests.

Correlations with Injury Characteristics

Correlations were also conducted for the TBI participants between pre-experience and post-experience prediction accuracy measures and injury characteristics (i.e., PTA, coma duration, and time since injury). No significant relationships were observed for coma duration, PTA duration, and time since injury for either the pre-experience predictions, *r*s range = .24 to .37, or the post-experience predictions, *r*s range = −.30 to −.02.

Discussion

The purpose of this study was to investigate memory self-awareness and memory self-monitoring abilities in individuals during the early stage of recovery from moderate to severe TBI. Using a performance-prediction paradigm, participants predicted their ability to recall verbal and visual-spatial material both before and after experience with the episodic memory tests. As expected, and consistent with previous research (e.g., Schmitter-Edgecombe et al., 2004; Vanderploeg et al., 2001), the TBI participants performed more poorly on measures of episodic memory than controls. The TBI group generally recalled less information during the learning trials (i.e., trial 1 and trial 5), and lost more information during the 20-minute delay. We were primarily interested in whether individuals in the early stages of recovery from a TBI would demonstrate accurate metamemorial abilities for their poorer memory performances.

In regard to memory self-awareness, on the episodic memory tasks administered, the findings showed that TBI participants in the early stage of recovery demonstrated accurate awareness for their memory abilities. First, consistent with actual recall performance, the group with TBI predicted they would recall less episodic material than controls. Furthermore, as seen in Table 2, a comparison of predicted performance scores with actual recall scores shows that both groups generally underestimated their actual performances on the memory tasks. Second, the TBI group demonstrated knowledge of how differing task demands would influence their performance. More specifically, similar to controls, the TBI participants predicted an increase in the amount of material recalled following multiple learning trials and a decrease in information recalled following a 20-minute delay. Third, the prediction accuracy data revealed no difference between the TBI and control groups in the accuracy of their memory predictions.

These findings suggest that in the early stages of recovery from a brain injury, individuals with TBI can demonstrate accurate memory self-awareness. Using a similar prediction-performance paradigm, Schmitter-Edgecombe and Woo (2004) found accurate memory self-awareness abilities in individuals with severe TBI who were more than 1 year post injury. The results of the current study contrast with some of the previous literature, which suggests that persons in the early stages of recovery from a TBI exhibit difficulties with memory self-awareness (e.g., Boake et al., 1995; Port et al., 2002; Roche et al., 2002; Sbordone et al., 1998). The techniques used in these earlier studies, however, mostly relied on contrasting participant self-report with ratings provided by the participant's family member or rehabilitation staff. This methodology has been referred to as “off-line assessment” because the questionnaires and interviews used to gather information about the patient's memory beliefs and knowledge are temporally distal from any particular memory task (Bunnell, Baken, & Richards-Ward, 1999). In the present study, we used an “on-line assessment” technique which allowed participants to make estimates about their memory performance in close temporal proximity to completing the memory tests.

While use of this performance-prediction paradigm allowed us to investigate the self-monitoring aspect of metamemory, it should be noted that this technique requires an explicit, externally-driven demand for self-reflection and therefore may limit generalization to more incidental self-awareness involved in everyday situations.

In regard to memory self-monitoring abilities, we found that during the early stages of recovery participants with TBI were able to utilize task experience to update self-knowledge of memory abilities. More specifically, the post-experience memory estimates of both groups were more accurate than their pre-experience predictions. In addition, results from the performance prediction correlations revealed that the post-experience correlations of the TBI group were significantly stronger than their pre-experience estimates in predicting actual memory performance. In the case of the visual-spatial memory task, a negative pre-experience correlation became a significant positive post-experience correlation. This suggests that participants with TBI were able to use experience to increase the prediction accuracy of their estimates. These findings are consistent with previous research (Giacino & Cicenrone, 1998; Schlund, 1999) which suggests that individuals in the early stages of recovery following a TBI can benefit from experience with tasks to update and improve their self-knowledge of memory abilities. These findings also support prior studies which have shown that TBI patients receiving inpatient rehabilitation can benefit from feedback about their performance to better future performances and ultimately increase their gains from rehabilitation (Lam et al., 1988).

Past research has documented relationships between participants' metamemory skills and frontal lobe abilities (Janowsky et al., 1989; Kikyo et al., 2002; Vilkki et al., 1999), attention/speeded processing skills (Schmitter-Edgecombe & Woo, 2004), and medial-temporal functions (Schmitter-Edgecombe & Anderson, 2007). In the present study, we did not find a consistent association for the TBI group between pre-experience or post-experience prediction accuracy and neuropsychological tests sensitive to different cognitive abilities. This contrasts with an earlier performance-prediction study from our laboratory (Schmitter-Edgecombe & Woo, 2004) where individuals with higher levels of executive functioning and attention/speeded processing abilities were found to be more accurate in predicting their memory performance before receiving experience with the memory tasks. In this prior study, all participants were tested at least one year after injury (i.e., 1 to 29 years post injury) allowing for varying levels of recovery in cognitive skills to be reached. In the present study, however, all participants were tested shortly after emergence from PTA, at a time when many individuals with TBI show reduced performances on standardized neuropsychological tests. Additional research is needed to better understand neural correlates that influence metamemorial predictions.

Before concluding, we consider limitations to the present study. First, the participants in this study all had a diffuse closed-head injury as a result of a moderate to severe TBI. In addition, all the TBI participants were Caucasian individuals under the age of 55 who were not demented and were within 8 weeks of emerging from PTA. Since none of the TBI participants were in the demented range of functioning at the time of testing, the results may not generalize to persons whose cognitive functioning is so impaired that they are unable to demonstrate awareness of their own level of functioning. Additionally, since all TBI participants were actively participating in inpatient rehabilitation at the time of testing (time since injury *range* = 13 − 78 days), these results may not generalize to TBI participants in the early stage of recovery who are not actively engaged in rehabilitation training as the rehabilitation program itself may have been responsible for providing some elements of awareness training. We did not, however, find significant correlations between time since injury and accuracy of memory self-awareness and memory self-monitoring abilities.

Furthermore, since the TBI participants generally sustained diffuse injury, the current findings may not extend to individuals with more focal injuries such as lesions to the frontal lobe, which has been linked to metamemory (Janowsky et al., 1989; Kikyo et al., 2002; Vilkki et al., 1999). One recent study found that compared to TBI participants without frontal neuropathology, TBI participants with frontal neuropathology (e.g., frontal contusion, hematoma) had more difficulty making item-by-item predictions (Kennedy, 2004). Such an analysis was precluded in this study as only seven of the participants with TBI did not have some identified frontal neuropathology as documented in medical records. Future work is needed to tie metamemorial accuracy with underlying areas of neuropathology (Kennedy, 2004). Additionally, in the present study we utilized global memory predictions to assess metamemorial abilities. Given that other studies with chronic TBI participants have effectively used different measurement techniques (e.g., Kennedy, 2004; Kennedy & Nawrocki, 2003; Kennedy & Yorkston, 2000; Schmitter-Edgecombe & Anderson, 2007), future research is needed to extend the present findings to different metamemorial judgments of memory, such as item-by-item judgments (e.g., feeling-of-knowing). Future research may also want to investigate other variables that could affect metamemorial knowledge such as task difficulty and a person's knowledge and skill in the domain being assessed.

Finally, although this research methodology provides a snapshot of participants' metamemory abilities, participants were cued by the experimenter to evaluate their memory abilities. In addition, the episodic memory tasks used in this laboratory study were clinical instruments designed to assess memory abilities under optimal conditions rather than real-world situations. Therefore, additional research is needed to better understand whether individuals in the early stages of recovery following TBI would accurately assess the demands of real-world metamemorial situations.

In summary, this study used a performance-prediction paradigm to investigate memory self-awareness and memory self-monitoring abilities for verbal and visual-spatial material in moderate to severe TBI participants following emergence from PTA. Despite exhibiting poorer performances on episodic memory measures, we found that TBI participants who were actively receiving inpatient rehabilitation demonstrated intact metamemorial abilities. More specifically, the TBI participants correctly predicted that their memory performance would be poorer than that of controls, accurately adjusted their predictions in accordance with the demands of the tasks, and successfully modified their predictions following experience with the tasks. These findings suggest that, similar to controls, TBI individuals with episodic memory impairments can competently assess the demands of externally-driven metememorial situations and utilize experience with tasks to accurately update their knowledge of memory abilities. As previous research has suggested (Lam et al., 1988), the more persons with TBI are aware of deficits the more likely they are to benefit from rehabilitation.

APPENDIX

Addendum 1

Instructions for Self-Awareness Trials of list-learning task

Trial 1 Memory Prediction—*Say:* "Before I administer this test, I am going to ask you to predict for me how you think you might perform on the test. I am going to read a list of 15 words. When I am through, I will want you to say back as many of the 15 words as you can. I would like you to tell me how many of the 15 words that you think you will remember."

Trial 5 Memory Prediction—*Say:* "I will then read the list to you a second time and ask you to repeat back as many of the 15 words as you can. We will repeat this procedure until I have read the list to you five times. After hearing the list five times, how many of the 15 words do you think that you will remember?

Long-delay Free Recall Memory Prediction—*Say:* "How many of the 15 words do you think that you will recall after 20 minutes?"

Administer trials 1-5, trial b, and short-delay trial.

Instructions for Self-Monitoring Trial of list-learning task

Note to administrator: Administer after short-delay trial.

Say: "If I asked you to recall the words again in 20 minutes, how many of the 15 words do you think you will be able to recall in 20 minutes?"

Instructions for Self-Awareness Trials of visual-spatial learning test

Trial 1 Memory Prediction

Say: "Before I administer this test, I again want you to predict for me how you think you might perform. I am going to show you a checkerboard that is like the one in front of you except that it will have a pattern consisting of 7 checkers. After I let you look at the pattern for 10 seconds, I will take it away and have you reconstruct the pattern from memory. How many of the 7 checkers do you think you will be able to correctly place on the blank checkerboard?"

Trial 5 Memory Prediction

Say: "I will then show you the pattern a second time and again ask you to reconstruct the pattern from memory as nearly as you can. We will repeat this procedure until I have shown you the pattern five times. After seeing the pattern five times, how many of the 7 checkers do you think you will be able to correctly place on the checkerboard?"

Long-delay Free Recall Memory Prediction

Say: "How many of the 7 checkers do you think you will be able to correctly place on the checkerboard after 20 minutes?"

Administer trials 1-5, trial b, and short-delay trial.

Instructions for Self-Monitoring Trial of visual-spatial learning test

Note to administrator: Administer after short-delay trial.

Say: "If I asked you to reproduce this pattern again in 20 minutes, how many of the 7 checkers do you think you will be able to correctly place on the checkerboard after 20 minutes?"

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Table 1

Demographic Data and Mean Summary Data for the Traumatic Brain Injury (TBI) and Control Groups

Test Variable	Mean		SD		N	
	TBI	Con	TBI	Con	TBI	Con
Demographics						
Age	31.17	28.28	13.06	12.78	29	29
Education	12.69	13.24	2.12	2.40	29	29
Gender	8F, 21M	12F, 17M				
General Ability						
Estimated Premorbid VIQ[a]	102.32	103.38	8.36	9.04	29	29
Word Knowledge/Word-finding						
SILS Vocabulary Total Correct	26.69	31.83**	4.96	4.09	26	29
TAWF Total Correct	33.14	35.14*	3.83	1.98	28	28
Attention/Speeded Processing						
SDMT Total Oral Correct	42.45	66.17**	9.12	11.31	29	29
SDMT Total Written Correct	34.93	55.76**	10.94	8.14	29	29
Trails A (time)	42.69	23.93**	16.60	8.07	29	29
Visuospatial Skills						
VFD Total Correct	13.00	14.69**	2.25	1.51	29	29
Executive Functioning						
Trails B (time)	110.14	56.86**	50.06	18.54	29	29
WAIS-III L-N Sequencing	9.62	11.00†	2.51	3.21	29	29
COWA Total Correct (PRW)	23.69	41.45**	10.02	10.73	29	29
SOPT Total Correct	14.17	15.76**	1.71	1.53	29	29
5-Point Test % Perseverations	0.11	0.04*	0.17	0.06	29	29
PEDL Total Score	21.24	21.48	3.12	3.50	29	29

Notes. Unless otherwise indicated, mean scores are raw scores. TBI = traumatic brain injury; Con = control; VIQ = Verbal Intelligence Quotient; TAWF = Test of Adult Word Finding; SDMT = Symbol Digit Modalities Test; WAIS-III = Wechsler Adult Intelligence Scale-Third Edition; L-N Sequencing = Letter-Number Sequencing subtest; VFD = Visual Form Discrimination test; COWA = Controlled Oral Word Association test (PRW); SOPT = Self Ordered Pointing Test; PEDL = Problems of Everyday Living Scale.

[a]Estimated Premorbid Wechsler Adult Intelligence Scale-Revised VIQ 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.

† $p = .07$

* $p < .05$

** $p < .001$.

Table 2

Mean Proportion of Actual Recall, Recall Predictions, and Prediction Accuracy for Episodic Memory Performance for the Traumatic Brain Injury (TBI) and Control Groups by Task and Time.

	Trial 1				Trial 5				Long-Delay Free Recall			
	Mean		SD		Mean		SD		Mean		SD	
Test Variable	TBI	Con	TBI	Con	TBI	Con	TBI	Con	TBI	Con	TBI	Con
Actual Recall												
RAVLT	5.79	7.21	1.45	1.70	10.93	13.35	2.40	1.76	7.35	11.28	3.55	2.72
7/24 Spatial Recall	.4.86	6.00	1.48	1.51	6.59	6.90	0.95	0.56	5.24	6.31	1.96	1.54
Memory Predictions												
RAVLT	6.83	8.10	2.19	2.01	9.17	11.72	2.89	2.70	5.79	7.83	2.73	3.87
7/24 Spatial Recall	4.55	5.41	1.38	1.18	6.07	6.45	1.13	1.02	4.45	4.93	1.43	1.49
Prediction Accuracy												
RAVLT	1.86	2.14	1.78	1.64	2.72	2.31	1.85	2.04	3.83	3.79	2.32	2.93
7/24 Spatial Recall	1.69	1.69	1.14	1.17	1.00	0.52	1.13	0.98	2.24	2.14	1.50	1.46

Notes. Prediction accuracy scores are absolute difference scores between predicted and actual recall. TBI = traumatic brain injury; Con = control; RAVLT = Rey Verbal Learning Test; 7/24 Spatial Recall = 7/24 Spatial Recall Test.

Table 3

Mean Proportional Recall Predictions, Prediction Accuracy, and Pearson Product-Moment Correlations for the Traumatic Brain Injury (TBI) and the Control Group by Task and Time.

	Pre-Experience Delayed Recall				Post-Experience Delayed Recall			
	Mean		SD		Mean		SD	
Test Variable	**TBI**	**Con**	**TBI**	**Con**	**TBI**	**Con**	**TBI**	**Con**
Memory Predictions								
RAVLT	5.79	7.83	2.73	3.87	5.48	8.10	2.75	4.21
7/24 Spatial Recall	4.45	4.93	1.43	1.49	4.45	5.28	1.43	1.49
Prediction Accuracy								
RAVLT	3.83	3.79	2.32	2.32	2.62	3.24	1.84	2.75
7/24 Spatial Recall	2.24	2.14	1.50	1.50	1.76	1.52	1.09	1.09
Product-Moment Correlations								
RAVLT	.10	.53**					.68**	.75**
7/24 Spatial Recall	-.17	-.07					.38*	.06

Notes. Prediction accuracy scores are absolute difference scores between predicted and actual recall. TBI = traumatic brain injury; Con = control; RAVLT = Rey Verbal Learning Test; 7/24 Spatial Recall = 7/24 Spatial Recall Test.

* $p < .05$

** $p < .001$.