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Research Article

Predicting Remembering: Judgments of Prospective Memory After Traumatic Brain Injury

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Purpose: Adults with traumatic brain injuries (TBIs) often struggle with prospective memory (PM), the ability to remember to complete tasks in the future, such as taking medicines on a schedule. Metamemory judgments (or how well we think we will do at remembering) are linked to strategy use and are critical for managing demands of daily living. The current project used an Internet-based virtual reality tool to assess metamemory judgments of PM following TBI.
Method: Eighteen adults with moderate to severe TBI and 20 healthy controls (HCs) played *Tying the String,* a virtual reality game with PM items embedded across the course of a virtual work week. Participants studied PM items and made two judgments of learning about the likelihood of recognizing the CUE, that is, when the task should be done, and of recalling the TASK, that is, what needed to be done.
Results: Participants with TBI adjusted their metamemory expectations downward, but not enough to account for poorer recall performance. Absolute difference scores of metamemory accuracy showed that healthy adults were underconfident across PM components, whereas adults with TBI were markedly overconfident about their ability to recall TASKs.
Conclusions: Adults with TBI appear to have a general knowledge that PM tasks will be difficult but are poor monitors of actual levels of success. Because metamemory monitoring is linked to strategy use, future work should examine using this link to direct PM intervention approaches.

Prospective memory (PM), or remembering to perform a task at a particular time in the future (McDaniel & Einstein, 2007), is frequently impaired after traumatic brain injury (TBI). PM deficits after TBI are common across injury severity (Carlesimo, Casadio, & Caltagirone, 2004; Fish, Wilson, & Manly, 2010; Schmitter-Edgecombe & Wright, 2004; Tay, Ang, Lau, Meyyappan, & Collinson, 2010; see Shum, Levin, & Chan, 2011, for review) and contribute to disability by limiting social integration and independence (Kinsella et al., 1996). PM failures, such as forgetting appointments, missing events, or neglecting to complete tasks, also place a strain on social relationships (Winograd, 1988). Peers may overlook the difficulty of remembering future events and instead focus on personal attributes of the individual for not following through (Penningroth, Scott, & Freuen, 2011). At the same time, individuals with TBI are sensitive to the importance of PM and report that these failures are more problematic than typical adults (Huang et al., 2014).

PM

Behavioral and neuroimaging studies have confirmed that PM consists of two distinct components (McDaniel & Einstein, 2007; Poppenk, Moscovitch, McIntosh, Ozcelik, & Craik, 2010): the cue and the task. The cue specifies the conditions of retrieval, and the task is the action to be performed in response to the cue. Both of these components, the cue and task, must be encoded and recalled, such that retrospective memory (RM) plays a large role in successful PM performance (Einstein & McDaniel, 1996).

Time-based PM specifies execution of the task after an amount of time or at a specific time in the future (e.g., "at 10:00 pm" or "in 30 min"). Event-based PM specifies performance in conjunction with a particular occurrence (e.g., "on the way home" or "after breakfast"). Experimental designs assessing PM require that the target cue–task sequence be performed in the presence of an ongoing distractor task. Moment-to-moment living provides multiple distractions

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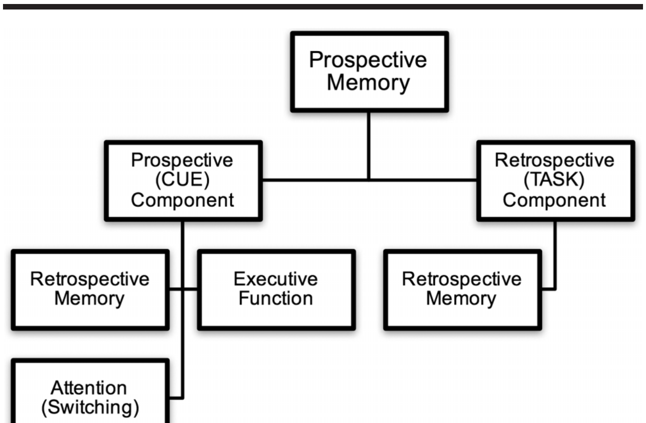
from holding the intended target in attentional focus. Therefore, in both time and event PM, even over relatively short time spans, attention shifts away from PM items. Recognizing a PM cue then requires that executive function direct attention away from distractions or current tasks to scan the environment for unmet goals and activate the cue and task retrieval sequence from RM when the cue is identified (McDaniel & Einstein, 2007). Coordination across memory, attention, and executive function within a cue-constrained window allows multiple opportunities for failure and suggests the need for a robust central executive system directing and integrating resources (Burgess, Veitch, Costello, & Shallice, 2000). Figure 1 depicts cognitive processes underlying PM, outlining the role of RM in recalling both cues and tasks. Accurately responding to PM cues requires additional resources and control to alert attention to the presence of the cue in spite of the presence of distractors (attention and RM), switch attention to unmet goals (attention and executive function), and then retrieve information from memory stores to execute the task (RM). Such requirements map directly on to the typical deficits associated with TBI and frontal lobe damage, namely, deficits in memory, attention, and executive function (Lezak, 1995; Stuss & Levine, 2002). Several studies examining associations between standard neuropsychological assessment and PM in adults with TBI have confirmed the role of these systems play in the execution of PM tasks (Fleming et al., 2008; Maujean, Shum, & McQueen, 2003; Shum et al., 2011).

In considering factors underlying successful cue versus task execution of PM, Kinch and McDonald (2001) examined the performance of individuals with acute TBI. They found that overall performance on event-based tasks (e.g., delivering a message when the researcher entered the room) was predicted by standardized measures of RM and anxiety scales. However, two different models emerged when each PM component was examined. Besides the contribution of RM measures and anxiety, cue recognition of event-based PM tasks was also predicted by verbal fluency and the Wisconsin Card Sorting Test (Berg, 1948), indicators of executive functions. However, none of these measures predicted task recall performance. These researchers concluded that RM contributes generally to PM performance, whereas executive function and, in this case, anxiety play a particular role in alerting to PM cues.

Fish et al. (2007) also found that occasional cueing using the neutral phrase "STOP" increased success at PM performance for adults with TBI, indicating that difficulty in performing PM was not in remembering "what" it was that had to be done (i.e., the task) but rather in remembering to do it "when" required to do so (i.e., the cue). Shifting away from distractors and ongoing everyday tasks was more difficult than learning tasks to be completed. Similarly, Mioni, Rendell, Henry, Cantagallo, and Stablum (2013) used a computerized PM board game named *Virtual Week* (Rendell & Henry, 2009) with adults with TBI. Adults with TBI had difficulty with both recurring and novel event-based tasks, suggesting the problem was not one of encoding (participants were regularly reminded of recurring tasks), but that as they became involved in the game, cueing to both recurring and novel tasks was neglected. These studies suggest that, although RM impairments after TBI are common, problems with executive function and spontaneous retrieval of cues in the face of ongoing tasks and distractions play an important role in PM failures for individuals with TBI.

Figure 1. Cognitive processes underlying the two primary components of prospective memory.



Retrospective and Prospective Metamemory

Metamemory for RM has been studied extensively in populations with brain injury, both as a result of injury to these systems or because of slow updating of metacognitive beliefs about cognitive function following a sudden change to what had been a previously stable system (Kennedy & Yorkston, 2000; Shimamura & Squire, 1986; Stuss & Levine, 2002). Typically, metamemory has been studied by asking participants to make either judgments about the likelihood of future recall (e.g., Kennedy, Carney, & Peters, 2003) or confidence ratings after a recall attempt (e.g., Kennedy, 2001). Greater alignment between either predictions or confidence ratings and actual recall indicate greater metamemory accuracy. Metamemory monitoring is linked to control or strategy use (Nelson & Narens, 1990), so that accurate monitoring is more likely to result in strategy use. Rehabilitation settings often train individuals with TBI to use memory strategies, both to retrain new learned information (RM) and to perform tasks in the future, as with PM (Sohlberg & Mateer, 2001). However, strategy use relies on an understanding of when and how strategies should be used in functional settings. Metamemory, or understanding strengths and weaknesses of the memory system, is critical in signaling that a strategy needs to be applied (Kennedy & Coelho, 2005). Using external memory aides, such as a Post-it note on the garage door to remind oneself of an errand, is based on the belief that one could forget to do this without a reminder. So, developing and applying these kinds of strategies to complete PM tasks require a metamemory understanding that, without enhanced cues or alerts, it is likely the task will not be carried out. Similarly, a person may be trained to enter an alert in a smart phone to pick up milk, but if the person believes that this can be recalled without the alert, they are unlikely to set up the alert.

However, there is no clear consensus that impairments to metamemory after TBI are the rule. Studies have found particular strengths in retrospective metamemory judgments, such as judgments of learning (JOLs; Nelson & Dunlosky, 1991), in which participants make an estimation on a 0–100 percentage scale of the likelihood of future success. Typically though, the strengths are in narrow domains, such as when listening to stories (Kennedy & Nawrocki, 2003) or learning verbal paired associates (Schmitter-Edgecombe & Anderson, 2007). A series of studies by Kennedy et al. (Kennedy, 2001; Kennedy et al., 2003; Kennedy & Yorkston, 2000) revealed that, under some conditions, individuals with TBI can accurately monitor memory and, in other conditions, may be overconfident. For example, Kennedy (2001) found that, when unsure about their recall, adults with TBI tended to err in the direction of overconfidence, whereas adults without TBI tended to err in the direction of underconfidence.

Fewer studies have examined prospective metamemory. When comparing adults with TBI to uninjured controls, Knight, Harnett, and Titov (2005) used a video task to assess participants' ability to complete a series of PM errands in response to visual cues in a virtual environment. Although predictions of future recall performance across the two groups were similar, the group with TBI was much less accurate at the PM tasks as compared to HCs, performing far fewer PM items. In contrast, healthy adults accurately performed more items than they had predicted. Therefore, although the groups made similar predictions, the group with TBI was overconfident, performing few items accurately, whereas controls were underconfident, performing better than predicted. Similarities in predictions across the two groups suggest that individuals with TBI made judgments reflecting their preinjury memory abilities and had not updated their metamemory beliefs following changes to the memory system after TBI.

There have been some mixed results of typical adults' prospective metamemory accuracy. Devolder, Brigham, and Pressley (1990) found that typical adults were not able to accurately predict their ability to place a series of phone calls at given times. Participants believed themselves to be more accurate than they in fact were, consistent with overconfidence. Meeks, Hicks, and Marsh (2007) found the opposite effect on a controlled laboratory task of PM, so that adults were underconfident on a lexical decision task. In examining the effect of predictions on PM, Rummel, Kuhlmann, and Touron (2013) used a lexical discrimination task similar to Meeks et al. (2007), finding overconfidence across groups. They also found that predicting future performance boosted accuracy, appearing to alert participants to the importance of performing studied PM items. However, this effect was largely mitigated by having participants make predictions about distractor tasks as well as the target PM items.

Schnitzspahn, Zeintl, Jäger, and Kliegel (2011) examined prospective metamemory by the cue and task components in healthy adults, believing that discrepancies in over- versus underconfident predictions in previous work might be explained by the fact that participants made general judgments about remembering to perform a task in the future, rather than differentiating between recognizing and responding to the cue (e.g., "on the way home") and remembering the action (e.g., "buy milk"). Results from prediction ratings and performance accuracy showed that typical adults were more certain they would recall a task to be completed than that they would recognize the cue at the correct time. In this way, typical adults appear to be sensitive to the difficulty of remembering to perform PM in the face of competing distractors.

Current Study

The current study examines if adults with TBI are sensitive to differences between PM components as well or if in fact individuals with brain injuries are more successful at recalling a prospective action rather than performing it at the designated time. Because accurate metamemory performance underlies the ability to adjust and strategize around anticipated failures (Kennedy et al., 2003; Kennedy & Coelho, 2005), the effectiveness of training after TBI in the use of strategies for PM relies on the individual accurately monitoring when such compensatory techniques should be applied. By examining component processes of PM metamemory, we aim to guide clinical approaches toward management of PM deficits and strategy training. Differential results across PM components would implicate differing needs for training in metamemory around being able to recognize and be alert to PM cues versus recalling PM tasks to be completed.

Tying the String, a new tool to assess metamemory for PM in adult populations, was developed to create a web-based, immersive virtual experience, with PM targets embedded in an engaging, but unrelated, visual distractor task. Specific research questions addressed differences across and within groups, organized by first considering PM accuracy, then prospective metamemory judgments, and finally engagement with the ongoing distractor task.

PM

1. Does accuracy for PM differ across components (CUE and TASK) for adults with and without TBI for novel items? We hypothesized that healthy adults would perform CUE and TASK components of PM with greater accuracy than adults with TBI for novel items during free recall and that CUEs would be identified more readily than TASKs for both groups.
2. Does accuracy for PM differ across components (CUE and TASK) for adults with and without TBI for recurring items? Our hypotheses were similar to the above, although we anticipated that the accuracy

of the adults with TBI would more closely approximate that of the HCs when performing recurring items.

3. Do participants with and without TBI recognize more studied TASKs than they perform during free recall? Regardless of TBI, we expected that participants' recall for TASKs would increase when recognizing items from a list, but that the group with TBI would show a greater discrepancy between free recall and recognition accuracy.

Prospective Metamemory

4. Do adults with and without TBI differentially predict performance across novel PM components (CUE and TASK)? We hypothesized that adults with TBI would make prospective metamemory judgments that were similar to healthy adults and that both groups would anticipate better performance on CUEs than TASKs.

5. How accurate are typical adults and adults with TBI at predicting PM performance on both CUE and TASK components? Because we anticipate lower PM accuracy from the group with TBI, we also hypothesized that adults with TBI would be overconfident across PM components (performing more poorly than predicted) and for healthy adults to be underconfident (or perform better than predicted).

Ongoing Distractor Task

6. Do both groups engage with the ongoing distractor task in finding irrelevant visual distractors? We expected both groups to engage with the visual distractor task, but that healthy adults would exhibit greater success at finding irrelevant visual targets than adults with TBI.

7. Do visual distractor JOLs differ between the two groups and with regard to predictions made about PM? We had no a priori hypothesis about visual distractor judgments between groups but expected that both groups might exhibit an awareness of the difficulty of the visual distractor task by reducing judgments as compared to PM.

Method

Participants

Participants were 18 adults (12 male) with history of chronic moderate to severe TBI and 20 age- and education-matched HCs (10 male). Participants with TBI were recruited from postings in local brain injury association newsletters. HCs were recruited through social media postings and flyers posted in public spaces. Some HCs were also recruited through Research Match, a national database of people who have registered to be contacted about research studies available in their area.

Table 1 describes detailed demographics and neuropsychological descriptors of both groups. Adults with TBI had a history of moderate to severe closed TBI sustained at age 15 or older, Glasgow Coma Scale (Teasdale & Jennett, 1974) of less than 12, loss of consciousness of greater than 30 min, and positive brain imaging. Participants with TBI self-reported a history of brain injury, but medical records substantiated the injury and its characteristics. Participants were excluded if they reported a history of rehabilitation for substance abuse, neurological history other than TBI, learning disability, presence of aphasia, sensory impairment, or significant mental illness not managed by outpatient monitoring. Participants in both groups spoke English as a first language and reported being comfortable with computers, including both typing on a keyboard and use of a mouse to navigate. The two groups were matched by age and education. There were no significant differences between groups by these factors; however, the TBI group contained more male participants than the evenly balanced control group. Incidence of TBI is higher among male participants and is thus reflected in the gender imbalance in that group (e.g., Faul, Xu, Wald, & Coronado, 2010). Injury information for each participant with TBI is listed in Table 2. Furthermore, the Mayo–Portland Participation Index (M2PI; Malec, 2004) indicates that this particular group of individuals reported fewer problems with activities of daily living than a normative sample of adults with TBI.

Table 1. Demographic and neuropsychological descriptors.

	TBI	Control
Variable	Mean (*SD*)	Mean (*SD*)
Demographics	12 M, 6 F	10 M, 10 F
Age	47.06 (14.77)	43.15 (13.00)
Education	16.06 (2.07)	16.60 (1.35)
WTAR* standard scores, *M* = 100	110.00 (9.81)	117.40 (6.76)
DKEFS standard score, *M* = 10		
Verbal Fluency: Letter	10.56 (2.91)	12.70 (3.93)
Verbal Fluency: Category*	10.61 (3.18)	13.60 (3.72)
Working Memory raw partial scores (36 possible)		
Operation Span	14.17 (10.56)	19.45 (9.63)
RBANS index scores, *M = 100*		
Immediate Memory***	81.78 (16.05)	106.20 (12.12)
Visuospatial	86.78 (17.30)	97.35 (18.06)
Language***	93.50 (10.11)	108.55 (12.09)
Attention**	91.44 (17.57)	106.40 (16.56)
Delayed Memory***	76.06 (23.98)	102.80 (9.47)
Total Scale***	81.56 (15.28)	105.95 (13.20)
CAMPROMPT raw scores (36 total)		
Total raw***	20.44 (7.87)	31.60 (5.35)
PRMQ *T* scores, *M* = 50, lower scores indicate more problems		
Prospective*	39.33 (13.69)	49.20 (9.16)
Retrospective**	40.56 (12.39)	52.40 (7.82)
Total**	39.83 (13.76)	51.75 (8.92)

Note. Asterisks indicate significant differences between the two groups on these measures. TBI = traumatic brain injury; M = male; F = female; WTAR = Wechsler Test of Adult Reading; DKEFS = Delis Kaplan Executive Function System; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status; CAMPROMPT = Cambridge Test of Prospective Memory; PRMQ = Prospective–Retrospective Memory Questionnaire.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 2. TBI participant injury information.

Participant	Time postinjury (months)	LOC	Severity of injury	Description of injury	M2PI
1	90	1 week	Severe	MVA	46
2	101	6 weeks	Severe	Bike	33
3	228	10 days	Severe	MVA	48
4	77	2 weeks	Severe	MVA	43
5	18	> 30 min	Moderate	Fall	36
6	305	10 days	Severe	Motorcycle	54
7	89	4 weeks	Severe	Motorcycle	48
8	96	2 hr	Moderate	Pedestrian, hit by car	39
9	127	4 weeks	Severe	MVA	54
10	173	10 weeks	Severe	MVA	36
11	92	2 weeks	Severe	ATV	33
12	516	4 weeks	Severe	MVA	4
13	323	8 days	Severe	MVA	46
14	47	10 days	Severe	Skiing	33
15	307	2 weeks	Severe	MVA	33
16	390	3 days	Severe	Airplane	43
17	367	3 weeks	Severe	Motorcycle	43
18	84	2 hr	Moderate	Fall	56
M (SD)	190.56 (143.18)				40.44 (11.87)

Note. LOC = loss of consciousness/length of coma; M2PI = Mayo–Portland Participation Index, *T* scores (50 = average problems reported by a person with TBI; lower scores indicate fewer problems); MVA = motor vehicle accident; ATV = all-terrain vehicle; TBI = traumatic brain injury.

Participants in both groups completed standard neuropsychological assessments of PM using the Cambridge Test of Prospective Memory (Wilson et al., 2005), working memory using a computerized version of operation span (Oswald, McAbee, Redick, & Hambrick, 2015), verbal IQ with the Wechsler Test of Adult Reading (Wechsler, 2001), and RM and cognitive status using the Repeatable Battery for the Assessment of Neuropsychological Status (Randolph, 1998). The verbal fluency subtest from the Delis Kaplan Executive Function System (Delis, Kaplan, & Kramer, 2001) was used to assess executive functions because it has been associated with PM (e.g., Fleming et al., 2008; Kinch & McDonald, 2001; Maujean et al., 2003) Participants also completed the Prospective–Retrospective Memory Questionnaire (Smith, Della Sala, Logie, & Maylor, 2000), a measure of metacognitive beliefs related to everyday memory failures. Adults with TBI evidenced expected deficits in memory, attention, and executive function, but with some relative strengths at working memory and verbal IQ (see Table 1).

General Procedure

All testing was completed in a single session in a quiet room with a trained research assistant (RA) and monitored by the primary investigator. All sessions were audio-recorded for verification purposes. Following consent, participants completed the *Tying the String* game. Because many aspects of *Tying the String* are self-paced (including training, study time, and recognition recall), time to completion of the game varied (M = 75.57 min, SD = 7.30 min). Participants took a 10- to 15-min break before completing the neuropsychological battery. Breaks were also offered between each neuropsychological assessment. In total, sessions varied in length between 3 and 4.5 hr. Participants with TBI tended to take more breaks than HCs and required more time to complete the standardized assessments.

Participants were paid at a flat rate of $30. This study was completed under the oversight of the institutional review board of the University of Minnesota.

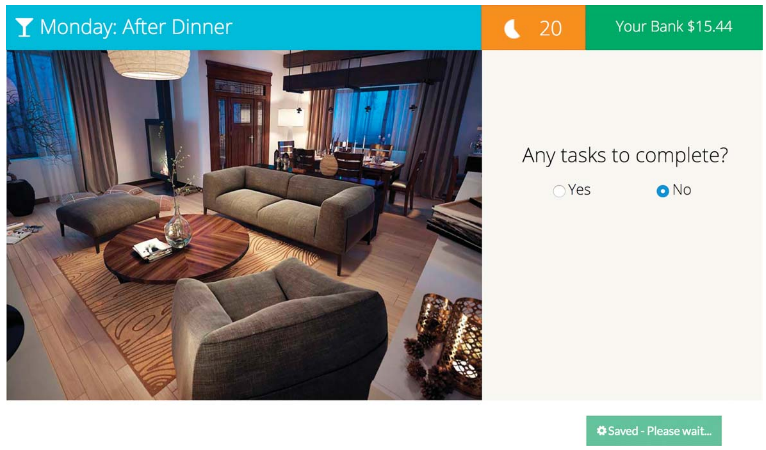
Experimental Task

Overview

Tying the String was developed in conjunction with a web programmer who used PHP programming language and can be played on any standard browser with login information and an Internet connection.[1] RAs familiarized participants with the computer equipment, audio headset, and navigation of the game. RAs remained in the room while participants completed the game independently. The game presents a virtual work week, in which the participant works at an advertising agency and is preparing a proposal for work, while also planning a birthday party for a friend. The game has 10 images with titles representing distinct events or scenes during the day (see Figure 2; e.g., an unmade bed for "Waking Up," a car backing out of the garage for the "Drive to Work," a living room for "After

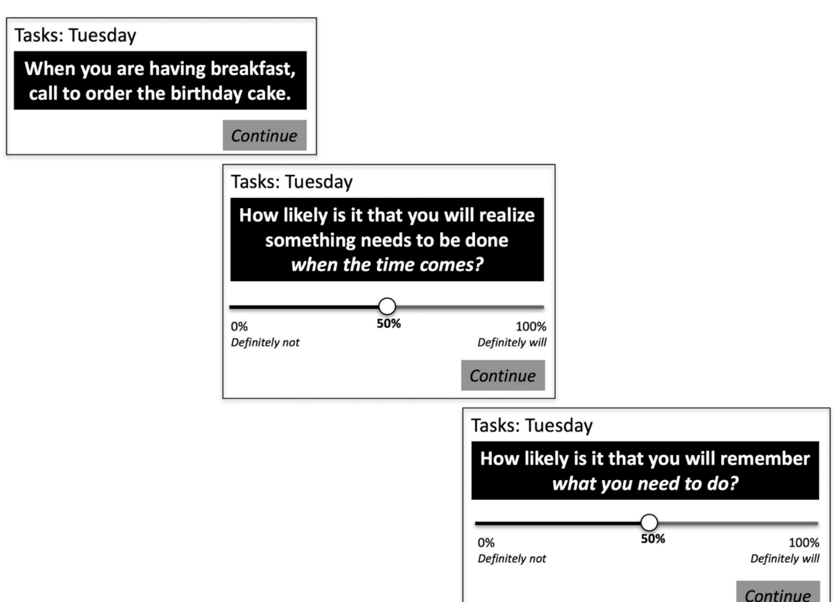
[1]Pilot data collected with eight adults (23–70 years of age) demonstrated that the game was understandable for participants to complete independently in a single sitting. Feedback resulted in adding more reminders during training that participants should perform recurring tasks on every virtual day throughout the game. No other feedback was provided, and participants reported the game to be engaging.

Figure 2. Screen capture of experimental scene. Moving left to right, the top bar indicates the day and scene, followed by the scene's timer, then the participant "bank." Participants select the radial buttons to the right to indicate if tasks are to be completed. If "yes" is selected, a text box appears for free recall entry. For the visual distractor task, participants scan the mouse over the image, and gold coins appear. By clicking on these coins, virtual money is added to the participant bank. Photo credit: Kuprynenko Andrii/Shutterstock.com.



Dinner," etc.). The game progressed Monday through Friday, playing the 10 scenes in order for each day. As each scene played, an audio narrative provided background context to engage the listener in the virtual experience. The narrative referenced work goals or the upcoming birthday party, but no cues were provided to studied PM items. A self-paced study screen appeared at the beginning of each virtual day (see Figure 3) for the PM items that were to be completed on that day. These novel items referenced the upcoming birthday party (e.g., "On the drive home from work, buy candles") as well as work or daily living tasks (e.g., "During lunch, get the oil changed in your car"). Three recurring items were presented during training (e.g., "Every morning when you wake up, feed the dog"), and reminders were given to complete these tasks during the virtual week. Across the 5 days of the virtual workweek, this resulted in 15 total opportunities to complete the three recurring tasks. The 20 novel items were spaced across the five virtual days

Figure 3. Example of PM item study and JOL sequence. Items were self-paced, so that screens advanced as participants selected the continue button. PM = prospective memory; JOL = judgment-of-learning predictions.



of the workweek, whereas participants should have completed the three recurring items each day (see Table 3 for sample schedule of recurring and novel targets). All PM items were self-paced and presented in both written and auditory form via a voiceover.

Because PM requires that a person be engaged in tasks other than what is to be remembered (McDaniel & Einstein, 2007), the game also included an ongoing visual distractor task. Participants scanned the daily scenes for gold coins, collecting money by clicking on the coins as they appeared. Making judgments can also influence future recall, so JOL predictions were made about the ongoing distractor task as recommended by Rummel et al. (2013). Participants indicated the likelihood of remembering where the coins had been found using a sliding visual scale.

Training

Before the game entered the Monday-to-Friday work week, a training period oriented the user to the procedures and interface, explaining how the game was played. Recurring PM items were presented and rehearsed multiple times during game training (e.g., “Every morning when you wake up, let the dog out.”). A video demonstration (for excerpt, see https://www.youtube.com/watch?v=JIBHE_fowJ8) showed users how each virtual event/scene would appear, including where to enter PM CUEs and TASKs and how to find the distractor hidden money (e.g., the ongoing distractor task, further details are below). For practice, the game then progressed through the 10 scenes in order for two virtual days. Reminders were provided to participants to perform the recurring tasks throughout the game. After training and practice was complete, the game started at “Monday” and proceeded through the week. None of the TBI or HC participants demonstrated difficulty in understanding the game; they attempted PM items and reported to RAs that they understood the game.

PM

Free recall of novel and recurring items. To assess accuracy at executing novel and recurring PM items, a side bar appeared in each virtual scene asking if any tasks were to be performed during this time frame (see Figure 2). Participants used the mouse to select either “Yes” or “No.” If participants selected the button that a task was to be completed, a text box appeared below for participants to type in their answer.

- CUEs were marked as correct if the participant correctly alerted to a task (i.e., correctly selected “yes”) or rejected that a task (i.e., correctly selected “no”) was to be completed during that scene.
- TASKs were marked as correct if participants provided an approximation of the designated task for that scene. Spelling and typing errors were allowed.

Recognition accuracy. At the end of each virtual day, participants selected target TASKs (novel and recurring) from a list that included two to four foils (see Figure 4). This recognition task was used to determine if individuals were adequately encoding PM TASKs presented each day (because participants performed PM TASKs during all scenes across the virtual week, CUEs were not included in the recognition measure). Accurate recognition indicates that TASKs had been stored in RM whether or not those TASKs had been accurately performed during the virtual day. Therefore, the recognition task was used to compare retrospective versus prospective accuracy.

Prospective Metamemory

JOL predictions. Participants made two immediate JOLs after each novel target was introduced (see Figure 3). The first JOL assessed the CUE by asking “How likely is it that you will remember to perform this task *when* the time comes?” The JOL for the TASK component was assessed by asking “How likely is it that you will remember *what* you need to do?” Each participant made 40 PM JOLs: 20 JOL predictions related to the CUE (i.e., “when”) and 20 predictions related to the TASK (i.e., “what”). Participants used a slider bar to indicate the likelihood of future recall, from 0% to 100%. The slider bar had anchors at

Table 3. Excerpt of schedule of prospective memory items.

Scene	Cue	Practice Day 1	Practice Day 2	Monday
1	Wake up	**Let out dog**	**Let out dog**	**Let out dog**
2	Get ready for the day			
3	Breakfast	**Take vitamins**	**Take vitamins**	**Take vitamins**
4	Go to work		Drop package at post office	Buy donuts for new employee
5	At the office			Send invitations
6	Lunch	**Work out**	**Work out**	**Work out**
7	Afternoon meeting		Set up projector	
8	Drive home			Buy birthday gift
9	Home			
10	After dinner		Call mom	

Note. Sample prospective memory items from practice days and first virtual day (Monday) are listed. Recurring items are shown in bold. Scenes listed are CUEs, and TASKs are listed under each day. Participants studied all items for a virtual day at the beginning of each day. For example, the first box includes a recurring item and was presented as, “Every morning when you wake up, feed the dog.” Practice Day 2 also includes novel items, for example, “When you go to work, drop the package at the post office.”

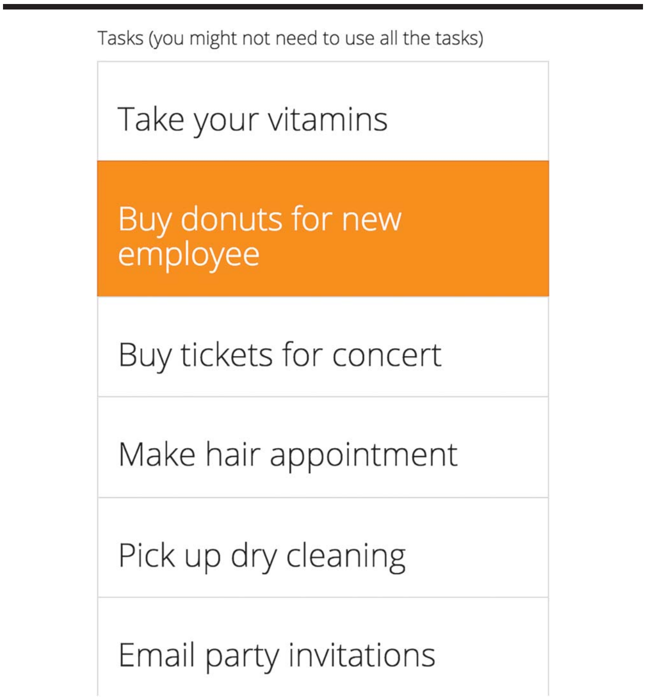


Figure 4. End of virtual day recognition task. Participants selected both novel and recurring tasks from the right-hand column that were to be completed during that day.

either end stating “0% definitely will not remember” and “100% definitely will remember.”

Ongoing Distractor Tasks

Ongoing visual distractor. PM requires that a person be engaged in an ongoing task unrelated to the target items (McDaniel & Einstein, 2007), so we also measured engagement with the distractor task as a validity check. During the game, participants scanned the images for each day with the mouse looking for hidden coins where money could be collected. When participants clicked on a coin, money was added to their “Bank.” At the end of the virtual day, the amount of money that was in the participant’s “Bank” was visible on a leaderboard with the top five daily totals across participants, providing motivation to look for money in subsequent days and scenes.

Ongoing JOL distractor. Because making JOL predictions can boost performance by directing resources toward target items (Rhodes & Tauber, 2011; Rummel et al., 2013), we also asked participants to make judgments about the visual distractor. In two randomly selected scenes for each day, a JOL prompt was provided during the visual distractor task, stating “How likely is it that you can remember *where* you found the money hidden in this scene?” This “where” JOL prediction and slider bar was otherwise identical to the CUE and TASK JOL screens. At the end of each virtual day, the scenes in which JOL distractor predictions were made appeared, and participants clicked the locations in the scene where they had found money.

Data Analysis

PM Accuracy

Novel and recurring free recall. Free recall of CUE and TASK accuracy for novel and recurring items was described using hits and misses. For CUEs, hits occurred when participants selected “yes” when items needed to be performed or “no” when items did not need to be performed. TASK accuracy was similarly calculated as hits and misses, with hits representing correct approximations of the TASK to be performed. Participants had 20 opportunities to complete novel tasks and 15 opportunities to complete recurring tasks. Data were analyzed separately for novel and recurring items using binary logistic regression with group (HC, TBI) and PM component (CUE, TASK) as predictors.

Recognition accuracy. Participants also performed a recognition task at the end of each virtual day, selecting novel and recurring TASKs from a list including two to four foils. Accuracy was calculated as percentage of TASKs correctly recognized. This recognition accuracy for novel and recurring TASKs was compared to percentage of free recall accuracy for novel and recurring TASKs. Data were analyzed again by group and PM component, but nonparametric statistical procedures were applied because of unequal variances across groups. A Mann–Whitney U test was used for between-groups comparisons, and Friedman’s two-way analysis of variance by ranks was used for within-group comparisons.

Prospective Metamemory Accuracy

JOLs. JOL predictions were measured as the numeric value from 0 to 100 assigned to each novel PM CUE and TASK. Two means were generated for each participant: one for the CUE and one for the TASK. These were analyzed using a 2×2 mixed analysis of variance with group as the between-subjects measure and PM component as the within-subject measure.

Absolute metamemory. Absolute difference scores were calculated for each participant by subtracting mean free recall performance on novel tasks from mean JOL ratings for each PM component. Negative scores indicate underconfidence, meaning that more items were recalled than predicted by overall JOLs. Positive scores indicate overconfidence, meaning fewer items than predicted were recalled. Because of unequal variances, a series of Welch’s unequal variances t tests were conducted by group and PM component.

Ongoing Distractor Task Accuracy

Visual distractor engagement. Engagement in the ongoing task was measured by the total amount of money found by selecting hidden coins. Simple group comparisons were made using Welch’s unequal variances t tests for independent samples.

Visual distractor JOL task. Visual distractor WHERE JOLs were calculated similarly to PM JOLS, that is, as a mean rating for each participant of their judgment on a numeric scale from 0 to 100. Independent sample *t* tests were performed for between-groups comparisons. Follow-up within-group comparisons to compare these distractor WHERE JOLs to the two PM JOLs for CUE and TASK were conducted using paired sample *t* tests.

Results

PM Accuracy

Free Recall of Novel Items

To determine if the HCs outperformed the group with TBI at recalling cue–task sequences, a logistic regression was fit to explore the relationship between accuracy of the two PM components (CUE, TASK) and group (TBI, HC). Table 4 provides a summary of these data expressed as overall percent correct for each group. There was a main effect of group revealing that HCs recalled more than the group with TBI ($\beta = 2.98$, $p < .001$). There was an effect of PM component ($\beta = 1.57$, $p < .001$) in favor of recognizing the CUE and a significant interaction ($\beta = -1.40$, $p < .001$). This revealed that HCs recalled both PM components equally well, whereas the group with TBI recalled fewer TASKs than the CUEs. That is, participants with TBI had more difficulty in recalling TASKs (i.e., the "what") than alerting to the CUE when a task needed to be completed (i.e., the "when"). We had anticipated that both groups would perform with greater accuracy to the CUE, whereas the HCs exhibited similar performance across both components of PM. The HCs did perform with greater accuracy than the group with TBI, as expected.

Free Recall of Recurring Items

As with the novel items, hits and misses for recurring items were entered into a binary logistic regression with PM component (CUE, TASK) and group (TBI, HC) as predictors. These data are provided in Table 4. Similar to novel items, there was a main effect of group revealing that HCs recalled more than the group with TBI ($\beta = 2.97$, $p < .001$). There was also an effect of PM component TBI ($\beta = 1.20$, $p < .001$) in favor of recognizing the CUE. The interaction was not significant ($\beta = -0.55$, $p = .26$), indicating that both groups performed better at the CUE and that the HC group outperformed the group with TBI across both PM components. This was in line with our hypothesis.

Free Recall Versus Recognition Accuracy of TASKs

Percent accuracy of free recall of novel and recurring TASKs was compared to recognition of those same items across groups. Because of the variability in performance of the group with TBI, a Mann–Whitney *U* test was used to examine between-groups differences in performance at free recall of novel tasks, free recall of recurring tasks, recognition of novel tasks, and recognition of recurring tasks (see Figure 5 for comparison across free recall and recognition; data for recognition accuracy is presented in Table 5). Analyses showed that all comparisons were significantly different between groups ($p < .001$), with the exception of recurring recognition ($p = .47$). HCs and participants with TBI recognized the recurring items with similar accuracy.

Within-group contrasts were conducted using Friedman's two-way analysis of variance by ranks. Post hoc analysis with Wilcoxon signed-rank tests was conducted with a Bonferroni–Holm correction applied. HCs performed more poorly on free recall of novel items ($p < .001$) as compared to the other three recall conditions. Performance across recognition of novel items and both types of recall of recurring items was stable. For the group with TBI, all comparisons were significant after correction; recall accuracy increased in a steplike fashion from free recall to recognition of recurring items. As observed here, we had hypothesized that both groups would benefit from the support of recurring items and recognition testing and that the group with TBI would demonstrate much larger gains with this support. Overall, HCs showed little variability in performance across recall types, with lower performance on novel free recall only. HCs also outperformed the group with TBI across recall types, with the exception of recurring recognition, the most supported recall condition.

Prospective Metamemory Accuracy

JOLs

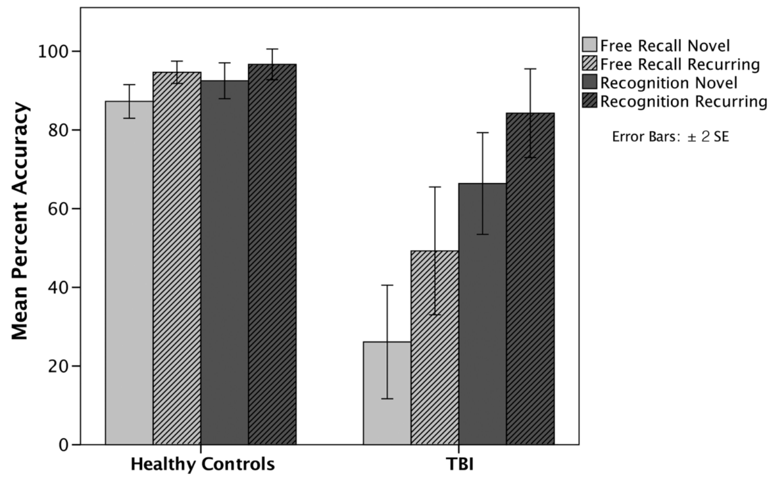
A mixed design factorial analysis of variance with group (HC, TBI) as the between-subjects factor and type of JOL (CUE, TASK) as the within-subjects factor revealed a main effect of group, $F(1, 36) = 5.07$, $p = .03$. HCs gave

Table 4. Participant mean scores and standard deviations for prospective memory accuracy at novel and recurring items, judgments of learning, and absolute difference of metamemory accuracy.

	Novel recall accuracy		Recurring recall accuracy		JOL rating		Absolute difference	
Group	Cue	Task	Cue	Task	Cue	Task	Cue	Task
TBI	62.50 (29.27)	26.11 (30.61)	76.30 (23.90)	49.26 (34.46)	62.81 (17.33)	57.34 (20.42)	.04 (32.20)	30.45 (33.03)
HC	89.25 (8.93)	87.25 (9.53)	97.33 (5.47)	94.67 (6.34)	73.24 (17.43)	71.80 (15.04)	−16.46 (16.76)	−13.46 (15.29)

Note. Group means (standard deviations) are reported. Novel and recurring recall accuracy are reported as percent correct of free recall items. JOL ratings are expressed as mean percent measured using the sliding 0–100 scale. Absolute difference is metamemory accuracy measured as novel free recall accuracy subtracted from JOL rating for each participant; mean data are presented for each group. TBI = traumatic brain injury; JOL = judgment-of-learning predictions; HC = healthy controls.

Figure 5. Comparison of TASK recall accuracy by recurrence (novel or recurring) and type of recall (free recall or recognition). TBI = traumatic brain injury.



higher ratings of future success than the group with TBI (see Table 4). There was a main effect of JOL type, $F(1, 36) = 5.68$, $p = .02$, where higher ratings in the likelihood of recalling the CUE than the TASK. The interaction was not significant, $F(1, 36) = 1.93$, $p = .17$. Our hypothesis had been that adults with TBI would make similar predictions to HCs, but this group had adjusted their judgments downward as compared to the HCs, showing some knowledge of the likelihood of reduced recall for PM.

Absolute Metamemory Accuracy

Alignment between JOLs and novel accuracy were compared using a difference score (see Table 4 and Figure 6) and a series of Welch's unequal variances *t* tests by group and PM component. There was a trend toward but no effect of group when comparing absolute accuracy for the CUE ($t = 1.95$, $p = .06$) overall. In contrast, there was a strong effect of group so that HCs were underconfident in their ability to recall the TASK, whereas the group with TBI was overconfident ($t = 5.16$, $g = 1.74$, $p < .001$). Within-group differences between the CUE and the TASK were compared using a simple linear model. There was again a strong effect so that differences between absolute metamemory accuracy for the CUE and the TASK was smaller for the HCs than for adults with TBI, $F(1,36) = 13.75$, $r^2 = .28$, $p < .001$. We had hypothesized that the group with TBI would be overconfident across components of PM. Instead, this group was overconfident only for the TASK. In contrast and as expected, HCs were underconfident across both PM components.

Table 5. Participant mean scores and standard deviations for prospective memory recognition accuracy for TASKs.

Group	Novel	Recurring
TBI	66.39 (27.43)	84.26 (23.90)
HC	92.50 (10.20)	96.67 (8.72)

Note. Group means (standard deviations) as percent correct are reported. TBI = traumatic brain injury; HC = healthy controls.

Ongoing Distractor Task Accuracy

Visual Distractor Task

Total amount of money found. Independent *t* tests assuming unequal variances were conducted to compare total money found by groups (see Table 6). Importantly, both groups collected money, indicating that they were indeed engaged in this task; however, as expected, the HCs found

Figure 6. Absolute metamemory accuracy by group and PM component. Bars below zero indicate underconfidence, and those above zero indicate overconfidence. PM = prospective memory; TBI = traumatic brain injury.

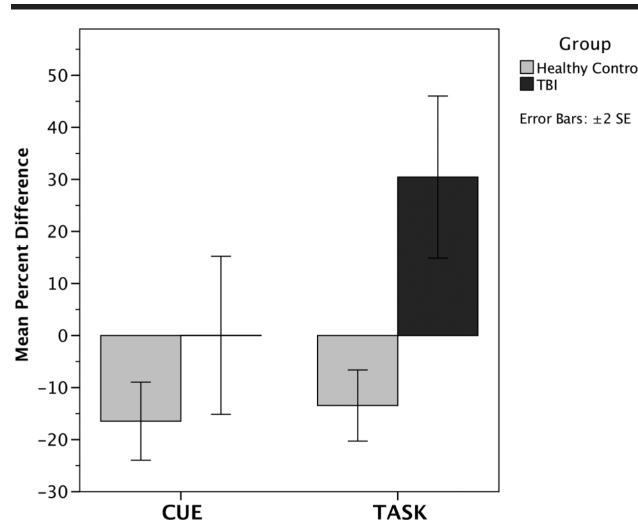


Table 6. Participant means and standard deviations on distractor tasks.

Group	Money found***	WHERE JOLs
TBI	\$85.89 (66.28)	40.09 (27.67)
HC	\$188.80 (38.82)	26.03 (23.07)

Note. Group means (standard deviations) are reported. Money is presented as raw values from coins found in virtual dollars. WHERE JOLs are mean group ratings using the 0–100 sliding scale. Asterisks indicate significant differences between the two groups on money found. TBI = traumatic brain injury; HC = healthy controls; JOL = judgment-of-learning predictions.

***$p < .001$.

significantly more money that the group with TBI, $t(26.83) = 5.76$, $g = 1.93$, $p < .001$. HCs were likely better able to shift between the ongoing task and PM completion, allowing more time and opportunities to find hidden money.

Distractor JOL

To further distract participants from PM JOLs, participants also made JOL predictions about the likelihood of recalling where money had been found in selected scenes. Here, the dependent variable was the average WHERE JOLs ratings (see Table 6). Means were compared using an independent *t* test with equal variances. These distractor WHERE JOLs were not significantly different between groups, $t(35) = -1.69$, $p = .10$, perhaps due to large standard deviations for both groups. Comparisons were then made within each group using a series of paired samples *t* tests. HC ratings for WHERE JOLs were lower as compared to both CUE, $t(19) = 7.64$, $p < .001$, and TASK judgments, $t(19) = 7.91$, $p < .001$. The group with TBI showed a similar pattern of lowering expectations when making WHERE judgments as compared to both CUE, $t(17) = 3.82$, $p =.001$, and TASK judgments, $t(17) = 2.75$, $p =.01$. In support of our hypothesis that both groups would recognize the difficulty of the WHERE task, both groups gave lower judgments as compared to PM JOLs.

Discussion

The current study used an online assessment, *Tying the String,* to investigate how adults with and without TBI think about their PM and how metamemory monitoring and beliefs relate to performance at tasks of PM. PM is necessary across a range of activities of daily living, such as remembering to perform tasks for work like returning phone calls or delivering messages, family tasks such as picking up children from school or day care, and social commitments such as meeting for dinner or remembering special events like birthday cards. Extensive research has demonstrated that it takes time after a TBI for individuals to adapt to cognitive changes and accurately monitor memory ability (O'Keeffe, Dockree, Moloney, Carton, & Robertson, 2007).

PM

In terms of recall accuracy, participants with TBI performed more poorly at all PM items. Recall accuracy was greater for recognizing the prospective component of "when" a task was to be performed (i.e., the CUE) rather than recalling retrospective component of "what" the task to be performed was (i.e., the TASK). Less than half of the time, if participants with TBI felt that a task should be completed, they were unable to access that information. In contrast, PM performance by the HCs was stable across the PM components. This group could largely rely on recalling an action if able to recognize and alert to the cue.

Although the separation between these two components of PM had not been previously explored in adults with TBI, previous work had pointed to the challenge of the prospective component of recognizing cues by examining performance when tasks were recurring and thus well learned (Fish et al., 2007) or by comparing performance at recurring versus novel tasks (Mioni et al., 2013). Recurring tasks allow for adequate encoding in RM, so that failures may be assumed to those of PM. In the current study, adults with TBI may have benefitted from having the prompt "Any Tasks to Perform?" on every screen, just as participants in Fish et al. (2007) increased the likelihood of performing PM tasks when cued with the single word "STOP." Participants were also selecting the presence of CUEs from a binary choice (yes/no), rather than the open-ended response required in reporting TASKs to be performed.

Given the support of a recognition task, the TBI group was able to identify a majority of the PM tasks. However, because recognition was well below ceiling, the group with TBI made both retrospective and prospective errors, that is, not all items were encoded and stored and not all stored items were performed. In returning to Figure 1, errors made during the game could have occurred because of failures of any of those cognitive systems—RM encoding and storing CUEs and TASKs, executive function directing resources to unmet goals, or attention alerting to cues as they occurred. In contrast, failures at the recognition task directly implicate problems with RM. Items that were recognized but not performed during the game describe "prospective" errors. Those items were adequately stored in RM but missed when the opportunity to perform them arose. In that sense, the results here describe the double deficit that individuals with TBI face in performing PM tasks that is likely a result of dual memory and executive function impairments (Groot, Wilson, Evans, & Watson, 2002). In considering the group with TBI's neuropsychological assessment results (see Table 1), this is consistent with deficits observed in attention, immediate memory, and delayed memory on the Repeatable Battery for the Assessment of Neuropsychological Status, as well as executive function measured by category fluency.

Participants also performed three recurring tasks across 5 days for 15 total recurring tasks. HCs performed at or near ceiling at free recall and recognition of recurring items (see Figure 5). The group with TBI again showed increased recall as support increased, also performing near ceiling at recognizing recurring tasks. Similar to Mioni et al. (2013), even though participants with TBI demonstrated adequate RM for recurring tasks, participants performed less than half of these recurring tasks (M = 49.26%) during the PM experimental task. This further characterizes the difficulties that individuals with TBI have with PM. Even when items are familiar and well learned, many tasks may still be forgotten. Participants with TBI were also particularly susceptible to interference, selecting a total of 45 foils from the list of tasks during recognition recall, whereas HCs as a group selected only two. Pavawalla, Schmitter-Edgecombe, and Smith (2012) found similar deficits in adults with TBI at discriminating targets and nontargets on a PM task, suggesting impairments were related to deficits in allocation of attentional resources. This aligns with deficits in the group with TBI described by neuropsychological testing here as well.

Despite the deficits described by neuropsychological testing and on the experimental task, adults with TBI rated themselves as having fewer overall problems with activities of daily living than the normative sample of adults with acquired brain injury as measured by the M2Pi Participation Subscale (see Table 2). On average, this group reported mild problems with activities such as financial management, transportation, social contact, and self-care. However, mild problems on the M2PI are characterized as the need for "extra prompting" or that "others may have concerns about safety." All participants were able to understand the experimental task, and recognition testing showed that most items were encoded, so that prompting would have likely resulted in accurate responses. Given the number of PM items missed by the group with TBI, both novel and recurring, it is also likely that others would have concerns about medication management or other critical tasks of PM being completed independently. In that sense, the results here align with reports of general problems with activities of daily living and reveal the importance of PM in maintaining independence.

In summary, individuals with TBI performed more poorly than HCs on tasks of PM. The group with TBI alerted to fewer cues, but the discrepancy between groups was much larger at recall of tasks. Participants with TBI performed few tasks of PM with accuracy, including recurring items that had been well learned. However, given the preliminary nature of this virtual environment study, the performance gap between CUE and TASK should be further explored in less structured recall designs.

Prospective Metamemory

Prospective metamemory was measured using an absolute difference score, comparing mean JOL prediction ratings to actual performance. That the group with TBI was less confident about future recall of PM items is encouraging. Knight et al. (2005) found no difference in JOLs between TBI and HC groups. Although it is not immediately clear why participants in the current study exhibited reduced confidence in recall when those in Knight did not, adults with TBI in that study had a mean time post onset (TPO) of 9.48 years, whereas the TBI group in the current study had a mean of 15.88 years postonset. All participants in the current study had also completed some cognitive rehabilitation postinjury. Experience living with cognitive changes after TBI has been shown to be related to increased accuracy at metamemory tasks (Hart, Seignourel, & Sherer, 2009; Prigatano, 2005). When asked about memory problems using the Prospective–Retrospective Memory Questionnaire, adults with TBI did report more problems than HCs on both prospective and retrospective subscales, whereas HCs reported problems commensurate with normative data (see Table 1). However, even though JOL findings and this questionnaire of metamemory beliefs showed that adults with TBI were less confident about their memory than HCs, this decreased confidence was not enough to account for poor performance at recalling tasks.

Both groups were slightly more confident about recall in the CUE over the TASK, meaning both groups thought it was more likely that the time "when" a task needed to be performed would be easier to recognize than recalling the task to be completed. In a similar design comparing the two components of PM, Schnitzspahn et al. (2011) found no difference between immediate JOLs for the CUE and the TASK in a group of healthy young adults, but overall levels of judgment were commensurate with those observed here (M = 65 and 68, respectively). In the current study, participants may have adjusted their CUE judgments based on the fact that the 10 scenes repeated each day. Different tasks were to be performed, but the set of items to learn with regard to the CUE was narrower than that of the TASKs. CUEs were also present in the virtual environment (see Figure 2) as a heading above each image. Participants may have been sensitive to this, rating CUE JOLs slightly higher because they could use environmental features to trigger attentional resources toward recalling CUE–TASK sequences from memory. Using environmental cues rather than self-generated cues for retrieval is associated with ease of recall (Craik, 1986).

Absolute difference scores compare mean JOL predictions with mean recall accuracy, providing a measure of how participants are anchoring beliefs about future success (Lichtenstein, Fischhoff, & Phillips, 1982). Negative scores indicate underconfidence or that participants recalled more items than had been predicted. Positive scores reflect overconfidence, that is, that predictions were greater than recall accuracy. HCs were underconfident about both recognizing the cue and recalling the task to be performed. Individuals with TBI were well calibrated about success at the cue, but poor task recall led to marked overconfidence on that PM component. Because CUEs were assessed with a yes/no choice, accuracy for CUEs and JOLs made for that component by the participants with TBI reflect slightly better than chance accuracy (62.5% accuracy and mean JOL of 62.81). Making JOLs around a binary choice may have presented fewer factors to consider in judgments. The closer alignment between CUE judgments and performance over TASKs for the group with TBI may also be associated with variability in performance rather than in judgment. Participants with TBI appear to have accurately surmised that they could recognize CUEs with better than chance accuracy but not have taken into account the difficulty of free recall required for the TASK component. HCs had similar metamemory accuracy across components but also had similar performance.

Although the near-zero difference score on the CUE component by the TBI group would appear to reflect good calibration, the underconfidence of the control group indicates that perfect calibration is not necessarily the target. Instead, underconfidence may be beneficial, spurring strategic planning to ensure future recall. Similarly, Kennedy and Yorkston (2000) and Kennedy (2001) found the same pattern of overconfidence in adults with TBI and underconfidence in matched controls on a verbal learning task using JOLs and retrospective confidence judgments. In that light, metamemory underconfidence appears to be a typical baseline state of healthy adults, and the overconfidence reflected in the TBI group's TASK absolute difference scores in this investigation becomes even more striking.

Strategy use was not formally assessed in the experimental task, but one strategy that was available to participants was study time for PM items. Items were self-paced, so that participants could spend as much time as they felt necessary to learn items adequately. Should participants with TBI spend more time studying items than HCs, this would align with metamemory monitoring (reduced JOLs) being linked to increased strategic control over learning. However, no such pattern emerged (M_{HC} = 27.53 s; M_{TBI} = 26.64 s), and both groups studied items for a similar amount of time, $t(36) = 0.49$, $p = .63$. Study time may have been too subtle for either group to take advantage of this strategy. Nonetheless, similar study times across groups do mean that equal time was afforded the group with TBI to learn information as the HCs.

Ongoing Visual Distractor Task

Although a JOL of the distractor task was included in the experimental design to attenuate the effects of PM JOLs diverting attention toward those items, this measure provided further insight into metamemory processing in the adults with TBI. This JOL required participants to make predictions about the likelihood of recalling where money was found in two randomly selected scenes each virtual day. Adults with TBI moderately reduced their WHERE JOLs as compared to PM JOLs (see Tables 4 and 6; $d_{\mathrm{CUE}} = 0.98$, $d_{\mathrm{TASK}} = 0.71$), whereas HCs made large reductions ($d_{\mathrm{CUE}} = 2.31$, $d_{\mathrm{TASK}} = 2.35$). Although recall requirements of this task differ by visual versus verbal domains, this task is made most difficult by the sequencing. For PM JOLs, participants studied self-paced items with the knowledge that these were to be encoded for future recall. In contrast, for WHERE JOLs, participants did not know which scenes would be selected for JOLs and recall until after the scene advanced. By the time participants made judgments about the likelihood of future recall, there was no opportunity to carefully study items. Furthermore, there is a large amount of interference inherent in the distractor task, as participants will continue to find money in subsequent scenes and may have found money on previous virtual days in the same scene.

HCs reduced JOLs in response to the demands of this distractor task, whereas the TBI group was sensitive to the greater difficulty of the distractor recall task but was more conservative in reducing JOL predictions. In contrast to the PM JOLs, the group with TBI expressed greater confidence in recall than the controls. Visual metamemory research describes memory strength and certainty of recall as underlying JOL predictions of future recognition, with certainty increasing following rehearsal. However, feelings of certainty are not affected by increasing duration, so that forgetting with time or interference is discounted (Busey, Tunnicliff, Loftus, & Loftus, 2000). This is consistent with theories of JOLs in verbal learning, specifically that individuals do not have direct access to memory stores but infer recall ability based on factors such as accessibility, intrinsic features like stimulus processing, or extrinsic features such as conditions of item presentation (Koriat, 1997, 2002).

The muted response of the TBI group in reducing JOLs for the visual recall task likely reflects impaired processing or incorrect inferencing about memory stores, but several explanations are possible. Participants may have been overly optimistic that recently viewed items would remain in memory despite being aware of the delay until recall. The effect of interference could also have been discounted. For example, in a study of verbal learning predictions, Kennedy (2001) found that adults with TBI were more susceptible to overconfidence when errors were due to interference (e.g., remembering items that were not part of studied lists or were variations of studied items). Participants with TBI could also be less flexible in making metamemory judgments, so that repeated exposure and explicit feedback are necessary in order for these individuals to monitor memory performance and make corresponding adjustments to predictions. Alternatively, the TBI group may have responded to the JOL prediction in a relative, rather than absolute standpoint, so that the reduction in judgments to the WHERE JOL revealed an acknowledgment of the decreased odds of recalling the items but did not reflect magnitude. In effect, participants with TBI may have been using less of the sliding scale to describe likelihood of recall than HCs. In contrast, HCs reduced JOLs for the distractor task in a manner that suggests a strong belief in the unlikelihood of recall and the independence of this task from the PM tasks.

Limitations

With regard to limitations, participants could study PM items at a self-selected pace, but participants with TBI may benefit from having additional study time or opportunities to reduce RM failures. For example, participants viewed the three recurring tasks three times to ensure adequate encoding and storage. Although participants with TBI recognized these tasks at greater than 90% accuracy, they performed only half of those tasks at the appropriate time. The multiple study opportunities allowed these participants to overcome RM deficits while revealing PM failures.

The current study is also preliminary in nature, expanding on past research, but with a novel computerized paradigm that will require replication and further exploration before clinical implications can be solidified. Virtual reality tools of PM have been demonstrated to be effective at classifying adults with TBI and provide convergent results to traditional measures (Banville & Nolin, 2012; Canty et al., 2014). Computerized testing also continues to gain favor across the life span as electronic interfaces are judged to be less stressful and more neutral to failures than traditional face-to-face assessments (Collerton et al., 2007; Hansen, Haferstrom, Brunner, Lehn, & Håberg, 2015).

Implications and Future Directions

Results of the current study indicate a disconnect between how well individuals with TBI are able to perform PM tasks and how well people with TBI think they will do at performing those tasks. As compared to healthy adults, adults with TBI were poor monitors of PM recall. The group with TBI in the current study indicated expectations of moderate levels of success but frequently forgot tasks to be performed, even when these tasks were well learned (i.e., recurring tasks).

Because of the link between metamemory monitoring and strategy implementation, poor monitoring of performance suggests that these individuals will also struggle to deploy strategies appropriately to manage memory impairments (Robertson & Schmitter-Edgecombe, 2015). Participants in the current study completed standardized testing of PM using the Cambridge Test of Prospective Memory, which allows and encourages strategy use. Despite having access to and using compensatory strategies at a rate similar to HCs, the use of self-selected strategies by the group with TBI was not effective in approximating the performance of HCs ($t = 5.05$, $p < .001$, $d = 1.67$; see Table 1). Future research should further explore the link between metamemory monitoring and strategy use for the two components of PM, as it may be that individuals with TBI may have the metamemory awareness to use strategies but that knowledge is incomplete, so that strategies used do not fully address memory needs.

Current scoring did not account for near or far misses, or responses that were correct tasks, but entered at a time just before or after the assigned screen for recall. Completing such an analysis could further elucidate retrospective versus prospective errors and further separate the two components of PM. For example, if a participant entered the task "Take Vitamins" during the "Get Ready for the Day" scene rather than "Breakfast," this would be a nearer miss than entering that task during the scene "After Dinner." Nearer misses would more likely demonstrate that the task had been encoded but missed because of competing demands. Currently near, far, and absent responses are given equal weight as errors.

Subsequent research may also benefit from considering JOLs of recurring items. Intermittent probes for judgments of success at recurring tasks could reveal patterns of increased metamemory accuracy with increasing numbers of trials. Moreover, an analysis of adjustment of JOLs over the course of the virtual week may also give an indication of the degree to which individuals with and without TBI are actively monitoring their recall versus basing decisions on metamemory beliefs.

Tying the String uses a virtual work setting and gives multiple PM targets to be completed each day. Managing a calendar and appointments is frequently a target of PM intervention post-TBI (e.g., Sohlberg et al., 2007), as being able to schedule and keep appointments is functional across a variety of settings. PM tasks assessed in the current study target a different level of PM though, requiring multiple responses in changing settings across a virtual day. In contrast, appointments are highly structured, and individuals with or without TBI are often given time to record these into the external device of choice (calendar, smart phone, journal, etc.). For example, when leaving the dentist's office, the receptionist will often wait for the person to record the next appointment and also offer a reminder card. Contrast this with a phone call from a coworker asking if you can take his afternoon meeting, but you will need to get the key for the conference room from the receptionist before she leaves for lunch. Here, encoding and retrieval are much less structured, and it is unlikely the person on the other end of the phone will repeat these instructions or allow time to record them unless the conversation partner explicitly requests this. These kinds of tasks more closely resemble PM assessed in the current paradigm, as well as challenges an individual might face when returning to productivity. Future work should more explicitly link the virtual task with activity and participation needs and outcomes, including "errand" or "to-do list" type PM items, in addition to highly structured calendar appointments.

Conclusion

PM plays an important role in success across social, vocational, and personal settings. Individuals with TBI frequently struggle both to complete tasks of PM and to understand the nature of PM failures in order to apply appropriate strategies. The current study adds to a growing literature indicating the importance of considering metamemory when designing memory intervention approaches for this population, extending findings to include future recall required in PM.

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