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Recovery of Content and Temporal Order Memory for Performed Activities following Moderate to Severe Traumatic Brain Injury

Maureen Schmitter-Edgecombe and Adriana M. Seelye

Department of Psychology, Washington State University, Pullman, Washington

Abstract

Few studies have investigated the complex nature of everyday activity memory following traumatic brain injury (TBI). This study examined recovery of content and temporal order memory for performed activities during the first year in individuals who suffered moderate to severe TBI. TBI and control participants completed eight different cognitive activities at baseline (i.e., acutely following injury for TBI) and then again approximately one year later (follow-up). Participants' free recall of the activities provided a measure of content memory. Temporal order memory was assessed with a reconstruction task. Self-report and informant-report of everyday memory problems at follow-up was used to examine the relationship between activity memory performances and everyday memory. TBI participants showed significant recovery in both content and temporal order memory for activities during the first year. Despite showing significant recovery, the TBI group's activity memory performances remained poorer than controls at follow-up. Greater self- and informant-report of everyday memory difficulties was associated with poorer temporal order memory but not content memory for activities. These findings demonstrate recovery in multiple memory processes that support activity memory following moderate to severe TBI. The findings also suggest a stronger link between everyday memory abilities and temporal order memory for activities in comparison to activity memory content in a TBI population.

Keywords

activity memory; closed head injury; recovery; episodic memory; everyday memory

Multiple memory processes are involved in the activities we carry out everyday. For example, memory for the content of completed activities (what happened: sent an email reply) as well as the temporal order of activities in time (when it happened: after lunch) are both important components of everyday remembering. In the traumatic brain injury (TBI) literature, data concerning memory impairments has primarily been gathered using verbal memory paradigms that assess for the content of information being learned, such as memory for a list of words (e.g., Ashman et al., 2008; Bercaw et al., 2011). Activity memory paradigms and paradigms that allow for the simultaneous investigation of multiple aspects of memory processing have been less widely investigated in the TBI literature. Given that multiple memory processes are needed to support everyday activities (Schmitter-Edgecombe, Woo, & Greeley, 2009), research is needed to better characterize the complex nature of activity memory following TBI.

Contact Address: Maureen Schmitter-Edgecombe, Department of Psychology, Washington State University, P.O. Box 644820, Pullman, Washington 99164-4820, Phone: 509-335-0170, FAX: 509-335-5043, schmitter-e@wsu.edu.

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Within the memory literature, a distinction has been made between memory for the content of an activity and memory for the context in which an event occurs, including perceptual, spatio-temporal, affective or social details (Craig & Jennings, 1992; Johnson, Hashtroudi, & Lindsay, 1993). While some types of context are likely to be encoded in conjunction with content memory (e.g., episodic source from which a specific item was acquired), other aspects of context are thought to be encoded independently, such as memory for temporal order. Content memory has been linked with the integrity of the medial temporal lobes (e.g., Delacourte et al., 1999; Guillozet, Weintraub, Mash, & Mesulam, 2003), whereas temporal order memory has been linked with frontal lobe functioning (e.g., Milner, Petrides, & Smith, 1985; Schmitter-Edgecombe et al., 2009; Shimamura, Janowsky, & Squire, 1990). In the present study, we examine both content and temporal order memory for performed activities during the first year of recovery in individuals who suffered a moderate to severe TBI.

Past research utilizing verbal learning paradigms has shown that individuals with TBI in the early stages of recovery perform more poorly than controls on tests of episodic verbal memory (e.g., Anderson & Schmitter-Edgecombe, 2009; Vanderploeg et al., 2001), but demonstrate a good recovery curve of verbal memory abilities within the first year post-injury (Christensen et al., 2008). Although there has been debate in the literature about whether the content of activity memories is retained differently than the content of verbal information (Kausler & Lichty, 1988; Schmitter-Edgecombe & Simpson, 2001), studies have consistently shown that recall for subject-performed tasks (SPTs) is better than for verbal material (Zimmer, Helstrup, & Engelkamp, 2000; Engelkamp, Seiler, & Zimmer, 2005). One possible explanation is that enactment of an activity may involve distinctive actions and multimodal cue features that increase the salience of the material when compared to verbal learning (Engelkamp, 1995; Zimmer & Engelkamp, 1999; also see Zacks, Speer, Vettel, & Jacoby, 2006). Like neurologically normal participants, individuals with TBI have shown better recall for the content of subject-performed tasks compared to verbal materials (e.g., Cooke & Kausler, 1995; Larsson & Ronnberg, 1987). In these studies, however, recall for the content of the performed activities has consistently remained poorer for the TBI participants relative to the controls.

Tasks employed in activity memory paradigms have varied from discrete actions that last only several seconds (e.g., "Pick up the paperclip.") to continuous activities that can last for several minutes (e.g., "Connect the dots" or "Trace the maze"; Kausler & Hakami, 1983; Kausler & Lichty, 1988; Kausler et al., 1985). To our knowledge, only two published studies have examined content and temporal order memory for performed activities in patients with TBI (Cooke & Kausler, 1995; Schmitter-Edgecombe & Wright, 2003). In Cooke and Kausler's (1995) study, TBI participants and controls completed either 12 (short-list) or 24 (long-list) SPTs in either incidental or intentional instruction conditions. Each task took only a few seconds to complete and was either a usual (open the umbrella) or unusual (stir the glass of water with the chalk) action. The authors found that the TBI groups demonstrated both poorer temporal order and content memory for the performed actions when compared to controls. In addition, the TBI groups performed as well on temporal order recall in the incidental instruction condition as in the intentional instruction condition, providing support for the idea that temporal order memory for activities may not be dependent on intentional encoding strategies such as rehearsal (Kausler & Phillips, 1988; Salthouse, Kausler, & Sauls, 1988 but see Schmitter-Edgecombe & Simpson, 2001).

In Schmitter-Edgecombe and Wright's study (2003), TBI and control participants completed eight different laboratory tests of cognitive functioning (e.g., Trail Making Test) in an incidental learning condition. In contrast to the previous discrete action study by Cooke and Kausler (1995), this study used a continuous memory activity paradigm where each task took at least 3 minutes, but not longer than 15 minutes, to complete. After completion of the

eight activities, participants were tested on their recall, recognition and temporal order memory proficiency for the activities. Consistent with prior studies (Cooke & Kausler, 1995), the TBI group recalled and recognized fewer activities than the control group. The TBI and control groups did not differ in temporal order memory for the activities, supporting the assumption that content and temporal order memory are dissociable. This finding, however, contrasts with the poorer temporal order memory performance of TBI participants found in the Cooke and Kausler (1995) study. The authors offered several possible reasons for the contrasting findings. First, participants in their study spent more time completing each task, which might have resulted in increased opportunity to encode task information. In addition the context in which each task was encoded was more distinct and participants completed fewer activities (8 as compared to 12 and 24).

Both of these prior studies examined activity memory in TBI populations who were at least one year post-injury. Currently, it remains unknown whether memory abilities for the content and the temporal order of performed activities will show some and/or complete recovery during the first year post injury. In addition, because multiple encoding and retrieval processes may play a role in temporal order abilities, including some processes that may be automatic and others that may benefit from intentional processing (Mangels, 1997; Naveh-Benjamin & Jonides, 1986), further research is needed to better understand the boundary conditions in which temporal order memory may be intact following TBI.

To begin to address these questions, in the present study, TBI and control participants completed eight different tests of cognitive functioning in an intentional learning condition. Each activity (test) took at least three minutes, but no more than fifteen minutes, to complete. We choose to use continuous performance tasks in order to mimic as closely as possible everyday activities. That is, many everyday tasks are performed for a number of minutes (e.g., reading a magazine), thereby providing considerable time for the encoding of task participation. An intentional rather than incidental learning condition was employed given the repeated nature of the assessment and our interest in testing the boundary conditions of prior findings (Schmitter-Edgecombe & Wright, 2003). The activity memory paradigm was administered to TBI participants during the acute phase of recovery (baseline) and then again within the first year post injury (follow-up). Similar intervals were employed for the control group. Consistent with prior research (e.g., Schmitter-Edgecombe & Wright, 2003), we expected that the TBI group would show poorer recall than controls for the content of performed activities both acutely after injury and at follow-up. We also expected to see recovery in memory for the content of performed activities by the TBI participants. We were especially interested in the temporal order memory performances of the TBI participants both acutely and at follow-up. Given the earlier findings of Schmitter-Edgecombe and Wright (2003), and the supposition that the processes involved in the encoding of temporal order information are largely automatic, we hypothesized that temporal order memory for activities will be intact at follow-up.

We were also interested in whether there might be relationships between content memory and temporal order memory and neuropsychological tests that presumably tap temporal lobe and frontal lobe functioning, respectively. The pattern of correlations among the memory components and tests sensitive to frontal and temporal lobe functions could provide information about those factors that might contribute to activity memory proficiency following moderate to severe TBI. In addition, recent research has found a unique role for the impact of non-content memory processes (e.g., prospective memory, temporal order memory, source memory) on everyday functioning in other brain impaired populations (e.g., Duchek, Balota, & Cortese, 2006; Jones, Livner, & Backman, 2006; Schmitter-Edgecombe et al., 2009). We therefore also explore the relationship between content and temporal order

memory for performed activities and self-report and knowledgeable informant report of everyday memory problems being experienced by individuals with TBI at follow-up.

Methods

Participants

Participants were 59 individuals (19 females, 40 males) who had suffered a moderate to severe TBI and 59 neurologically normal controls (26 females, 33 males). The TBI participants were identified from 147 consecutive admissions between December 2003 and December 2008 to a regional traumatic brain injury inpatient rehabilitation program in the Pacific Northwest. Forty-eight potential participants declined to participate or medical record review revealed a primary diagnosis other than a TBI. This study was conducted as part of a larger study investigating recovery of cognitive skills following TBI. Participants for this study were excluded if they had a pre-existing neurological, psychiatric, or developmental disorder(s) other than a TBI, a history of treatment for substance abuse, a history of multiple head injuries, or an age and education matched control participant could not be identified ($N = 22$). To minimize possible developmental effects on performance, TBI participants under the age of 15 or over the age of 55 were also excluded from this sample ($N = 18$). The TBI patients were first tested following emergence from post-traumatic amnesia. TBI participants received feedback regarding their cognitive functioning in return for their time. Control participants were recruited from the community through the use of advertisements and received monetary compensation.

Thirty-seven of the TBI participants suffered a severe TBI; defined by a Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) score of 8 or less, documented at the scene of the accident or in the emergency room. The remaining 22 TBI participants suffered a moderate TBI classified by a GCS between 9 and 12 ($n = 7$) or by a GCS of higher than 12 accompanied by positive neuroimaging findings and/or neurosurgery ($n = 15$; Dennis et al., 2001; Fletcher et al., 1990; Taylor et al., 2002). The majority of the TBI participants experienced a coma duration longer than two hours as reported in medical records or by careful clinical questioning of the participant and/or knowledgeable informant, such as a family member ($M = 78.84$; $SD = 169.98$, $range = 0 - 720$ hours). All participants exhibited at least a one-day period of post-traumatic amnesia (PTA; $M = 21.72$; $SD = 22.16$; $range = 1 - 150$ days). Emergence from PTA was determined either by repeated administration of the Galveston Orientation and Amnesia Test (GOAT; $n = 40$; Levin, O'Donnell, & Grossman, 1979) or, in those cases where the TBI participant had emerged from PTA prior to arriving at the rehabilitation institute, by careful clinical questioning of the TBI participant to recall their memories after the injury in chronological order until the examiner was satisfied that normal continuous memory was being described ($n = 6$; King et al, 1997; McMillan, Jongen, & Greenwood, 1996). For the baseline session, the majority of TBI participants were assessed within 3 weeks of emergence from PTA ($n = 66\%$) ($M = 19.05$ days; $SD = 13.44$, $range = 0 - 58$ days) with time since injury ranging from 9 – 168 days ($M = 41.85$, $SD = 25.68$). Participants head injuries resulted from motor vehicle accidents ($N = 37$), motorcycle accidents ($N = 8$), sports ($N = 2$), falls ($N = 9$), and assault ($N = 2$).

To increase the likelihood that the groups were roughly equivalent in premorbid abilities, the age ($M = 28.49$; $SD = 11.85$) and educational level ($M = 12.92$; $SD = 2.13$) of the TBI participants were closely matched to the age ($M = 26.93$; $SD = 11.08$; $t = .74$) and educational level ($M = 13.56$; $SD = 2.13$; $t = -1.64$) of control participants. In addition, an estimate of premorbid Wechsler Adult Intelligence Scale-Revised (WAIS-R, Wechsler, 1997) Verbal Intelligence Quotient (VIQ) 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 TBI ($M = 101.92$; $SD = 7.98$)

and control ($M = 103.21$; $SD = 7.41$) groups did not differ significantly in estimated premorbid abilities, $t = -.92$.

Thirty-two of the TBI participants were retested at an average of 9 months post injury ($M = 289$ days, $SD = 85$, $range = 190\text{--}475$ days). As can be seen in Table 1, the sample of TBI participants who were re-tested were on average older than those who were not retested, $t(57) = -2.54$, $p < .05$. There were, however, no significant differences between the returning and non-returning TBI participants in level of education, GCS, coma duration, PTA estimate, or estimated VIQ, $t's < 1.4$. In addition, the time between initial testing and the current assessment did not differ between the returning TBI participants ($M = 246$ days, $SD = 82$, $range = 175\text{--}445$ days) and their matched control participants who were also retested ($M = 213$ days, $SD = 63$, $range = 161\text{--}430$ days), $t(62) = 1.83$.

Materials

Similar to the study by Schmitter-Edgecombe and Wright (2003), eight cognitive activities which could all be completed within a 1 to 1.5 hour duration were selected from a set of intellectual and neuropsychological tasks. Each activity took at least 3 minutes, but no longer than 15 minutes to complete, inclusive of instructions. In addition, the instructions for all eight activities took less than 60 seconds, and half took less than 15 seconds, to give. The eight activities were administered in accordance with standardized instructions, and the order of administration of the eight activities was random for each participant. The eight activities included the Letter-Number Sequencing subtests from the WAIS-III (WAIS-III, Wechsler, 1997), Controlled Oral Word Association Test (COWAT, FAS version, Benton & Hamsher, 1976), Trail Making Test (TMT, Reitan, 1958), Benton Visual Form Discrimination Test (VFDT, Benton et al., 1994), Five-point test (Regard, Strauss, & Knapp, 1985), and the Symbol Digit Modalities Test (SDMT, Smith, 1991). The remaining two tasks included a variant of the Self-Order Pointing Test (SOPT, Schmitter-Edgecombe & Chaytor, 2003) and an object definitions test (McWilliams & Schmitter-Edgecombe, 2008). For the Self-Ordered Pointing Test, participants completed two trials wherein they were asked to point to nine different abstract designs, one on each of nine sheets, without pointing to any design more than once. For the object definitions test, participants had one minute to describe each of six objects as if they were describing them to someone who had never heard or seen such things before.

Procedure

Initial Instruction—For both initial and follow-up testing, participants were told that they would be completing a variety of different tasks over the course of one hour. They were informed that after completing all tasks their memory for the tasks and for the order of completion of the tasks would be tested. They were told to try to remember each task and the order in which the task was completed.

Memory Testing—Memory testing began immediately following completion of the eight activities and the memory tests were administered in the following fixed order: free recall, recognition, and temporal order. This fixed order was necessary since completion of the temporal memory task involved providing participants with cards that contained a description of each of the eight tasks (see Temporal Order Test description below). Administration of the recall and recognition (content memory) tests prior to the temporal ordering task was not expected to adversely affect temporal memory proficiency. Prior research has shown that completing a free recall test prior to a temporal order test has no overall effect on temporal judgment performance (Jackson & Michon, 1984; Jackson et al., 1986).

Free Recall Test—Participants were asked to recall, in any order, the tasks that they had just completed. They were told to provide enough description of each task so that the experimenter would recognize the task they were referring to. The experimenter asked for clarity whenever necessary. Recall of an activity was scored as correct if the experimenter was able to recognize the described task (e.g., the Trail Making Test test was often described as “connecting numbers to numbers and numbers to letters in circles”). A second experimenter double-checked the scoring of the first experimenter. In all cases there was 100% agreement. The total number of eight activities recalled was used as the primary measure of activity content memory.

Recognition Test—For the recognition test, participants were read aloud descriptions of 16 tasks. Following each task description, participants were asked to say “yes” if they had completed the activity or “no” if they had not. The experimenter recorded each participant’s response. Eight of the descriptions corresponded to the target tasks that the participant had performed. The remaining eight distractor tasks consisted of descriptions that had one task element in common with a performed activity. For example, the target description for the VFDT was “You were shown a stimulus design and asked to match the stimulus design with one of four other presented designs.” The distractor description was “You were shown pictures of objects that were obliterated by snow-like spatters and you identified the hard-to-see objects.”

We used the two-high threshold model to compute discrimination (P_r) and response bias (B_r) indices for the recognition test (Snodgrass & Corwin, 1988). For each participant, a hit rate (i.e., proportion of completed activities correctly recognized) and false alarm rate (i.e., proportion of uncompleted tasks incorrectly attributed to having been completed) were first computed. To avoid the problem of division by zero in the computation of the bias measure (B_r), the hit rate was calculated as $(\text{number of hits} + 0.5) / (\text{number of target stimuli} + 1)$ and the false alarm rate was calculated as $(\text{number of false alarms} + 0.5) / (\text{number of distractor stimuli} + 1)$. P_r was then calculated by subtracting the false alarm rate from the hit rate. B_r was computed by dividing the false alarm rate by $(1 - P_r)$. P_r ranges from 0 (indicating no sensitivity) to 1 (indicating perfect discrimination); for B_r , .50 indicates neutral response bias.

Temporal Order Test—For the temporal order test, 8 cards were put in front of the participants. The order of placement of the 8 cards was determined randomly for each participant. Each card contained a description of one of the tasks that the participant had completed. Participants were instructed to arrange the cards in the order that they had completed the 8 tasks.

Several different methods for estimating temporal order have been used in the literature (e.g., Naveh-Benjamin, 1990; Vakil & Blachstein, 1994). For this study, the following three measures of temporal order were computed - (a) *Hits*: the proportion of activities correctly placed at their original serial position (Vakil, Biederman, Liran, Groswasser, & Aberbuch, 1994); (b) *Correlation*: the Pearson’s product-moment correlation between participants’ remembered order of activity completion and the true order (Tzeng, Lee, & Wetzel, 1979); and (c) *Absolute Deviation*: the sum of the absolute value of the difference between each activity’s remembered position and its actual position (Mangels, 1997). Because the data comparing the TBI and control groups revealed a similar pattern of findings for all three measures of temporal order, for simplicity, we describe only the absolute deviation measure in the results section but display all three measures of temporal order memory in the Tables.

Everyday Memory Questionnaire—At follow-up, both the participant with TBI and an individual who was knowledgeable about the everyday memory functioning of each

participant completed the Everyday Memory Questionnaire (EMQ, Sunderland, Harris & Baddeley, 1983). The EMQ is a 35-item questionnaire originally developed and used among a population with TBI to measure the extent of memory failures that may occur in everyday living (e.g., forgetting to check whether you have done something; when talking to someone, forgetting what you just said). The items are rated on a Likert-scale ranging from 4 (several times a day) to 0 (never), with regard to memory lapses occurring in the past month. Higher scores suggest greater everyday memory lapses.

Results

Cross-sectional Data: Full Sample

Means and standard deviations for activity recall, activity recognition, and temporal order reconstruction scores are presented in Table 2 for the TBI group ($N = 59$) and control group ($N = 59$) at baseline. Unless otherwise stated, an alpha level of $p < .05$ was used for all analyses.

Content Memory: Activity Recall Data—A t-test analysis revealed that the TBI participants ($M = 4.41$, $SD = 1.88$) correctly recalled fewer of the 8 activities than controls ($M = 6.53$, $SD = 1.16$) acutely following injury, $t(116) = -7.37$, $d = 1.36$.

Activity Recognition Data—Table 2 displays discrimination (P_r) and response bias (B_r) for each group, as well as the hit and false alarm rates used to generate these measures. P_r values were reliably different from zero for both the control group, $t(58) > 46.16$, and the TBI group, $t(57) > 41.50$, confirming the above-chance discrimination between target activities and distractor activities. A t-test analysis on P_r values revealed that the controls ($M = .80$, $SD = .13$) exhibited reliably better recognition performance than the CHI participants ($M = .70$, $SD = .13$) acutely after injury, $t(115) = -4.11$, $d = .77$. A t-test comparison for the bias index revealed no reliable difference between the control group ($M = .46$, $SD = .24$) and the TBI group ($M = .43$, $SD = .15$), $t(115) < 1$. These findings indicate that the poorer discrimination performance of the TBI participants cannot be attributed to group differences in response bias.

Activity Temporal Order Memory Data—A t-test analysis using the absolute deviation measure of temporal order memory revealed that the sum of the absolute value of the difference between each activities remembered position and its actual position was greater for the TBI group ($M = 12.25$, $SD = 6.52$) compared to the control group ($M = 4.68$, $SD = 3.59$), $t(116) = -6.85$, $d = 1.44$.

Longitudinal Data: Subsample

Means and standard deviations for activity recall, activity recognition, and temporal order reconstruction scores at baseline and at follow-up are presented in Table 3 for the returning TBI group ($N = 32$) and the control group ($N = 32$).

Content Memory: Activity Recall Data—A 2 group (TBI, control) by 2 time (baseline, follow-up) mixed model ANOVA revealed a significant main effect of group, $F(1, 62) = 25.25$, $MSE = 2.91$, $p < .001$, $\eta^2 = .29$. There was also a significant main effect of time, $F(1, 62) = 13.04$, $MSE = 1.44$, $p < .001$, $\eta^2 = .17$, that was modified by a group by time interaction, $F(1, 62) = 6.07$, $MSE = 1.44$, $p < .05$, $\eta^2 = .07$. As can be seen in Table 3, the TBI participants demonstrated significant improvement in their ability to recall the content of the performed activities between baseline ($M = 4.38$) and time 2 ($M = 5.59$), $t(31) = -3.57$, $p = .001$ while there was no significant change in the performance of the control group, ($M = 6.34$ vs. $M = 6.66$), $t(31) = -1.24$. In addition, despite the improved

performance of the TBI group, their ability to recall the content of the activities remained poorer than that of the controls at follow-up, $t(62) = -3.47, p = .001$.

Activity Recognition Data—A group (TBI, control) by time (baseline, follow-up) ANOVA on the discrimination index revealed a significant main effect of group, $F(1, 60) = 7.40, MSE = .01, p = .009, \eta^2 = .11$, that was modified by a group by time interaction, $F(1, 60) = 6.56, MSE = .01, p < .05, \eta^2 = .10$. The main effect of time was not significant, $F(1, 60) = 1.67, MSE = .01$. As can be seen in Table 3, only the TBI group demonstrated significant improvement in their ability to discriminate between target activities and distractor activities from baseline ($M = .70$) to follow-up ($M = .76$), $t(30) = -2.74, p = .01$. In addition, there was no longer a difference in discrimination accuracy between the TBI ($M = .76$) and control group ($M = .79$) at follow-up, $t(61) = -.83$. For the response bias index, no reliable differences were found across group, $F(1, 60) = .05, MSE = .04$, or across time, $F(1, 60) = .28, MSE = .03$. The group by time interaction was also not significant, $F(1, 60) = .00, MSE = .03$, indicating no difference in response bias rate across groups or time (see Table 3).

Activity Temporal Order Memory Data—A 2 group by 2 time ANOVA on the absolute deviation measure revealed a significant main effect of group, $F(1, 62) = 22.99, MSE = 35.67, p < .001, \eta^2 = .27$, and a significant group by time interaction, $F(1, 62) = 6.66, MSE = 17.46, \eta^2 = .10, p = .01$. As can be seen in Table 3, the TBI participants demonstrated significant improvement in temporal order memory between baseline ($M = 12.66$) and follow-up ($M = 9.81$), $t(31) = 2.76, p = .01$, while there was no significant change in the performance of the control group ($M = 5.69$ vs. $M = 6.65$), $t(31) = -1.24$. Despite the improved performance of the TBI group, temporal order memory remained poorer than that of controls at follow-up, $t(62) = 2.70, p = .009$.

Correlational Analyses: Injury Related Characteristics

Correlational analyses were computed for the subset of longitudinal TBI participants between injury characteristics (i.e., coma depth, coma duration, PTA duration, and time since injury) and content memory and activity temporal order memory (absolute deviation) at both baseline and follow-up. Because age did not correlate significantly at baseline or follow-up with either the content (.04 and -.02, respectively) or temporal order memory (.11 and .23, respectively) measures for the TBI group, we did not partial age out in subsequent correlational analyses. To decrease Type 1 error, a more conservative alpha of $p < .01$ was used for significance. At baseline, GCS score ($r = .45, p = .009$) correlated significantly with the activity content memory score. At follow-up, both the GCS score ($r = .58, p < .001$) and coma duration ($r = -.45, p = .009$) correlated significantly with content memory. No significant correlations with content memory were found for time since injury. In addition, there were no significant correlations between any of the injury characteristics and temporal order memory at either baseline or follow up (See Table 4).

Correlational Analyses: Neuropsychological Tests

Correlational analyses were computed separately for the longitudinal group of TBI and control participants to determine whether we would find dissociation between our measures of content memory (activity recall) and temporal order memory (absolute deviation) at baseline and at follow-up. We were also interested in whether the content memory measures would correlate more highly with memory tasks that load heavily on medial temporal lobe functions (RAVLT learning and delayed recall), while the temporal order memory measure would correlate more highly with tasks sensitive to frontal lobe functions (COWAT total words, WAIS-III LNS total correct, (TMT B-A)/A, 5-point test proportion perseverations; SOPT total correct).

Because of the large number of correlations, a more conservative alpha of $p < .01$ was used to decrease Type 1 error. Correlations between the content and temporal order memory measures did not reach significance at baseline for either the control group ($r = -.26, p = .11$) or the CHI group ($r = -.29, p = .11$). At follow-up, a moderate correlation was found between the content and temporal order measures for both the control ($r = -.45, p = .01$) and TBI ($r = -.47, p = .005$) groups. At baseline for the control group, the content memory measure was found to correlate significantly with a task thought to rely heavily on medial temporal lobe functions (i.e., RAVLT list learning, $r = .47$). No other correlations reached significance (see Table 4). At follow-up for the control group, RAVLT list learning ($r = -.49$) and one of the tasks thought to rely heavily on frontal lobe functioning (i.e., the WAIS-III LNS task; $r = -.55$) correlated significantly with the temporal order memory measure. For the TBI group, at baseline, both content and temporal order memory scores correlated significantly with the tasks thought to rely heavily on temporal lobe functioning (i.e., RAVLT list learning and RAVLT long delay recall; see Table 4). No other correlations reached significance. At follow-up, only the content memory measure correlated significantly with the RAVLT list learning ($r = .70$) and long delay recall measures ($r = .65$). However, both the content ($r = .51$) and temporal order memory ($r = -.48$) measures correlated with the WAIS-III LNS task for the TBI group at follow-up.

Correlational Analyses: Everyday Memory Measure

We then looked at the relationship between the content and temporal order memory measures and self-report and knowledgeable informant report of everyday memory difficulties being experienced by the TBI group at follow-up. A significant relationship was found between temporal order memory scores at both baseline and follow-up for participant self-report (r 's = .59 and .57, respectively, p 's < .01) and knowledgeable informant report (r 's = .53 and .59, respectively, p 's < .01) of everyday memory problems. Poorer scores on the temporal order task at both baseline and follow-up were associated with higher self and informant reports of everyday memory difficulties at follow-up. The correlations for the content memory measure did not reach significance at either baseline or follow-up for the participant or the knowledgeable informant (see Table 4).

Discussion

The purpose of this study was to examine recovery in content and temporal order memory abilities for performed activities during the first year following moderate to severe TBI. Participants completed 8 activities (cognitive tests) in an intentional learning condition, and were tested on their recall and recognition (content memory) and temporal order memory for the activities at two time points, acutely after injury and at about 1 year post injury. As expected, the TBI participants showed poorer recall and recognition than controls for the content of performed activities acutely after injury (baseline). Correlational analyses also revealed that individuals who sustained more severe TBIs also tended to have poorer content memory scores at both baseline and follow-up.

In addition, the data revealed that the TBI participants also demonstrated significant recovery in their ability to both recall and recognize the content of performed activities between baseline and follow-up testing. There was no significant change in performance between baseline and follow-up for the control group. Furthermore, the TBI group's recall memory for the content of performed activities remained poorer than that of controls at follow-up.¹ There was, however, no difference in performance between the two groups in their ability to discriminate between completed activities and distracters at one year. While this may represent a possible ceiling effect for the recognition measure, it may also reflect the less effortful nature of the recognition test along with the more automatic process of familiarity that is involved in recognition judgments. Similar to findings that have been

obtained with episodic verbal learning paradigms (e.g., Ashman et al., 2008; Bercaw et al., 2011), these findings demonstrate significant recovery in episodic content memory for performed activities during the first year following moderate to severe TBI.

Of primary interest was the temporal order memory performance of the TBI group. We found that the TBI participants demonstrated poorer temporal order memory for the performed activities than control participants acutely after injury. In addition, unlike controls, the TBI participants demonstrated significant improvement in temporal order memory between baseline and follow-up; however, they still performed more poorly than the control group at follow-up. Unlike for content memory, correlational analyses revealed no significant relationship between injury severity and temporal order memory proficiency at either baseline or follow-up. These findings indicate that temporal memory proficiency for performed activities is impaired in the acute stage of recovery from a moderate to severe TBI and that these abilities recover to some degree within the first year post injury. The finding of poorer temporal order memory for performed activities in the TBI group at one year post injury is consistent with a prior study by Cooke and Kausler (1995). The findings conflict, however, with the prior results of Schmitter-Edgecombe and Wright (2003). Two possible explanations for this contrasting finding are that Schmitter-Edgecombe and Wright (2003) used an incidental instruction condition as compared to an intentional instruction condition, and that their participants were all more than 1 year post injury. It may be that under intentional encoding conditions, intentional encoding strategies like rehearsal can facilitate temporal order memory for activities (Schmitter-Edgecombe & Simpson, 2001), thereby providing a disproportionate advantage for controls who may be better able to use effortful, intentional encoding strategies. It is also possible that recovery of temporal order memory for activities continues past the point we collected the follow-up testing data for the TBI participants.

Past research has documented a relationship between temporal order memory and frontal lobe functioning (e.g., Milner et al., 1985; Schmitter-Edgecombe et al., 2009; Shimamura et al., 1990). For the control group, content memory was found to correlate with a test sensitive to temporal lobe functioning (i.e., RAVLT list learning) at baseline, while temporal order memory proficiency was found to correlate with a test sensitive to frontal lobe functioning (i.e., WAIS-III LNS task) and temporal lobe functioning (i.e., RAVLT list learning) at follow-up. For the TBI group, at initial testing both the content and temporal order memory measures were associated with the tests sensitive to temporal lobe functions (i.e., RAVLT list learning and delayed recall). While this might suggest that the RAVLT reflects processes mediated by the frontal as well as the temporal lobes, no significant correlations were found between the temporal order memory measure and tests of frontal lobe functioning at baseline. In addition, at follow up, only content memory remained significantly associated with the RAVLT list learning and delayed recall tests for the TBI group. Both content memory and temporal order memory were associated with a test sensitive to frontal lobe functioning (e.g., WAIS LNS). These findings might be interpreted to suggest that as recovery occurs following moderate to severe TBI, temporal lobe functioning might make decreasing contributions to temporal order memory proficiency for activities. However, this explanation does not seem consistent with the finding of a significant relationship between

¹We found a similar pattern of performance when evaluating content memory data from a more traditional verbal learning paradigm (i.e., the RAVLT). A 2 group (TBI, control) by 2 time (baseline, follow-up) mixed model ANOVA on the RAVLT delayed memory measure revealed a significant main effect of group, $F(1, 62) = 12.54$, $MSE = 20.66$, $p < .001$, $\eta^2 = .17$. The significant main effect of time, $F(1, 62) = 20.55$, $MSE = 3.46$, $p < .001$, $\eta^2 = .26$, was modified by a group by time interaction, $F(1, 62) = 8.67$, $MSE = 3.46$, $p = .005$, $\eta^2 = .13$. The TBI participants demonstrated significant improvement in their ability to retain the content of a list of words between baseline ($M = 7.47$) and time 2 ($M = 9.97$), $t(31) = -5.73$, $p < .001$, while there was no significant change in the performance of the control group, ($M = 11.34$ vs. $M = 11.87$), $t(31) = -1.06$. In addition, despite the improved performance of the TBI group, their ability to retain the content of the list of words remained poorer than that of controls at follow-up, $t(62) = -2.10$, $p < .05$.

the temporal order and content memory measures of the TBI group at follow-up but not at baseline. While this may suggest that content and temporal order memory are not dissociable, it may also reflect the ability of the TBI participants to more efficiently apply effortful, intentional learning strategies to support the learning of both content and temporal order information at follow-up as compared to baseline. Future research which directly compares incidental and intentional encoding conditions and uses larger sample sizes will be needed to better elucidate the nature of these relationships.

Recent research has shown that non-content memory processes (e.g., prospective memory, source memory, temporal order memory for activities) may be better predictors of everyday functional status than content memory measures in a memory impaired population (Schmitter-Edgecombe et al., 2009). Consistent with this finding, TBI participants' performances on the temporal order activity memory measure at both baseline and follow-up were significantly associated with both self- and informant-report of everyday memory difficulties. The direction of the relationship suggested that the poorer temporal memory for activity scores at both baseline and follow-up were associated with greater self- and informant-report of everyday memory difficulties at follow-up. No significant relationships were found between the activity content memory measure and reports of everyday memory problems. Future research is needed to determine whether non-content memory measures, such as temporal order memory for activities, might be useful predictors of subsequent everyday memory performance in individuals recovering from TBI. Research is also needed to investigate whether interventions targeted at improving temporal order memory for activities in this population generalize to improvements in everyday memory performance.

One limitation of the present study is the lower sample size of TBI participants at follow-up, which lowered the study's power. In addition, the returning TBI participants were on average older than those who did not return, which may limit generalizability to the larger TBI population. Another limitation is that the activity memory tests used in the present study was conducted in a laboratory setting, which may limit the generalizability of the findings to real-world temporal order memory situations. In addition, the activities memory paradigm used in this study incorporated explicit, intentional instructions to remember temporal order information and therefore may limit generalization to more incidental everyday memory situations. Finally, the TBI sample was comprised largely of men, which may limit generalizability to women with TBI.

In summary, results from the present study showed that, compared to controls, TBI participants demonstrated poorer content and temporal order memory abilities for performed activities at baseline testing and at follow-up when assessed with an intentional activities memory paradigm. Importantly, TBI participants showed significant recovery in both content and temporal order memory for activities from baseline testing to follow-up, demonstrating recovery in multiple memory processes that support activity memory following moderate to severe TBI. In addition, self- and informant-report of greater everyday memory difficulties at follow-up related to poorer performance on the temporal order memory measure for activities at both baseline testing and follow-up. No relationship with everyday memory lapses was found for the activity content memory measure, suggesting a stronger link between everyday memory abilities and temporal order memory for activities as compared to memory for the content of activities. Additional studies are needed to replicate the present findings and further explore the relationship between everyday functioning and temporal order memory for activities in individuals with TBI.

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References

- Anderson J, Schmitter-Edgecombe M. Predictions of episodic memory performance following moderate-to-severe traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*. 2009; 31:425–438. [PubMed: 18686113]
- Ashman TA, Cantor JB, Gordon WA, Sacks A, Spielman L, Egan M, et al. A comparison of cognitive functioning in older adults with and without traumatic brain injury. *The Journal of Head Trauma Rehabilitation*. 2008; 23(3):139–148. [PubMed: 18520426]
- Barona A, Reynolds CR, Chastain R. A demographically based index of pre-morbid intelligence for the WAIS-R. *Journal of Consulting and Clinical Psychology*. 1984; 52:885–887.
- Benton, A.; Hamsher, K. Multilingual aphasia examination. Iowa City: University of Iowa; 1976.
- Benton, AL.; Sivan, AB.; Hamsher, KD.; Varney, N.; Spreen, O. Contributions to neuropsychological assessment. 2nd ed. New York: Oxford University Press; 1994. Visual Form Discrimination; p. 65–72.
- Bercaw EL, Hanks RA, Mills SR, Gola TJ. Changes in neuropsychological performance after traumatic brain injury from inpatient rehabilitation to 1-year follow-up in predicting 2-year functional outcomes. *The Clinical Neuropsychologist*. 2011; 25(1):72–89. [PubMed: 21120763]
- Chistensen BK, Colella B, Inness E, Hebert D, Monette G, Bayley M, et al. Recovery of cognitive function after traumatic brain injury: A multilevel modeling analysis of Canadian outcomes. *Archives of Physical Medicine and Rehabilitation*. 2008; 89:S3–S15.
- Cooke DL, Kausler DH. Content memory and temporal memory for actions in survivors of traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*. 1995; 17:90–99. [PubMed: 7608307]
- Craik, FIM.; Jennings, JM. Human memory. In: MCraik, FIM.; Salthouse, TA., editors. *The handbook of aging and cognition*. Hillsdale: Lawrence Erlbaum Associates; 1992. p. 51–110.
- Delacourte A, David JP, Sergeant N, Buée L, Watzé A, Vermersch P, et al. The biochemical pathway of neurofibrillary degeneration in aging and Alzheimer's disease. *Neurology*. 1999; 52:1158–1165. [PubMed: 10214737]
- Dennis M, Guger S, Roncadin C, Barnes M, Schachar R. Attentional-inhibitory control and social-behavioral regulation after childhood closed head injury: do biological, developmental, and recovery variables predict outcome? *Journal of the International Neuropsychological Society*. 2001; 7:683–692. [PubMed: 11575590]
- Duchek JM, Balota DA, Cortese M. Prospective Memory and Apolipoprotein E in Healthy Aging and Early Stage Alzheimer's Disease. *Neuropsychology*. 2006; 20:633–644. [PubMed: 17100508]
- Engelkamp J. Visual imagery and enactments of action in memory. *British Journal of Psychology*. 1995; 86:227–240. [PubMed: 7795943]
- Engelkamp J, Zimmer HD. Memory for action events: A new field of research. *Psychological Research*. 1989; 51:153–157. [PubMed: 2694204]
- Engelkamp J, Seiler KH, Zimmer HD. Differential relational encoding of categorical information in memory for action events. *Memory & Cognition*. 2005; 33(3):371–379.
- Fletcher JM, Ewing-Cobbs L, Miner ME, Levin HS, Eisenberg H. Behavioral changes after closed head injury in children. *Journal of Consulting and Clinical Psychology*. 1990; 58:93–98. [PubMed: 2319050]
- Guillozet AL, Weintraub S, Mash DC, Mesulam MM. Neurofibrillary tangles, amyloid, and memory in aging and mild cognitive impairment. *Archives of Neurology*. 2003; 60:729–736. [PubMed: 12756137]

- Jackson JL, Michon JA. Effects of item concreteness on temporal coding. *Acta Psychologica*. 1984; 57:83–95.
- Jackson JL, Michon JA, Boonstra H, De Jonge D, De Velde Harsenhorst J. The effects of depth of processing on temporal judgment tasks. *Acta Psychologica*. 1986; 62:199–210. [PubMed: 3766196]
- Johnson MK, Hashtroudi S, Lindsay DS. Source monitoring. *Psychological Bulletin*. 1993; 114:3–28. [PubMed: 8346328]
- Jones S, Livner A, Backman L. Patterns of prospective and retrospective memory impairment in preclinical Alzheimer's disease. *Neuropsychology*. 2006; 20:144–152. [PubMed: 16594775]
- Kausler DL, Hakami MK. Memory for activities: Adult age differences and intentionality. *Developmental Psychology*. 1983; 19:889–894.
- Kausler, DH.; Lichty, W. Memory for activities: Rehearsal-independence and aging. In: Howe, ML.; Brainerd, CJ., editors. *Cognitive development in adulthood: Progress in cognitive development research*. New York: Springer-Verlag; 1988. p. 93-131.
- Kausler DH, Lichty W, Davis RT. Temporal memory for performed activities: Intentionality and adult age differences. *Developmental Psychology*. 1985; 21(6):1132–1138.
- Kausler DH, Phillips PL. Instructional variation and adult age differences in activity memory. *Experimental Aging Research*. 1988; 14(4):195–199. [PubMed: 3251765]
- King NS, Crawford S, Wenden FJ, Moss NEG, Wade DT, Caldwell FE. Measurement of post traumatic amnesia: How reliable is it? *Journal of Neurology, Neurosurgery and Psychiatry*. 1997; 62:38–42.
- Larsson C, Ronnberg J. Memory disorders as a function of traumatic brain injury. *Scandinavian Journal of Rehabilitation Medicine*. 1987; 19:99–104. [PubMed: 3441777]
- Levin HS, O'Donnell VM, Grossman RG. The Galveston Orientation and Amnesia Test: A practical scale to assess cognition after head injury. *Journal of Nervous and Mental Disease*. 1979; 167:675–684. [PubMed: 501342]
- Mangels JA. Strategic processing and memory for temporal order in patients with frontal lobe lesions. *Neuropsychology*. 1997; 11:207–221. [PubMed: 9110328]
- McMillan TM, Jongen ELM, Greenwood RJ. Assessment of post-traumatic amnesia after severe closed head injury: Retrospective or prospective? *Journal of Neurology, Neurosurgery, and Psychiatry*. 1996; 60:422–427.
- McWilliams J, Schmitter-Edgecombe M. Semantic memory organization during the early stage of recovery from traumatic brain injury. *Brain Injury*. 2008; 22:243–253. [PubMed: 18297596]
- Milner B, Petrides M, Smith ML. Frontal lobes and the temporal organization of memory. *Human Neurobiology*. 1985; 4:137–142. [PubMed: 4066424]
- Naveh-Benjamin. Coding of temporal order information: An automatic process? *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1990; 16:117–126.
- Naveh-Benjamin M, Jonides J. On the automaticity of frequency coding: Effects of competing task load, encoding strategy, and intention. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1986; 12:378–386.
- Regard M, Strauss E, Knapp P. Children's production on verbal and non-verbal fluency tasks. *Perceptual and Motor Skills*. 1985; 55:839–844. [PubMed: 7162920]
- Reitan RM. Validity of the Trail Making Test as an indicator of organic brain damage. *Perceptual and Motor Skills*. 1958; 8:271–276.
- Salthouse TA, Kausler DH, Saults JS. Investigation of student status, background variables, and the feasibility of standard tasks in cognitive aging research. *Psychology and Aging*. 1988; 3:29–37. [PubMed: 3268240]
- Schmitter-Edgecombe M, Chaytor N. Self-ordered pointing performance following severe closed-head injury. *Journal of Clinical and Experimental Neuropsychology*. 2003; 25:918–932. [PubMed: 13680440]
- Schmitter-Edgecombe M, Woo E, Greeley D. Characterizing multiple memory deficits and their relation to everyday functioning in individuals with mild cognitive impairment. *Neuropsychology*. 2009; 23:168–177. [PubMed: 19254090]

- Schmitter-Edgecombe M, Wright MJ. Content memory and temporal order memory for performed activities after severe closed-head injury. *Journal of Clinical and Experimental Neuropsychology*. 2003; 25:933–948. [PubMed: 13680441]
- Schmitter-Edgecombe M, Simpson AL. Effects of age and intentionality on content memory and temporal memory for performed activities. *Aging, Neuropsychology, & Cognition*. 2001; 8(2):81–97.
- Shimamura AP, Janowsky JS, Squire LR. Memory for temporal order of events in patients with frontal lobe lesions and amnesic patients. *Neuropsychologia*. 1990; 28:803–813. [PubMed: 2247207]
- Smith, A. Symbol Digit Modalities Test. Los Angeles, CA: Western Psychological Services; 1991.
- Snodgrass JG, Corwin J. Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General*. 1988; 117:34–50. [PubMed: 2966230]
- Sunderland A, Harris JE, Baddeley AD. Do laboratory tests predict everyday memory? A neuropsychological study. *Journal of Verbal Learning and Verbal Behavior*. 1983; 22:727–738.
- Taylor HG, Yeates KO, Wade SL, Drotar D, Stancin T, Minich N. A prospective study of short- and long-term outcome after traumatic brain injury in children: Behavior and Achievement. *Neuropsychology*. 2002; 16:15–27. [PubMed: 11853353]
- Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. *Lancet*. 1974; 2:81–83. [PubMed: 4136544]
- Tzeng OJL, Lee AT, Wetzel CD. Temporal coding in verbal information processing. *Journal of Experimental Psychology: Human Learning and Memory*. 1979; 5:53–64.
- Vakil E, Blachstein H. A supplementary measure in the Rey AVLT for assessing incidental learning of temporal order. *Journal of Clinical Psychology*. 1994; 50(2):240–245. [PubMed: 8014248]
- Vakil E, Biederman Y, Liran G, Groswasser Z, Aberbuch S. Head-injured patients and control group: Implicit versus explicit measures of frequency of occurrence. *Journal of Clinical and Experimental Neuropsychology*. 1994; 16:539–546. [PubMed: 7962358]
- Vanderploeg RD, Crowell TA, Curtiss G. Verbal learning and memory deficits in traumatic brain injury: Encoding, consolidation, and retrieval. *Journal of Clinical and Experimental Neuropsychology*. 2001; 23:185–195. [PubMed: 11309672]
- Wechsler, D. Wechsler Adult Intelligence Test-Third Edition. New York, NY: The Psychological Corporation; 1997.
- Zacks JM, Speer NK, Vettel JM, Jacoby LL. Event understanding and memory in healthy aging and dementia. *Psychology and Aging*. 2006; 21(3):466–482. [PubMed: 16953710]
- Zimmer HD, Helstrup T, Engelkamp J. Pop-out into memory: A retrieval mechanism that is enhanced with the recall of subject-performed tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 2000; 26(3):658–670.
- Zimmer HD, Engelkamp J. Levels-of-processing effects in subject-performed tasks. *Memory & Cognition*. 1999; 27(5):907–914.

Table 1

Demographic Data for the TBI and Control Groups at Baseline, and for Returning and Non-returning TBI Participants

	Baseline Group		TBI Group	
	TBI (N = 59)	Control (N = 59)	Returners (N = 32)	Non-Returners (N = 27)
Age				
M	28.49	26.93	31.94	24.41
SD	11.85	11.08	13.80	7.38
Education				
M	12.92	13.56	13.12	12.63
SD	2.13	2.13	2.41	1.74
Sex				
% male	68%	56%	72%	63%
Est. premorbid VIQ				
M	101.92	103.21	102.54	101.18
SD	7.98	7.41	8.16	7.85
GCS				
M	7.51	----	7.66	7.33
SD	4.49	----	4.40	4.67
Coma Duration				
M (hours)	78.84	----	77.09	80.93
SD	169.98	----	155.12	189.09
PTA estimate				
M (days)	21.72	----	25.34	17.44
SD	22.16	----	26.92	14.01
Time Since Injury				
M (days)	41.85	----	45.12	36.44
SD	25.68	----	30.42	18.04

Note: Est. premorbid VIQ = Estimated Wechsler Adult Intelligence Scale-Revised Premorbid Verbal Intelligence Quotient derived from the Barona Index equation; GCS = Glasgow Coma Score; PTA = Post-traumatic amnesia.

Table 2

Activity Memory Recall, Recognition, and Temporal Order Data for the TBI and Control Groups at Baseline, and for Returning and Non-returning TBI Participants

Activity Memory Measures	Baseline Group		TBI Group	
	TBI (N = 59)	Control (N = 59)	Returners (N = 32)	Non-Returners (N = 27)
Recall ^a				
M	4.41	6.53 **	4.38	4.44
SD	1.88	1.16	2.03	1.72
Recognition Hits				
M	7.05 ^a	7.47 *	7.00 ^b	7.11
SD	.91	.65	.93	.89
Recognition False Alarms				
M	.76 ^a	.29 *	.68 ^b	.85
SD	.98	.91	.91	1.06
Discrimination (Pr)				
M	.70 ^a	.80 **	.70 ^b	.70
SD	.13	.03	.11	.15
Response Bias (Br)				
M	.46 ^a	.43	.44 ^b	.48
SD	.24	.15	.25	.23
TO Hits				
M	2.61	4.73 **	2.63	2.59
SD	1.53	1.82	1.64	1.42
TO Correlation				
M	.54	.90 **	.50	.58
SD	.37	.14	.40	.33
TO Absolute Deviation				
M	12.25	4.68 **	12.66	11.78
SD	6.25	3.59	6.68	5.77

Note: TO = Temporal Order

^a sample size = 58;

^b sample size = 31

* $p < .01$,

** $p < .001$

Table 3

Activity Memory Recall, Recognition, and Temporal Order Data for the Returning TBI and Control Groups at Baseline and at Follow-up

Activity Memory Measures	Baseline		Follow-up	
	TBI (N = 32)	Control (N = 32)	TBI (N = 32)	Controls (N = 32)
Recall ^a				
M	4.38	6.34 **	5.59	6.66 **
SD	2.03	1.26	1.32	1.12
Recognition Hits				
M	7.00 ^a	7.50 *	7.30 ^a	7.47
SD	.93	.67	.90	.62
Recognition False Alarms				
M	.68 ^a	.19 *	.42 ^a	.34
SD	.91	.54	.67	.83
Discrimination (Pr)				
M	.70 ^a	.81 **	.76 ^a	.79
SD	.11	.12	.14	.13
Response Bias (Br)				
M	.44 ^a	.43	.45 ^a	.44
SD	.25	.12	.17	.16
TO Hits				
M	2.63	4.31 **	3.31	4.20 *
SD	1.64	2.04	1.71	1.59
TO Correlation				
M	.50	.86 **	.66	.81 *
SD	.40	.17	.27	.19
TO Absolute Deviation				
M	12.66	5.69 **	9.81	6.65 *
SD	6.68	4.22	5.26	4.00

Note: TO = Temporal Order

^a sample size = 31

**
 $p < .001$;

*
 $p < .05$

Table 4

Correlational Data for the Returning TBI Group at Baseline and Follow-up

Activity Memory Measures	Baseline			Follow-up		
	Content Memory		Temporal Order Memory	Content Memory		Temporal Order Memory
	TBI	Con		TBI	Con	
Injury Characteristics						
GCS ^a	.45*	---	-.40	---	.58**	---
Coma Duration ^a	-.37	---	.09	---	-.45*	.02
PTA Estimate ^a	-.27	---	.13	---	-.36	-.10
Time Since Injury ^b	-.10	---	.09	---	.13	.05
Medial Temporal						
RAVLT 1-5 ^b	.59**	.47**	-.50*	-.13	.70**	.18
RAVLT long delay ^b	.46*	.14	-.50*	-.01	.65**	.16
Frontal Functions						
COWAT tot words ^b	.43	.26	-.40	.13	.40	.29
LNS total correct ^b	.34	.37	-.43	-.08	.51*	.34
(TMT B-A)/A	-.11	.14	.02	-.32	-.09	.04
5-pt % persev ^b	-.21	-.14	.17	-.06	-.19	-.02
SOPT total correct ^b	.13	.14	-.34	-.25	.15	.18
Everyday Memory (follow-up)						
EMQ self-report ^c	.22	---	.59**	---	-.27	---
EMQ informant ^c	-.07	---	.53*	---	-.35	---

Note: TBI = traumatic brain injury; Con = controls; GCS = Glasgow Coma Score; PTA = Post-traumatic amnesia; RAVLT = Rey Auditory Verbal Learning Test; COWAT = Controlled Oral Word Association Test; LNS = Letter-Number Sequencing subtest; SOPT = Self-ordered Pointing Test; EMQ = Everyday Memory Questionnaire.

^abaseline data used for all correlations with activity memory measures

^abaseline data used for baseline correlations with activity memory measures and follow-up data used for follow-up correlations with activity memory measures

^cfollow-up data used for all correlations with activity memory measures

* $p < .01$;

** $p < .005$