Remembering to Remember:
Metamemory Judgments of Prospective Memory after Traumatic Brain Injury

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Dedication

This dissertation is dedicated to Jonas and Ronan, for reminding me to be the best version of myself.

Abstract

Background: Impairments to prospective memory (PM) are ubiquitous after traumatic brain injury (TBI). PM is remembering to complete an intention at a future time – like picking up milk on the way home – and is critical for independent living. PM includes two primary components: recognizing the CUE when a task should occur, and recalling the TASK to be completed. Many adults use memory aids for PM, such as notes or phone alarms. Such strategy use is related to metamemory judgments, or self-assessments of future success.

Purpose: The purpose of the current study was to examine how adults with and without TBI consider PM performance. Research questions compared predictions and recall performance at PM, as well as the relationship between PM metamemory predictions and standardized assessments of cognitive function.

Methods: Eighteen adults with chronic moderate to severe TBI and 20 matched healthy controls played *Tying the String*, an online simulated workweek PM game. Participants studied PM items and made two judgments of learning about the likelihood of recognizing a PM CUE, and of recalling the PM TASK. Participants also completed a standard neuropsychological battery.

Results: Participants with TBI were less confident in future recall than healthy controls and both groups were less confident about the TASK. For recall performance, healthy controls performed similarly across the CUE and TASK. In contrast, adults with TBI at times recognized a CUE, but were unlikely to remember the corresponding TASK. Absolute difference scores of metamemory accuracy showed that healthy adults were underconfident across PM, whereas adults with TBI were overconfident about the task. Adults with TBI adjusted judgments downward as the game progressed at a rate greater than healthy controls. During standardized testing, participants with TBI chose to use PM strategies, but those strategies were not effective at triggering PM recall.

Discussion: Participants with TBI adjusted metamemory expectations downward, but not enough to account for poor recall performance. Individuals with TBI have metamemory awareness to use strategies, but deficient monitoring of memory performance results in incomplete metamemory knowledge. Future work should address linking PM metamemory monitoring with strategy use to direct intervention approaches.

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Introduction

Project Overview

The current research developed a tool to assess metamemory judgments about prospective memory (PM) in healthy controls and adults with TBI. Laboratory tasks of PM require two broad components – an ongoing task that serves in place of the distractions of everyday life, and the PM task. Through a simplified virtual reality game, participants recalled everyday activities while completing assigned prospective tasks. Participants prepared for a birthday party while being presented with a series of photos with hidden embedded hyperlinks of virtual “money.” At the beginning of each virtual “day,” participants studied PM tasks, then made judgments of learning (JOLs) about the likelihood of recalling the CUE (when to perform the task) and the task (the action to be completed). Participants collected money hidden in the photos. A small pilot study used healthy controls to receive feedback on the game design. The main experiment used the game with adults with TBI and matched healthy controls to compare patterns of JOL and recall performance across the components of PM.

Background

An estimated 2.2 million individuals in the United States sustain a traumatic brain injury (TBI) each year, making TBI the leading cause of disability for individuals under the age of 34. Annually, $60 billion dollars are lost to direct and indirect costs associated with TBI (Centers for Disease Control and Prevention [CDC], 2011). While up to 90% of people who sustain a single, mild brain injury are expected to fully recover within one to two months (McCrea, 2008), the remaining 10% of the “miserable minority” as well as those sustaining moderate or severe TBIs often face ongoing cognitive problems, including difficulty with attention, memory, executive function, organization, or even perception (Ruff & Jamora, 2009; Stuss, 1991).

TBI, or a head injury, is defined by the CDC as a blow or bump to the head that results in changes to the normal function of the brain. In closed head injuries (CHI; in which the skull is not penetrated), neurological damage is often diffuse from the stretching and tearing of long axons in the brain (CDC, 2011). Frontal lobe deficits after TBI are common as a result both of the greater movement possible in the anterior to posterior plane as opposed to laterally within the skull, as well as the spiny protuberances lining the surface of the inferior skull base, resulting in damage to the inferior surface of the frontal and temporal lobes (Ylvisaker, Szekeres, & Feeney, 2001). Functionally, these individuals typically present as having frontal and medial temporal lobe deficits, including executive function impairments, poor decision making, impaired memory, reduced ability to generate ideas, and poor generalization (Brookshire, 2001; Stuss & Levine, 2002).

Prospective Memory

Retrospective memory is remembering events than have already occurred, like your last birthday party. Deficits to retrospective memory after TBI are considered a hallmark of the injury (Constantinidou & Kennedy, 2011; Elhardt et al., 2008; Kinsella et al., 1996; Vakil, 2005), but a less studied component of memory after TBI is prospective memory. Prospective memory (PM) is remembering to perform a previously encoded intention at a future time (McDaniel & Einstein, 2007). Activities of daily living are rife with examples of critical PM tasks. From remembering to drop a package at the post office, return a phone call, or shopping for groceries on the way home, to more dire needs such as recalling to take medications on a set schedule or picking up children at daycare, PM drives successful completion of tasks across an array of everyday settings.

The process of PM contains two primary components: a prospective component including the cue that specifies the conditions of retrieval, and a retrospective component that contains the action to be performed in response to the cue. In that both of these components, cue and task, must be encoded and recalled, retrospective memory (RM) plays a large role in successful PM performance (Einstein & McDaniel, 1996). However, the prospective component relies on processes above and beyond simple recall. Typical PM tasks occurring in naturalistic settings encompass a period of time greater than that served by working memory. Hours, days, or weeks often intercede between the formation of an intention (e.g. "Go to the dentist on April 3," or "Buy laundry detergent at the grocery store this weekend") and its execution. Even over relatively short time spans, intentions are forced from working memory and attentional focus by the distractions of other ongoing activities in the environment (e.g. "Take cookies out of the oven in 14 minutes"). Thus, cue recognition requires successful direction of attentional processes via executive function to scan the environment for unmet goals, then activate the cue and task retrieval sequence when the cue is identified (McDaniel & Einstein, 2007; see Figure 1 for schematic of cognitive processes underlying PM). PM can also be considered as either time- or event-based. Time-based PM tasks must occur at a given time or after a given interval has elapsed, i.e. “At 2:00, call your doctor” or “after 45 minutes, take the pie out of the oven.” Performance of event-based tasks by contrast, are tied to conditions in the environment, such as “when you call the doctor, ask him about your prescription,” or “After the pie is done, check the laundry in the dryer.”

Current theories of PM combine previous more simplistic theories into what has been termed the multi-process model. In this model, PM cues are sometimes alerted to by monitoring of the environment, while at other times spontaneous retrieval occurs as a result of a strong match between external cues and internal encoding (Marsh, Hicks, Cook, Hansen, & Pallos, 2003; McDaniel & Einstein, 2000; Smith, 2003; Smith, Hunt, McJay, McConnell, 2007). (It should also be noted that recurring PM tasks, such as feeding a dog every morning, may develop into routinized behaviors with repeated practice and accurate performance.) Some of the literature refers to “pop-up” versus “search” experiences, to differentiate between a cue-task sequence suddenly “popping” into mind and those times in which a person is actively scanning the environment, anticipating the match of an external cue to an stored sequence. Generally, search experiences are too costly to other ongoing tasks to occur very often in day-to-day life (Meier, von Wartburg, Matter, Rothen, & Reber, 2011).

However, explanations of spontaneous retrieval tend to be as incomplete or unsatisfying as much of the literature addressing self-regulation and executive function, often pointing toward a homunculus rather than a mechanism. As much as it has been described, the closer the conditions in the environment match the encoded cue and are sufficiently salient, the more fluid the cue-task enactment sequence (McDaniel & Einstein, 2007). For example, a person is more likely to recall an errand to the post office after work if their regular commute goes by the post office than if it does not. Similarly, a task to deliver a message to a friend about getting your house painted will be easier to recall if the person is a painter. In the former, visual association increases the likelihood of recall, and in the latter, a semantic association ties the PM task to characteristics of that person.

Because of the need to coordinate across cognitive functions to encode a cue-task sequence, then alert and switch attention to the cue as it occurs, PM is therefore a difficult task, made much more so by the impairments associated with TBI. Coordination across memory, attention and executive function within a cue-constrained window for success allows multiple opportunities for failure and suggests the need for a robust central executive system directing and integrating resources (Burgess, Veitch, de Lacy Costello, & Shallice, 2000). Such requirements map directly to the typical deficits associated with TBI and frontal lobe damage, namely, deficits in memory, attention and executive function. Impairments in PM following closed head injuries (CHI) is common (Shum, Levin, & Chan, 2011) and are considered to be primary contributors to disability and limitations to recovery of self-care, social integration and independence (Fleming, Shum, Strong, & Lightbody, 2005).

TBI and Prospective Memory

Research has consistently found PM to be impaired after TBI. Shum, Levin, and Chan provided a review of PM research and TBI in 2011, finding four broad categories of inquiry: self-other comparisons, intervention programs for PM, PM in pediatric populations, and PM in adults. Self-other comparisons rely on questionnaires describing memory failures. Results generally found that all adults, both healthy controls (HC) and those with TBI, reported some difficulty with PM tasks, although individuals with TBI reported more problems. Self and other reports, in which an individual with TBI completes a questionnaire regarding PM performance and results are compared with ratings of performance by a significant other, have produced a fair amount of agreement that PM failures are common in every day tasks. The intervention literature reviewed by Shum et al. was limited, and consisted of only case studies addressing both compensatory and remediation programs. Although results were encouraging, no maintenance data was collected and generalization of trained behaviors was unclear.

Shum et al. reviewed four studies of pediatric populations examining differing effects of PM. Children with mild TBIs (mTBI) were found to be more responsive to cueing than those with severe TBIs (McCauley & Levin, 2004), and monetary rewards were motivating for performance improvements across groups, although not in the acute stage (McCauley et al., 2010). Children also performed more poorly under conditions that created higher cognitive demand, and younger individuals were more affected by cognitive demand (Ward, Shum, McKinlay, Baker, & Wallace, 2007). Fourteen studies on PM performance in adults were included in the review. Initial work examined differences in performance between HC and TBI, but consistently poor performance in the TBI group soon led to more detailed investigations manipulating variables thought to influence correct PM performance. For example, studies explored the effect of the relatedness of the cue to the action (Carlesimo, Casadio, & Caltagirone, 2004), the time delay between encoding and performance (Carlesimo et al., 2004), accompanying distractions (Knight, Titov, & Crawford, 2006), the person generating the task (Kinsella, Ong, & Tucker, 2009), and the cognitive load of the ongoing task (Maujean, Shum, and McQueen, 2003). Only the last of these, was found to affect PM performance and will be discussed in more detail below.

Maujean et al. (2003) used a lexical discrimination task to assess PM. Participants decided if single words appearing on the screen where words or non-words, and pressed a key to indicate when PM targets – in this case, an animal – appeared as one of the words. Cognitive demand was manipulated by having the word either appear in its entirety on the screen, or having it appear one letter at a time. Researchers ensured that the final letter was necessary to discriminate a word from a non-word (e.g. “WOLB”, “WOLF”). Although both groups, HC and TBI, were slower and less accurate in the higher cognitive demand condition, the TBI group was more affected, performing much more poorly.

Despite this task having little resemblance to the kind of functional PM involved in returning a book to the library or taking medicines on a schedule, such an experimental design is not just common, but dominates the literature on PM. This kind of design, in which a single task (in this case, alerting to animal words) is repeated multiple times across an experiment, bears more resemblance to a selective attention task than retaining a novel cue-action sequence. Schmitter-Edgecombe and Wright (2004) for example, compared performance on a lexical discrimination task when the PM target was either a word (focal) or a patterned background (peripheral), but found no difference in PM performance for individuals with TBI between these two conditions. Again, however, individuals with TBI had fewer successful completions than HC.

A few studies have used stimuli designed to more closely approximate naturalistic tasks, but these are rarer. Kinch and McDonald (2001) examined the performance of individuals with acute TBI on a more functional assessment, and also separated each PM task so that it could be scored by both the prospective (cue or timing) and retrospective (action or content) component rather than a dichotomous global measure. Participants completed a standard neuropsychological battery and measures of anxiety and depression to determine which factors might be related to PM performance. Both time- and event-based tasks were included. For the time-based tasks, a research assistant asked the participant to complete a symbol-coding attention task, but only for five minutes. A clock was provided. Participants were told they could not complete the task in that time, but should stop when the time had elapsed and write their initials. Before beginning the symbol-coding, the research assistant was called out of the room. A telephone call to the room asked the participant to tell the research assistant when they returned about a meeting that afternoon. This was the event-based task, i.e. the message must be accurately relayed when the person returned.

Time and event-based PM tasks were related to differing constructs. Timing and content components had similarly differing relationships with standardized measures. Anxiety and depression were both negative predictors, so that individuals with anxiety were less likely to give the research assistant the phone message, and those who were depressed were less likely to stop the symbol-coding task at the correct time. A subgroup that was not asked to complete the ongoing symbol-coding time-based task was found to perform more poorly on the event-based task. Kinch and McDonald posited that the ongoing task may have prevented mind wandering and allowed the individual to alert more easily to the delayed intention when the research assistant return to the room.

Fleming et al. (2008) similarly used a neuropsychological battery and injury factors to characterize PM performance after TBI. The PM task was a standardized assessment, the Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2005). This test provides both time and event-based scores on tasks such as remembering to collect items at the conclusion of testing or after an interval of time. Scoring ranges from 0 to 6 for each item, to capture a range of performance success and necessary cueing. Despite including a number of measures of executive function, a questionnaire assessing beliefs about PM, and observations of compensatory strategies, no tests of RM were included. Results showed that the time-based CAMPROMPT scores correlated with semantic verbal fluency measured by the Controlled Oral Word Association Test (COWAT; Benton & Hamsher, 1989), length of post-traumatic amnesia (PTA), and independent note taking observed during CAMPROMPT testing. Event-based scores similarly correlated with the COWAT and PTA. Although PTA has been found to be associated with a number of functional outcomes after TBI, and note taking during time-based tasks may reflect the greater difficulty inherent in this type of PM, the relationship between verbal fluency and PM is less straightforward. Fleming et al. proposed that perhaps the spontaneous retrieval of lexical information within defined constraints is similar to the kind of spontaneous retrieval associated with the triggering of a PM cue-action sequence.

Fish et al. (2007) and Mioni, Rendell, Henry, Cantagallo, and Stablum (2013) both point to the difficulty of PM in individuals with TBI as being related to the cue rather than retrospective content. Fish et al. asked participants to call an answering service four times a day for 10 days. Researchers instructed participants that they may occasionally receive text messages stating “STOP!” and at that point they should scan their minds for unmet goals. On five randomly selected days, participants received the text messages. The key manipulation was that none of these text messages were delivered within one hour of a scheduled phone call. Despite this, accurate performance increased significantly on the days the text messages were sent. Because these days were randomly selected, Fish et al. interpreted this as meaning that the difficulty in performing the PM task was not that the participants with TBI had trouble remembering what it was they had to do, but rather, could not remember to do it *when* they were required to do so. Intermittent content free cueing appeared to have increased self initiated retrieval. However, the task remained stable across all 10 days, so that the RM load may have decreased as the task itself was repeatedly practiced.

Similarly, Mioni et al. (2013) used a promising PM board game named Virtual Week that allows for laboratory testing, but within a complex functional design (Rendell & Henry, 2009). In this game, individuals must complete circuits of the board corresponding to a single day, completing tasks along the way. On each day there are eight event-based tasks and two time-based tasks. Of the event-based, four recur daily, and four are novel. Mioni et al. found that individuals with TBI performed similarly on the recurring and novel event-based tasks, suggesting that the problem was not one of encoding (participants were able to state those tasks), but that as they became involved in the game, cueing to both the recurring and novel tasks was neglected. These studies suggest that while are RM impairments after TBI are common, problems with executive function and spontaneous retrieval of cues are more directly implicated in PM failures for individuals with TBI.

Overlap between the neurological structures thought to underlie PM performance and those typically affected by TBI may also play a role in this being a common area of memory failure. Just as the prefrontal cortex, frontal lobe more generally, and medial temporal lobe are commonly injured in TBI, PM relies on these same areas to encode and retrieve delayed intentions (see Figure 2 for a schematic of neurological bases of PM). For the retrospective components – encoding of the action and cue – PM relies on the medial temporal lobe and hippocampi, while the prospective components – alerting to or becoming aware of the cue – rely on prefrontal systems directing attentional resources (Poppenk, Moscovitch, McIntosh, Ozcelik, & Craik, 2009). In particular, the rostral prefrontal cortex (rostral PFC; Brodmann's area 10) has been found to be activated across a variety of PM tasks as well as complex monitoring tasks (Burgess, Scott, & Frith, 2003; Shimamura, 2008; Simons, Scholvink, Gilbert, Frith, & Burgess, 2006). Researchers have suggested that this area may be responsible for monitoring of internal and external stimuli and providing rapid switching between the two. Lesions to neighboring areas also result in decreased PM performance as well though, including such areas as the orbitofrontal cortex, left posterior dorsolateral PFC, medial prefrontal cortex, and the anterior cingulate cortex (Okuda et al. 2011; Volle, Gonen-Yaacovi, de Lacy Costello, Gilbert, and Burgess, 2011). Other lesion work suggests that injury to areas such as the orbitofrontal cortex and right rostral prefrontal cortex result in impairments in time-based prospective measures, while performance on event-based tasks is affected by damage to the left posterior dorsolateral prefrontal cortex and the medial prefrontal anterior cingulate cortex (Okuda et al., 2007; Volle et al., 2011).

Metacognition and Brain Injury

Metacognition has been studied extensively in brain injured populations, 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. The prefix “meta-“ means to “think about,” and can be added to a variety of processes, such as metacomprehension, or in the current discussion, metamemory. Metamemory beliefs are beliefs about one’s own memory, such as being a quick learner or having a so-called “photographic” memory for read material (Kennedy & Coelho, 2005). Changes to memory function, such as frequent retrospective memory failures after

TBI, result in mismatches between previously held beliefs about the ability to recall information. Even with these failures, updating to metacognitive beliefs is a slow and often incomplete process, particularly after frontal lobe damage (Kennedy & Yorkston, 2004). Of particular concern, such impairments in metamemory after TBI mean that poor predictions of memory function result in little attempt to remediate or strategize around possible memory failures.

However, there is no clear consensus that impairments to metamemory after TBI are the rule. Other studies have found particular strengths in metamemory judgments, although typically in particular domains, such as when listening to stories (Kennedy & Nawrocki, 2003), or learning paired associates (Schmitter-Edgecombe & Anderson, 2007). A series of studies by Kennedy et al. (Kennedy, 2001; Kennedy, Carney, & Peters, 2003; Kennedy & Yorkston, 2000) reveal that under some conditions, individuals with TBI can accurately monitor memory. Kennedy et al. (2003) used judgments of learning (JOLs; Nelson & Dunlosky, 1991) to compare adults with and without TBI and found that adults with TBI demonstrated an intact ability to make strategy decisions about memory and were most successful at recall tasks when self-selecting items to restudy. Schmitter-Edgecombe and Woo (2004) found that metamemory performance can sometimes outpace that of memory, so that individuals with TBI are able to be more accurate in judging their recall than they are in actually recalling information. Nevertheless, overconfidence has often been observed in individuals with TBI, perhaps as a result of poor monitoring, or because of metacognitive beliefs that may have been accurate before a TBI, but are no longer so after an injury changes cognitive skills.

All of this work on metamemory and TBI has been completed in the area of *retrospective* memory, or recalling events that have already happened, however. PM in general is a newer field of study, but particularly so in this neurologically impaired population (Shum, Levin, & Chan, 2011). Only a single study (Knight, Harnett, & Titov, 2005) has examined metamemory judgments of PM in adults with TBI, while a handful of others have examined metamemory and PM in healthy populations (e.g., Devolder, Brigham, & Pressley, 1990; Meeks, Hicks, & Marsh, 2007; Schnitzspahn, Zeintl, Jager, & Kliegel, 2011). Accurate memory monitoring and prediction of future success plays a crucial role in strategy selection, as many typical adults employ a variety of strategies to ensure that prospective tasks are completed, such as calendars, post-it notes, appointment cards, or the string around the finger of yore. Thus metamemory may be the critical element in ensuring successful PM performance, making this confluence of metacognition, cognition, and activities of daily living a particularly important avenue of inquiry.

Shimamura (2008) points to a functional overlap in the structures underlying PM that drives the current investigation. The prefrontal cortex not only plays a role in the direction of monitoring and attention to encoded intentions. This area is also considered the seat of metacognition, or reflecting on one’s own thinking (Fernandez-Duque, Baird, & Posner, 2000). The rostral PFC implicated in cue recognition during PM tasks has also been observed to be activated while individuals are making JOLs. JOLs are judgments made as to how likely a person thinks it is that an item will be recalled at a later time and are routinely used to assess retrospective metamemory (Nelson & Dunlosky, 1991).

Given the neural overlap between JOLs and the prospective component of PM, such work may provide particular insight into PM successes and failures, and as in the RM literature, insight into how individuals successfully strategize based on monitoring assessments.

Metacognition and Prospective Memory

Of those studies that have examined PM and metamemory, Devolder et al. (1990) found that typical adults were not able to accurately predict their ability to place a series of phone calls at given time, believing themselves to be more accurate than they in fact were. Meeks et al. (2007) found the opposite effect on a controlled laboratory task, finding adults to be underconfident on a lexical decision task. Knight et al. (2005) used a video task with adults with and without brain injury to assess participants' ability to complete a series of errands in response to visual cues in the virtual environment. Interestingly, predictions across the two groups were similar, but the group with TBI was not as accurate at completing the prospective tasks, resulting in overconfidence in the group with TBI, while successful performance by the control group made this group underconfident. Such similarities in predictions across the two groups suggests impaired updating of metamemory beliefs following changes to the memory system after TBI as discussed above.

Schnitzspahn et al. (2011) sought to further explain the inconsistencies in over- versus underconfident predictions across the previous three studies by examining PM by its component parts, namely the cue, or prospective component, and the action, or retrospective component. Given the differences in processing requirements of these two pieces, the authors hypothesized that JOLs may be considered differently. The study also looked to extend two well-established effects of the retrospective memory literature to that of PM, namely, the delayed JOL effect (Nelson & Dunlosky, 1991) and the underconfidence-with-practice effect (UWP; Koriat, Sheffer, & Ma'ayan, 2002). The delayed JOL effect describes the increase in metamemory accuracy occurring after a brief delay of study rather than an immediate judgment of likelihood of future recall. During an immediate JOL, the item to be recalled is still in working memory, while after a brief delay, the item has had time to leave working memory. A judgment of recall now relies on a covert retrieval attempt from long-term memory, thus increasing accuracy as to whether or not the item is available for retrieval. The UWP effect describes a tendency toward decreasing confidence in JOLs with repeated study. Multiple theories have been put forward with no consensus yet being reached, but Koriat et al. (2002) proposes a shift in focus from theory-based features (including metacognitive beliefs) to experience-based features, such as task difficulty or item relatedness. Other explanations focus on the discounting of performance improving with repeated trials or the facilitative effect of effortful retrieval in enriching encoding (Benjamin, Bjork, & Schwartz, 1998).

In the Schnitzspahn et al. (2011) study, distinguishing the two components of PM further demonstrated the differences between cue identification and action retrieval processes. The delayed JOL effect was replicated in both the prospective and retrospective components, but the UWP effect occurred only in the retrospective component, shifting predictions from being slightly overconfident to underconfident after three study trials. In the prospective component, participants were significantly underconfident in either the one or three encoding condition. Therefore, typical adults in this study were much more certain they would recall an action to be completed than that they will remember to do it at the correct time.

Left unclear is how such experimental designs that requires participants to make predictions (i.e. JOLs) about upcoming PM tasks may affect task performance. A recent meta-analysis reviewing the delayed JOL effect in the retrospective metamemory literature considered the effect of making such predictions on RM performance (Rhodes & Tauber, 2013). Results showed a robust delayed JOL effect, accounting for a large proportion of the variance in increased accuracy of predictions. Conversely, there was a very small effect of making the predictions on performance, so that results of the JOL studies can be assumed to be valid and are not contaminated by the act of making the predictions themselves.

PM may respond differently to predictions, however. As described previously, the difficulty of PM appears not to be the accuracy of recall, but accurate recall at the appropriate moment. Making a prediction may add salience to the cue and could facilitate such recall. Two studies have looked at the effect of predictions on PM. Meier et al. (2011) used object word pairs and asked participants to alert to the presence of either a "trumpet" or a "musical instrument" depending on the assigned condition, specific or categorical. Half of participants in each condition completed a six-item questionnaire about anticipated performance. Participants in the categorical condition experienced a boost in performance as a result of making predictions, but this did not carry over to the specific group. Meier et al. suggested making predictions may be a strategy for PM, but it is unclear if the task used would generalize to a functional context.

Rummel, Kuhlman, & Touron (2013) used a lexical discrimination task similar to Meeks et al. (2007), but divided participants into three groups, one that made predictions about PM performance, one that made predictions about both PM performance and performance on the ongoing task, and the final group that made no predictions. Individuals in the PM prediction group performed more slowly on the ongoing task, although this slowed rate did not facilitate improved performance. In fact, while the other two groups showed a correlation between response time and accuracy so that as time increased, accuracy did as well, the PM prediction group did not show this relationship. The PM prediction group did perform slightly better on the PM task. The group that made predictions about both PM and the ongoing task had similar performance to the no prediction group on the PM task, suggesting that making predictions about both tasks may attenuate the effects of predictions in experimental designs.

Assessment Considerations

To move the field forward, research examining PM requires experimental stimuli that resemble activities of daily living. Many studies in both typical and neurological populations rely on tests of selective attention as proxy measures of PM. The relationship between such tasks and functional PM is questionable and has not been explored. Uttl and Kibreab (2011) did compare self-ratings on a variety of questionnaires (e.g. Prospective Memory Questionnaire, Prospective and Retrospective Memory

Questionnaire, Comprehensive Assessment of Prospective Memory) and a laboratory PM task (circling target words on a pen and paper task), finding that the questionnaires had only low correlations with each other, but no relationship to objective measures. Uttl and Kibreab caution researchers not to use such questionnaires as measures of metacognitive monitoring ability. Because metacognitive theory suggests that there is an imperfect alignment between monitoring and beliefs (Chiou, Carlson, Arnett, Cosentino, & Hillary, 2011; Flavell, 1979; Schraw & Moshman, 1995), it is possible these questionnaires were assessing metacognitive beliefs about PM performance while the objective measures were assessing online monitoring, so that this study leaves open the question of whether or not such laboratory tasks relate to real world performance.

Both Knight et al. (2005) and Mioni et al. (2013) used tasks who surface features more closely resemble the requirements of real world PM. Knight et al. used a video task to simulate running errands, and Mioni et al. used Rendell and Henry's 2009 Virtual Week, a board game, but a complex one that involves participants in an ongoing task while constantly shifting the demands of both ongoing performance and PM tasks. However, the latter (Mioni et al., 2013), examined only PM performance and not metamemory. Virtual Week is not designed to assess metamemory judgments, and adding in such features may make the game too cumbersome, as individuals with TBI required 70 minutes to complete three "days" without the added component of JOL decisions.

Two important limitations with the Knight et al. study also point to the need to explore such differences between healthy controls and adults with TBI further as well.

First, this study used an absolute difference analysis that averages responses across tasks rather than looking at how prediction of a particular task corresponds to performance on that same task. This measure is more commonly used in conjunction with other, more precise analyses, such as Goodman-Kruskal gamma correlations or calibration curves (Gonzalez & Nelson, 1996; Lichtenstein, Fischhoff, & Phillips, 1982; Nelson, 1984), that would provide a clearer picture of how adults with TBI are monitoring their memory on an item-by-item basis.

Secondly, results of the limited literature on PM with healthy adults have been mixed, indicating both under- and overconfidence, a discrepancy possibly explained by having participants make general judgments about remembering to perform a task in the future, rather than differentiating between remembering the action (e.g. “buy milk”) and recognizing and responding to the cue (e.g. “on the way home”). Schnitzspahn et al. (2011) found that typical adults are much more certain they will recall an action to be completed than that they will remember to do it at the correct time. No studies have yet examined if adults with TBI are sensitive to this difference 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.

Currently, there are no evaluation tools to quickly assess one’s ability to predict PM. A computerized evaluation tool will fill this critical need not only for addressing this skill in adults with TBI, but also for any adults with PM impairments (e.g., typically aging adults). With an evaluation tool such as this, clinicians and researchers will be able to identify where a client's memory breakdown occurs, and therefore identify areas to be targeted in treatment.

Significance of the Study

The current study proposes to examine metamemory processes in adults with and without TBI to determine the relationship between online prospective metamemory monitoring and accuracy at PM tasks. Furthermore, the study looks to continue Schnitzspahn's et al. (2011) line of inquiry into the separability of the two components of PM (i.e. performing a task at the correct time, and recalling the task to be completed) and expand this to a neurological population. Behavioral as well as neuroimaging studies have confirmed that PM consists of two distinct processes (McDaniel & Einstein, 2007; Poppenk et al., 2009), alternatively called the cue and action, or prospective and retrospective, but will here be described as the CUE and TASK to distinguish from other uses of those terms. Inconsistencies thus far in the small metamemory literature regarding PM may be explained by these facets being grouped into single predictions. When participants make judgments as a whole about PM, it is unclear whether those judgments and possible strategy decisions are based on the likelihood of recognizing the cue or of remembering the action to be performed. Given Schnitzspahn's findings, it is likely indeed that participants are considering these two components quite differently.

PM deficits after TBI are common across severity (Carlesimo et al., 2004; Fish, Wilson, & Manly, 2010; Shum, Levin, & Chan, 2011; Tay, Ang, Lau, Meyyappan, & Collinson, 2010) and have a significant impact of participation in activities of daily living. In addition, whereas retrospective memory failures can often be considered as common and forgivable, demonstrated in the ubiquity of the phrase, "I'm so bad with names," PM failures are often viewed socially as a failure of character. Forgetting appointments, missing events, or neglecting to complete tasks for others have ramifications as being socially unacceptable (Penningroth, Scott, & Freuen, 2011). For example, leaving a friend waiting at the airport or children waiting at school is likely to alienate friends and family. The importance of effective PM performance does not end there, as in medication dependent populations such as individuals with HIV, PM performance has been identified as a key predictor of independent living (Woods et al., 2008). Impacts of PM reach across life domains and play a role in successful living in general.

There is then a particular need to increase effectiveness of PM performance in adults with TBI. Compensatory strategy training is common and is also used by healthy adults without brain injury in the form of smartphones, daily calendars, lists, reminder cards, etc. The effectiveness of this kind of training, however, relies on the individual accurately monitoring when such compensatory techniques should be applied. Accurate metamemory performance underlies the ability to adjust and strategize around anticipated failures.

The current study examined how metamemory accuracy differs between healthy and brain-injured populations as a step toward supporting effective strategy use for this critical skill. Given that healthy adults in Schnitzpahn et al. (2011) were markedly underconfident about cue recognition, and the pervasiveness of assistive technologies for recall in healthy populations, it is possible that successful PM in general relies on a feeling of underconfidence. If the current hypothesis that adults with TBI are overconfident about PM accuracy is supported, the implication would be that strategy training for these individuals could benefit from addressing metamemory beliefs and monitoring to more accurately reflect (or underestimate) actual ability, thereby spurring strategy use. Future studies would need to address the effectiveness of such training, but the current study would provide a theoretical rationale for the importance of including metamemory as a critical factor toward successful strategy application.

A small number of studies examining the effectiveness of PM training programs exist, although is largely confined to single subject designs, case studies, or simple pre-post designs (Shum, Levin, & Chan, 2011). While comprehensive rehabilitation packages are likely to continue to be necessary for individuals with brain injuries, the current study may suggest an avenue of inquiry to increase success at prospective tasks. Guidance toward effective PM intervention in adults with brain injury is likely to impact participation across settings, from social, to work, and personally relevant tasks. Exploration of the differential predictions for prospective (CUE) and retrospective (TASK) components will also allow for further insight into how metacognitive judgments may differ between adults with brain injury and adults without, and direct intervention and strategy use toward supporting the specific components of PM. Just as metamemory has been explored at length in the retrospective literature, exploration of this process in prospective tasks will provide further theoretical support for techniques that translate beyond clinical settings to real world successes.

Research Aims, Hypotheses, and Analyses

1. To determine if participants with TBI make JOL predictions similarly to matched healthy controls on the PM tasks by:
    - Comparing mean performance on the two components of prospective tasks across groups using JOL responses about the likelihood of recognizing the CUE and of recalling the TASK.
    - *Hypothesis:* Adults with TBI will make similar JOLs to HC for the PM tasks.
        - *Dependent Variable:* CUE JOL, TASK JOL
        - *Analysis:* Mean JOLs will be calculated for each participant for each of the 20 novel PM tasks and for each PM component.
        - *Implications*: Given the results of Knight et al. (2005), in which adults with TBI made similar predictions to a group of healthy controls, it is likely that the adults with TBI will make similar predictions across the CUE and TASK. If adults with TBI make lower self-ratings of future likely recall, this may reflect a updating of metamemory beliefs following TBI. Differences between the CUE and TASK, so that the group with TBI acknowledges the difficulty of alerting to the CUE or recalling the TASK, will provide more specific results as to how strategies may be deployed to manage memory impairments. However, metamemory accuracy will be assessed in aim 4 below.
2. To determine if participants with TBI perform similarly to matched healthy controls on the PM tasks by:

- Comparing performance on the two components of prospective tasks across groups using accuracy of presence of response to assess the prospective component (CUE recognition) and recall to assess the retrospective component (TASK recall).
- *Hypothesis:* Adults with TBI will be less accurate at completing the PM tasks.
    - *Dependent Variable:* percent correct of prospective tasks; percent correct of prospective tasks corrected for retrospective memory failures
    - *Analysis:* Accuracy will be measured as percent of prospective tasks performed during the appropriate time frame (during the assigned scene).
    - *Implications*: Given consistent reports of PM impairments after TBI, it is anticipated the group with TBI will have a lower accuracy rate in the prospective tasks. Should this difference occur, this would validate the sensitivity of this tool in detecting PM changes after TBI. If the tool does not differentiate the groups on this measure, then the game may need to be adjusted to either be more or less difficult so that both groups experience a range of success at the task. However, post-hoc analysis may determine the most appropriate course of action. It is anticipated that because of known retrospective memory deficits after TBI, the TBI group will perform more poorly than the healthy controls on recognition as well, although the recognition (rather than free recall) task should increase accuracy of the TBI group. If this is not the case, the game could be adjusted for future studies by

lengthening study time, stimuli presentation (daily scenes), or reducing the number of targets.

3. To determine if adults with TBI monitor metamemory for PM similarly to matched healthy controls on the prospective tasks by:
   - Describing and comparing absolute predictions of the two groups on the two components of PM (CUE and TASK) using difference scores.
   - Describing and comparing relative predictions of the two groups on the two components of PM (CUE and TASK) using gamma correlations.
   - Describing and comparing relative predictions of the two groups over time on the two components of PM (CUE and TASK) using regression modeling.
   - Analyzing these three types of metamemory measures for between (TBI and HC) and within (CUE and TASK predictions) group differences.
   - *Hypothesis:* Both groups will be less confident about the cue than the action (main effect of component), but the group with TBI will be overconfident in their ability to recognize and initiate the cue-action sequence when the cue is encountered (interaction).
     - *Dependent Variable:* Metamemory accuracy for the prospective cue and action to be recalled as measured by absolute difference (Dunlosky & Nelson, 1994) and Goodman-Kruskal gamma correlations (Nelson, 1984; Gonzelez & Nelson, 1996). Regression modeling will be used to consider metamemory adjustments over time (Krause & Kennedy, 2009).

- *Analysis:* Absolute differences will be calculated by averaging predictions across items and subtracting this from the mean total of prospective items accurately performed (after correction for retrospective memory failure). Gamma correlations instead observe the movement of predictions in relation to success and failure across items, assigning credit to predictions that are increasing for items correctly performed, and decreasing for those in error. To examine change over time, average performance for each item within group (HC or TBI) will be calculated, then modeled using multiple linear regression with item number and group as predictors. An ANOVA of group by prediction component will be performed for the two metamemory measures (absolute difference and gamma correlations) to address between (HC and TBI) and within (cue versus task) group differences.
- *Implications:* If the HC group differentially predicts performance across the two types of PM tasks (cue and action), so that predictions are underconfident toward the cue, but overconfident about the action, this will replicate the results of Schnitzspahn et al. (2011) with immediate JOLs. If adults with TBI do not display a similar pattern of prediction confidence and are overconfident about cue recognition, then this will reveal an important difference between typical adults and those with TBI. Such overestimates of performance may underlie poor strategizing around impairments and could direct intervention toward reducing confidence as well as drive future research into how to induce underconfidence in adults with TBI. If this hypothesis is not supported,

other methodological explanations will first be ruled out (i.e. insufficient data ranges). If adults with TBI as a group are underconfident about recalling PM cues, then this may be a relative strength in rehabilitating PM after TBI, in much the same way that Schmitter-Edgecombe and Woo (2004) revealed metamemory performance strengths in comparison to memory. A tool such as this, available for administration across a variety of settings, could help clinicians identify particular patterns of strengths or weaknesses at PM tasks. Future work could examine the utility of such applications, for example, by using the game as a clinical tool to identify and explain increased accuracy with routinized versus novel tasks, or the effect of PM difficulties after TBI on daily living.

4. To determine if metamemory accuracy for PM correlates with standard neuropsychological measures by:
   - Conducting correlational analyses of PM and metamemory accuracy with standard measures of cognitive functioning including: delayed recall, working memory, attention, verbal IQ, executive function, and PM.
   - Comparing PM and metamemory accuracy to self-reported metamemory beliefs collected with standardized questionnaire.
   - *Hypothesis:* Although exploratory, it is unlikely that metamemory will correlate with standard neuropsychological measures or questionnaires of metamemory beliefs (PRMQ). PM performance will correlate with results of the

CAMPROMPT as well as tests of delayed memory (RBANS) and executive function (DKEFS).

- *Dependent Variables:* Metamemory accuracy as measured by absolute difference and gamma correlations, results of RBANS (delayed memory, attention, total scale), Span (working memory), WTAR (estimated verbal IQ), DKEFS (executive function), CAMPROMPT (PM), PRMQ (retrospective and prospective metamemory beliefs).
- *Analysis:* Conduct correlational analyses to identify relationships between experimental measures (accuracy, retrospective memory failure rate; absolute difference and gamma correlations of cue and task predictions) and standardized test scores of overall cognitive functioning, delayed memory, attention, verbal IQ, executive function, and self-reported metamemory beliefs. The results of this analysis may support regression modeling to further explore overlaps in relationships between the measures.
- *Implications:* If the hypothesis that metamemory performance is unrelated to standardized measures or cognitive functioning or metamemory beliefs is supported, this would be in line with previous findings that online metamemory monitoring is a skill separate from that of memory assessed by standard measures, instead relying on internal inferences of existing knowledge and the viability of access to that knowledge. Previous work has shown little to no overlap between online monitoring of memory and questionnaires of metamemory beliefs, supporting the separability of those

components as well. However, if the hypothesis is not upheld, then the implications would have to be interpreted in light of which aspects of the cognitive functioning correlated with the metamemory measures. Should the hypothesis that PM performance is related to selected measures of retrospective recall, and executive function, then this would validate the game as assessing the construct it purports to assess. This would also replicate previous relationships between , recall, and executive control.

Methods

Overview

This study consists of an experiment in which individuals in one of two groups – adults with TBI and matched healthy controls – participated in a single experimental session. Participants completed standard neuropsychological assessments of cognitive status, questionnaires about memory beliefs and everyday functioning, and the experimental task. This task consisted of a computer game that assessed several types of memory and corresponding metamemory judgments. See Appendix A for details of a pilot feasibility experiment with healthy adults.

General Procedures

The Institutional Review Board of the University of Minnesota approved this study. Experimental sessions occurred on campus in Shevlin Hall for 34 of 38 participants. The four exceptions were participants who were not able to travel to the Twin Cities for testing. Those sessions occurred in publicly available spaces that allowed for quiet, private testing and access to wireless internet, such as a public libraries. The experimental task, revised version of *Tying the String*, and working memory assessments were administered on a PC. Either the Primary Investigator (PI) or one of three trained graduate research assistants (RA) under the supervision of the PI administered all other tasks.

The PI consented all participants by explaining the purpose, experimental tasks, risks and benefits, and participant rights, indicating each section on the consent form (see

Appendix B for sample consent form). Participants in experiment one were not compensated, and participants in experiment two were compensated at a flat rate of $30 for their time. All participants completed testing in a single experimental session.

Recruitment

Participants with TBI were recruited through a variety of community resources. A classified advertisement in the Brain Injury Alliance of Minnesota e-Newsletter ran six times and accounted for many of the participants with TBI. A few participants were recruited from previous studies conducted in the NeuroCognitive Communication Lab. Flyers were also distributed to rehabilitation centers (e.g. Courage Kenny Institute) and group homes (e.g. ReStart) for individuals with neurological impairments to recruit individuals with TBI. The PI also distributed flyers at brain injury support group meetings in the Twin Cities area.

For healthy controls, flyers were posted on bulletin boards on campus and in the community, in areas including coffee shops and local grocery stores. Some participants were recruited through word of mouth, and a few were identified through the Research Match database (researchmatch.org). Research Match is a national database that allows prospective participants to register to be contacted by research studies. Registrants provide brief health histories to allow investigators to target selected populations. For this study, individuals aged 40 to 65 were targeted so that the control group would more closely match the experimental sample. Many of the individuals identified through

Research Match indicated that they had participated in continuing education classes at the University of Minnesota.

The PI and RAs conducted all participant screenings over the phone. IRB approved scripts and questionnaires were used to describe the study, participant activities, and determine eligibility (see Appendix C). Exclusion criteria included: history of substance abuse, neurological history other than TBI, learning disability, identification as being academically gifted, aphasia, sensory impairment, or significant mental illness not managed by outpatient monitoring. Adults with TBI and profound memory deficits, i.e. those with amnesia, were also excluded to maximize participant opportunity to encode information during the experimental task, thus increasing the likelihood of observing prospective failures (failure to remember information at the appropriate time) rather than being restricted by retrospective memory failures (an inability to encode information for future use). Suspected amnesia was assessed using the intake interview by participant report of an inability to sign legal documents, recall of injury and post-injury rehabilitation, and return to productivity post-injury. Individuals with mild TBI, or concussion, were also excluded as this subgroups tend to experience a different pattern of recovery (Ruff & Jamora, 2009) and very few individuals continue to experience cognitive deficits in the chronic stage (McCrea, 2008).

Inclusion criteria for the experimental group were as follows: history of moderate to severe closed TBI sustained at age 15 or older, Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) of less than 12, loss of consciousness of greater than 30 minutes, and positive brain imaging. Participants with TBI could self-report a history of brain injury, but medical records were requested to substantiate the injury and provide further descriptive details, such as length of coma, time post onset, GCS scores, and neurological imaging findings. Participants in both groups spoke English as a first language. Healthy controls met the same exclusion requirements, although had not sustained a head injury.

Participants

Participants included 18 adults with history of moderate to severe TBI and 20 age and education matched healthy controls (HC) aged 18 to 65. See Table 1 for detailed demographics of both groups. The two groups were matched by age and education (respectively, M_{TBI} = 47.06, M_{HC} = 43.15; M_{TBI} = 16.06, M_{HC} = 16.60). There were not significant differences between groups by these factors; however, the TBI group contained more males than the evenly balanced control group.

Injury information for each participant with TBI is listed in Table 2. Fifteen adults had severe TBIs, and three had sustained moderate injuries. Time post onset (TPO) shows this to be a chronic group, averaging 190.56 months post onset (15 years; 10 months), although with a range of 18 to 516 months, there was substantial variation in TPO across participants.

Neuropsychological Testing

Standardized neuropsychological testing was conduced as part of the main experiment only to describe the sample and provide comparison to the experimental task.

Table 3 provides a description of assessments used and the domains assessed by each. Table 4 provides scores for each group as well as group comparisons.

Language Screening.

All participants were screened for language impairments using the Western Aphasia Battery Bedside Screening (WAB; Kersetz, 1982) and two stories, "The Baseball Game" and "The Painters," from the Discourse Comprehension Test (Brookshire & Nicholas, 1997). The Bedside WAB uses excerpts from the full battery to screen for deficits in conversational speech, naming, yes/no responses, auditory comprehension, repetition, reading, and writing. During the DCT, stories were presented auditorily and in written form, then the administrator asked a series of eight questions (for each story, resulting in a total possible score of 16) probing for stated and implied details and main ideas. All participants were also provided with written copies of the stories so that the questions targeted complex language comprehension rather than recall. All participants passed the WAB screening and there were no significant differences between groups on the DCT.

Self report questionnaires.

Participants filled out two questionnaires: the Mayo Portland Participation Index (MPAI; Malec, 2004) and the Prospective-Retrospective Memory Questionnaire (PRMQ; Smith, Della Sala, Logie, & Maylor, 2000). The MPAI provides an overview of the level of support individuals report needing to complete everyday tasks. Participants indicate how much difficulty, from none to severe, they have with daily tasks, such as social situations, finances, or transportation. Raw scores are used to calculate T-scores, in which 50 is the mean of reported difficulties for individuals who have experienced a TBI. Scores less than 50 indicate fewer problems. Expected differences emerged between the two groups, so that the group with TBI reported more problems than the controls, but slightly fewer problems than the normative sample of individuals with TBI.

The PRMQ is a measure of metacognitive beliefs related to everyday memory failures. It has been shown to be a reliable measure of everyday memory in adults and has also been demonstrated to measure factors relating to those constructs as well (Crawford et al., 2003). T-scores are generated, with a mean of 50 equaling difficulties reported by a sample of typical adults. Lower scores indicate more problems. Individuals with TBI reported more difficulties on both the prospective and retrospective subscales and the combined total scale.

Standardized measures.

Verbal intelligence.

The Wechsler Test of Adult Reading (WTAR; Wechsler, 2001) was administered to provide an estimate of verbal IQ. During this test, the administrator provides the participant with a written list of 50 words, and asks that the participant pronounce each word aloud. Pronunciation is marked either correct or incorrect to generate a raw score out of a total of 50. Scores are converted to standard scores with a mean of 100. Although there was a statistically significant difference between the groups, both groups performed slightly above average indicating strengths in verbal IQ.

Executive function.

Executive function was assessed with three subtests of the Delis-Kaplan Executive Function System battery (D-KEFS; Delis, Kaplan, & Kramer, 2001), namely Verbal Fluency, Tower Test, and Trail Making. Verbal fluency requires participants to generate as many words as possible during a 60 second time span under three conditions. In the first, letter fluency, participants generate words starting with F, A, and S. In the second, category fluency, participants generate words in the categories of animals and boy's names. In the final condition, switching, participants much switch back and forth between the categories of fruits and furniture. Raw scores are used to derive standard scores. Verbal fluency is a measure of lexical access, speeded processing, rule maintenance, shifting, and monitoring.

For the Tower test, participants must build towers using five disks on three pegs. The discs are graduated in size, so that there are larger and smaller discs. Participants must build pictured towers using the fewest number of moves possible and without placing a larger disc on top of a smaller disc. The test begins with only two discs, but increases in difficulty until all five discs are used. An achievement score is generated by counting the number of moves necessary to complete the towers as well as noting whether the person was able to complete the tower within the given time frame for that item. The Tower test assesses planning, inhibition, and maintaining cognitive set.

The Trail Making test includes five conditions in which participants must visually scan letters and numbers. The primary measure of executive function is Condition Four, Letter and Number Switching, while the others provide training and complementary scores. Condition One assesses visual cancellation by having participants cross out all occurrences of the number three. Condition Two and Three are number and letter sequencing, respectively, in which participants draw lines in progressive order for either numbers or letters. In Condition Four, participants much then switch back and forth between numbers and letters (i.e. “1-A-2-B-3-C” and so on), connecting them with lines as quickly as they can. Condition Five assesses motor speed by having participants trace a line between dots as quickly as possible. Time to completion is used as the raw score. The Speed/Switching contrast then corrects the score for Condition Four to account for motor slowing. Trail Making examines visual scanning and attention, while the switching condition (after motor speed correction score) specifically requires cognitive flexibility.

Raw scores for each of the DKEFS tests are converted to age corrected standard scores that have a mean of 10 and standard deviation of 3. Participants with TBI performed more poorly than healthy controls on several measures of executive function, but there was no difference between groups for Condition One – Letter Fluency on the Verbal fluency subtest, the Tower Test, and the corrected Switching score for the Trail Making Test. The largest group differences emerged on the sequencing and verbal fluency switching tasks.

Working memory.

Three shortened versions of standard working memory tasks were administered in computerized versions using E-Prime. The three tasks – operation, reading, and symmetry span – are administered sequentially and provide a domain-general measure of working memory (Oswald, McAbee, Redick, & Hambrick, 2015). Each provides training with the ongoing task, making true/false judgments about the named construct (e.g. math operations, reading sentences, or the symmetry of images), and in recalling presented items after a delay and interference of the ongoing task. Therefore, these complex span measures assess both storage (retention of presented items), and processing (judgments about the interfering task). The three measures generate a composite span score, indicating the number of items participants can recall. Healthy adults outperformed individuals with TBI on reading and symmetry span, but there was no difference between groups for operation span.

Cognition.

Cognition was assessed using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS; Randolph, 1998). This battery of 10 brief subtests provides scores of immediate and delayed retrospective memory, language, attention, and visuospatial processing. The composite score provides an overview of neuropsychological function. In the immediate and delayed memory tasks, the administrator presents participants with a list of ten unrelated words, a brief story, and a figure to copy. These are presented again at the conclusion of the test for delayed recall.

Language is measured by naming and category fluency. Attention is a composite of digits forward and a coding task in which participants enter numbers corresponding to symbols. Scores for visuospatial processing include the initial figure copy and line orientation. The control group outperformed the group with TBI on all measures with the exception of visuospatial processing, in which there were no differences between the two groups. As expected, there were large differences between the groups on measures of immediate and delayed memory.

Prospective memory.

The Cambridge Test of Prospective Memory (CAMPROMPT; Wilson et al., 2005) was developed from the Rivermead Behavioral Memory Test (RBMT; Wilson, Cockburn, & Baddeley, 1985) to provide a standalone assessment of functional PM. Participants are given a series of pen and paper tasks while also completing three event and three time-based tasks. At the start of the assessment, the experimenter gives the participant a pen and blank piece of paper and states that any strategy may be used to recall tasks. Scores are based on a cueing hierarchy, so that independent recall and task execution receives the maximum score of 6 points, while an administrator prompt that a task was to completed, followed by the participant completing that task earns four points. Up to two prompts are allowed before the administrator provides the task to the participant and no points are earned. Time and event based scores can total up to 18 points, for a total of 36 possible points for this test. Despite being given the opportunity to use a strategy, healthy controls performed significantly better than individuals with

TBI on both subscales and total scores for this assessment. The groups used strategies at a similar rate as well.

Experimental Task

Virtual reality game.

The virtual reality game, *Tying the String*, consists of 10 images with titles representing 10 distinct times during the day (e.g. an unmade bed for waking up, a car backing out of the garage for the drive to work, or a group of people gathered around an office table for an afternoon meeting; see Figure 3 for complete list of daily events and corresponding images). The game progressed through these 10 images in order for two practice "days." Data collection followed during the five consecutive days of a workweek (Monday through Friday), culminating in a birthday party on Friday night. Each scene was presented for 30 seconds before automatically advancing to the next scene. See Figure 4 for a schematic of the game design including practice days and the sequencing of game activities.

During training, participants learned three recurring tasks to be completed every day, then at the beginning of each day, three to five novel tasks were assigned that must be completed on that day. As each task was assigned, participants made immediate JOLs about how likely it was that they would remember to perform the task at the correct time (CUE), and if they would recall what the task was that must be performed at that time (TASK).

During the game, participants moused over the image to find hidden “money” as the ongoing distractor task. The money appeared as gold coins that when clicked generated a pop-up box stating how much money was found, and added it to a running total in the upper right hand corner of the screen. At the end of each day, participants matched the assigned tasks with the correct scenes. The instructions and narrative that played during the scenes assumed a second person voice, immersing the participant in the virtual workweek and providing context for the PM tasks, although no explicit reminders were provided.

On training days, participants listened to a narrative in written and auditory format explaining the busy week ahead. The game explained that the participant would be playing a virtual reality game in which s/he would be working at an advertising agency working on a new project. The participant would also be planning a birthday party for a friend that would occur on Friday night. Some tasks that would have to be completed during the virtual week would be related to work or home life, while others would be related to the birthday party. A screen capture video demonstrated how to play the game and pointed out features of the screen, including how to enter PM items into the game. Participants were then given time to practice entering tasks, finding money, and navigating the game screen.

The game then progressed to the first scene of the first day of training. See Figure 5 for an example screen. The bar at the top of the page stated the day and scene (e.g., “Practice Day One: Wake Up,” or “Monday: Lunch”). A timer displayed the countdown for each screen numerically and visually with a circle shaped like a timer that disappeared in a radial sweep as the 30 seconds for each scene progressed. Finally, the bar at the top contained the participant's "Bank," the ongoing tally of the amount of money found hidden in the image as the distractor task. The image associated with the scene was located on the left and sized 600 x 900 pixels. To complete a task, a query stating "Any tasks to complete?" with radial buttons to indicate "Yes" or "No" located just below was situated in the right portion of the screen. If participants selected "Yes," a text box would appear below for participants to enter the studied task to be completed. Multiple tasks could be entered if necessary. If the participant clicked "No," no box would appear, but the radial button would become dark to indicate that the game recorded this response. A "Save" box at the bottom right could be clicked to submit the response, although responses were also automatically submitted as the 30 seconds for each scene expired and the scene advanced.

The game was programmed in conjunction with a web programmer in PHP and can be played on any standard browser with an internet connection.

Prospective memory task.

Participants were asked to complete three recurring tasks every "day" of the simulated week and twenty novel tasks on specific days of the week (see Table 5 for complete schedule of targets), for a total of 35 PM item attempts (15 recurring, 20 novel) across the 50 scenes (10 scenes on 5 days). All tasks were presented in both written and auditory form via a voiceover. Recurring items were presented during day one of training, with reminders to perform those three tasks every day for the rest of the week occurring at the beginning of the week. However, these items were not presented a second time for re-study. The second day of training included novel items not counted toward data collection to practice learning new items each day, continuing to enter the recurring tasks, and navigating the game interface. The narrative reminded participants to continue performing the tasks learned during day one of training, and provided cueing to enter in all studied items, recurring and novel, during the corresponding scenes. All PM items were self-paced, so that the participant chose to study each item as long as s/he liked. The game presented the tasks alone on a screen for studying, followed by the immediate JOL series of screens (see Figure 6).

After the two days of training were completed, data collection commenced on "Monday." The 20 novel items to be completed each day were presented at the beginning of the day on which that task was to be performed. Three to five items novel items were presented each day.

***Ongoing distractor task*.**

For the ongoing distractor task, participants scanned the images with the mouse looking for hidden coins indicating money that can be collected. As participants moused over these locations, a gold coin appeared. When participants clicked on these locations, money was added to a static box present at the top right of every screen that gave a running total of money collected, referred to in the game as "The Bank."

Between each day, participants saw the top five bank totals on a leaderboard. This was provided as motivation for participants to continue looking for money in subsequent screens to "climb the daily leaderboard."

Judgment of learning predictions (JOLs).

Participants made two immediate JOLs after each target was introduced. The first JOL assessed the prospective component (CUE) by asking how likely it was that the person would become aware that something has to be done upon encountering the cue. The second assessed the retrospective component (TASK) similarly by asking how likely it was that the person would recall the action to be completed. A total of 46 PM JOLs were collected per participant, half addressing the cue component, and half addressing the task (3 recurring tasks, 20 novel tasks). However, only the novel targets were included in the analysis because the first three recurring items were used as training. Furthermore, participants had multiple opportunities to correctly perform the recurring items, so that judgments about recall did not align with a particular recall attempt.

Immediate JOL screens occurred immediately after a PM item was introduced. For the CUE, participants saw and heard the question: "How likely is it that you will remember to perform this task *when* the time comes?" and for the TASK: "How likely is it that you will remember *what* you need to do?" Participants used a slider bar below to indicate the percentage of likelihood they assigned to that JOL and probable recall (see Figure 6 for screenshot of JOL). The slider bar was labeled with anchors at either end stating "0% definitely will not remember," and ("100% definitely will remember"). As participants moved the slider bar, a numerical value associated with that place on the line (from 0 to 100) appeared in the center of the line. Each slider bar was initially set to 50%.

After two randomly selected scenes for each day, a JOL screen appeared for participants to make an immediate JOL about the ongoing distractor task. Participants were asked, “How likely is it that you can remember *where* you found the money hidden in this scene?” The screen and slider bar were otherwise identical to the CUE and TASK JOL screens.

Recall task.

At the end of each “day,” participants encountered a recall screen. Each scene appeared as a thumbnail in a list to the left. On the right side of the screen were listed the day’s novel tasks, one or two recurring tasks, and two to four foils. Participants selected each scene from the left, and then clicked on the task to the right to match the scenes to the tasks (see Figure 7). Not all tasks or scenes were used every day. This recognition task was used to determine if individuals were adequately encoding the PM items at the beginning of the game and each day.

Finally, the scenes in which predictions were made about the distractor task (two for each day) appeared and participants clicked the places in the scene in which money had been found. The day then concluded and the leaderboard of the top five bank totals appeared.

Procedure

Participants read the consent form and discussed any questions that they had with the primary investigator. Individuals with TBI also completed a HIPAA form so that medical records could be requested to provide details of the brain injury. Either the PI or research assistants (RAs, under the supervision of the PI) administered the testing. Participants first completed the WAB Screener and two stories from the DCT to screen for language impairments. Because all participants passed this screening, no one was excluded at this point in the study.

Participants were offered a break, then moved to the computer to play the game *Tying the String.* All participants completed the game using Google Chrome on a PC with an external mouse and keyboard. A Sennheiser headset was used for audio. Research assistants familiarized participants with the computer and navigation of the equipment for the game. Once the game began, the PI or RA remained in the room, but allowed the individual to complete the game independently. Following the game, participants had the first of two 10-minute mandatory breaks. Neuropsychological assessment followed as outlined in Table 3. The second mandatory break occurred between the working memory spans and the RBANS. After the final assessment, participants were debriefed and compensated at the flat rate of $30.

Analyses

This experiment relied on quantitative analysis. Independent and dependent variables are summarized below.

- Independent variables
    - Between groups: Group – HC and TBI
    - Within groups: PM component – CUE or TASK
- Dependent Variables, nested within PM component
    - JOLs
    - Recall Performance
        - Free recall
        - Matching
        - Recognition
    - Recurrence, nested within Recall Performance
        - Novel
        - Recurring

See Figure 8 for a schematic of IVs and DVs.

JOLs.

JOLs were measured as the mean percentage rating assigned in each PM component by participants. Because participants made JOLs about recurring tasks during training and had 15 opportunities (3 tasks across 5 days) to perform these tasks, it was unclear if participants yet understood the task or about which performance ratings were made. Therefore these recurring JOL ratings were removed from the analysis and JOLs were considered with performance on the novel tasks only.

Recall Accuracy.

Dependent variables were JOL recall accuracy in each of the two PM components – CUE and TASK. CUE accuracy was measured as percent of correct "yes" responses during the game that a task had to be completed, or correct rejections that a task was not occurring. TASK accuracy was measured three ways: free recall of tasks correctly entered into the text box during the game, matching accuracy at the end of each day measured as correct scenes paired to corresponding tasks, and recognition accuracy measured as percent of tasks correctly selected during end of day matching (i.e., tasks did not need to align with scenes, but were counted correct if selected from a list). PM tasks were also divided into two categories of recurrence, recurring and novel tasks. Recurring tasks included the 3 daily recurring tasks during the game (3 tasks on each of 5 days, equaling 15 total opportunities) and novel tasks included the 20 novel tasks about which participants made JOLs across the 5 days of the game.

Free recall data was used for both absolute and relative measures of metamemory accuracy. This accuracy measure allowed for examination of both the CUE and TASK components. Matching and recognition accuracy measures were instead used to validate the task and that participants were learning tasks, so that performance failure could be attributed to PM failures rather than only retrospective memory (poor encoding).

Metamemory Accuracy.

Absolute difference analyses subtracted mean recall performance on free recall novel tasks from mean predicted JOLs. A follow-up analysis compared JOLs with performance on the matching accuracy for the TASK only. Gamma correlations were calculated by comparing item-by-item performance to JOLs to determine if participants were increasing or decreasing judgments in relation to actual success or failure at specific tasks.

To examine JOL ratings over time, each item was averaged across participants within a group to develop a series of 20 composite scores. These rating scores were then entered into a linear regression model to examine how ratings may have shifted across the course of the game. Models were generated for both components, and then the data was divided into the two groups to determine if the healthy controls and people with TBI were adjusting JOLs and if the groups did so at different rates. Predictors for the complete models were item number and group. For the group models, item number was the predictor.

Ongoing Task Performance and JOLs.

Performance on the ongoing task was also measured to ensure that participants were engaged by the distractor task rather than focusing solely on the PM items to be completed. Independent sample t-tests compared performance between groups as total amount of money found. Mean distractor JOLs (e.g. judgment of the likelihood of remembering where money was found in a given image) were also calculated and compared between groups. These “WHERE” JOLs were then compared to JOLs on the target PM tasks to determine if groups made similar judgments across all tasks or were sensitive to the considerable differences between the visual memory recall task and the PM tasks.

Relationship to Standardized Measures.

Correlation matrices were examined to determine if or to what extent demographic, injury, or neuropsychological factors correlated with JOL ratings and performance on PM tasks. Expected relationships between measures of delayed memory and standardized PM tests would also provide validity to the design of the experimental task. Matrices were generated for the complete group in each component for JOL and free recall performance of novel tasks, then the data was divided into the two groups to determine if predictors were similar for individuals with and without brain injury. Finally, items that significantly correlated with performance or JOL ratings on the CUE and TASK were entered into a series of stepwise regressions to develop models descriptive of those tasks.

Results

Quantitative results are summarized below. The purpose of this experiment was to determine if adults with TBI differentially estimate performance on tasks based on component, and if they do so in a manner similar to healthy adults. To do so, this study matched a control group of healthy adults by age, education, and gender to a group of adults who had sustained traumatic brain injuries as adults. This experiment also included neuropsychological assessment to further characterize the experimental groups and to validate the experimental task through correlations with constructs relating to PM performance and metamemory accuracy.

The first research question addressed whether adults with and without TBI differentially predict performance on the PM tasks based on component – CUE or TASK. For this question, mean JOL for each participant was calculated in the two components for the novel tasks only, then compared within group by component, and between groups to examine differences between those with and without TBI. The second research question examined performance, anticipating that healthy adults would perform the PM tasks with greater accuracy than the group with TBI. Mean performance was considered by component, recurrence, and type of recall. The third research question addressed change in JOL ratings over time, anticipating both groups would adjust ratings downward in a similar fashion. The final research question served to verify the experimental task and characterize PM JOL ratings and performance through an examination of correlations with demographic, injury, and neuropsychological data followed by model building using stepwise regression.

JOLs

In regards to predictions of performance made with Judgments of Learning, a mixed design factorial ANOVA with group as the between subjects and component as the within subjects revealed a main effect of group [$F(1,36) = 5.07$, $p = .03$], so that the healthy controls gave overall higher ratings of the likelihood of recall than the group with TBI (see Table 6 and Figure 9 for a summary of ratings). Within groups, there was a main effect of component [$F(1,36) = 5.69$, $p = .02$]. Participants gave higher JOL ratings to the CUE over the TASK component, meaning participants believed they more likely to remember when to perform a task than what that task might be. The interaction between group and component [$F(1,36) = 1.93$, $p = .17$] was not significant (see Table 7 for JOL ANOVA summary).

PM Recall Accuracy

To determine if the healthy controls outperformed the group with TBI at performing the cue-task sequences, a series of mixed design factorial ANOVAs was conducted. Tasks were considered by recurrence (recurring or novel), and three types of recall – free recall, matching, or recognition. Only free recall included measures the two PM components: CUE and TASK. To consider the most basic measure of accuracy that can be compared to JOLs in subsequent analyses, a 2 x 2 mixed factorial ANOVA examined group as the between subjects factor and component, CUE or TASK accuracy at free recall during the game, as the within subjects factor (see Table 8 and Figure 10 for a summary of free recall performance). There was a significant main effect for group and component, as well as an interaction (see Table 9 for ANOVA summary). Healthy controls outperformed the group with TBI in both the CUE and TASK components [$F(1,36) = 49.99$, $p < .001$]. There was also a main effect of component so that participants were more accurate at the CUE than the TASK [$F(1,36) = 34.98$, $p < .001$]. However, the main effect of component was driven by the interaction effect, so that there was no difference between the healthy controls in the two components, whereas the group with TBI performed more poorly on the TASK than the CUE [$F(1,36) = 29.73$, $p < .001$]. Participants with TBI had more difficulty recalling tasks than alerting to the cue when a task needed to be completed. In other words, the adults with TBI had much more difficulty remembering *what* they needed to do, rather than remembering *when* they needed to do it.

Accuracy at recalling novel tasks as opposed to recurring tasks between groups was also considered, with the expectation that participants in both groups would be more accurate at the recurring tasks. Participants received multiple study opportunities as well as recall attempts on the recurring tasks, so that both groups should perform with greater accuracy on those tasks if the instructions were clear and study attempts adequate. A 2 x 2 x 2 mixed design ANOVA with group as the between factor and Component (CUE or TASK) and recurrence (recurring or novel) as the within comparisons (see Tables 10 and 11 for performance and ANOVA summaries). All comparisons were significant, so that there was a main effect of group, PM component, and recurrence. Healthy controls outperformed the group with TBI across components and recurrence, and participants were more accurate at the CUE component and when items were recurring rather than novel (see Figure 11). However, significant interactions between component and group [$F(1,36) = 28.21$, $p < .001$] as well as recurrence and group [$F(1,36) = 5.31$, $p = .03$] showed the individuals with TBI had greater reductions in performance from the CUE to TASK and from recurring to novel tasks than healthy adults. The three-way interaction of component by recurrence by group [$F(1,36) = 8.05$, $p = .007$] described the group with TBI exhibiting lower performance than healthy controls that deteriorated when moving from the CUE to the TASK and from recurring to novel tasks. Performance was lowest as these three factors combined, whereas performance of the group of healthy adults was relatively stable across these measures in comparison.

Finally, a 2 x 3 x 2 mixed design factorial ANOVA for TASK recall only was conducted with group (HC and TBI) as the between factor and type of recall (free recall, matching, and recognition) and recurrence (recurring and novel) as within subjects factors. Table 12 summarizes performance across the three measures by group and recurrence. All main effects were significant, so that the healthy controls outperformed the adults with TBI across all recall measures and recurrence [$F(1,36) = 39.09$, $p < .001$], and participants were more accurate at recalling recurring rather than novel tasks [$F(1,36) = 43.56$, $p < .001$]. In regards to type of recall, post hoc comparisons with Bonferroni corrections revealed significant differences across all three types, so that participants recalled the most items on the recognition task ($M = 87.69$), fewer on the matching task ($M = 73.23$), and the least number of items on free recall ($M = 64.35$). A two-way type by group interaction qualified this as being driven by the TBI group [$F(2,60.92) = 48.35$, $p <$

.001]. A similar two-way interaction between recurrence and group also characterized differences in performance between recurring and novel tasks as occurring in the TBI group ([$F(1,36) = 13.31$, $p < .001$]. Type by recurrence [$F(1.84,66.36) = 2.54$, $p = .09$] and the three way interaction of type by recurrence by group [$F(1.84,66.36) = .47$, $p = .61$] were not significant (see Table 13 for ANOVA summary, Figure 12 for recurring tasks and Figure 13 for novel task means). That participants with TBI were able to recognize PM tasks indicates that encoding was happening, and failures to recall items during the game were likely due to PM failures. This is further confirmed by examining performance on the recurring measures. Despite recognizing recurring tasks more than 90% of trials, adults with TBI continued to struggle to recall these tasks at the correct time.

Absolute Metamemory Accuracy

Absolute difference scores were calculated by subtracting mean free recall performance on novel tasks from mean JOL ratings for each component (see Table 14, Figure 14). Negative scores indicate underconfidence, meaning that participants recalled more items than had been predicted with JOLs. Positive scores indicate overconfidence, meaning fewer items than predicted were recalled. ANOVA results revealed all effects to be significant at the alpha < .05 level (see Table 15). There was a main effect of group, so that the group with TBI was overconfident, while the healthy controls were underconfident [$F(1,36) = 16.98$, $p < .001$]. The main effect of component showed participants to be less confident about the CUE than the TASK [$F(1,36) = 20.44$, $p <$

.001]. However, the interaction showed participants with TBI to be much more overconfident about the TASK than the CUE [$F(1,36) = 13.75$, $p < .001$].

Measures of mean recall accuracy are plotted against JOLs for the CUE component in Figure 15, and for the TASK in Figure 16. In both graphs, the diagonal line indicates perfect calibration, or that the mean JOL rating matches mean recall performance. Data plotted above this diagonal line indicates overconfidence (that recall is poorer than predicted), while data below the line indicates underconfidence (that recall is greater than predicted). Visual inspection of the data in this manner coincides with the above quantitative analysis. Healthy controls tend toward underconfidence in both graphs, while adults with TBI scatter to both sides of the calibration line for the CUE, but show a greater move toward overconfidence for the TASK. Only one individual who performed at floor for the TASK gave an average JOL rating of less than 50%. The other six individuals all gave ratings greater than 50% despite performing with 0% recall accuracy.

Relative Metamemory Accuracy

Gamma scores were calculated for each participant by comparing performance on each item with its corresponding prediction in each component (see Table 16, Figure 17). Scores in the correlation matrix were marked as correct if participants had assigned higher ratings to correct items and lower rating to incorrect items. ANOVA results revealed no main effect of group [$F(1,25) = 0.68$, $p = .42$] or component [$F(1,25) = 0.74$, $p = .40$]. There was an interaction effect [$F(1,25) = 4.16$, $p = .05$] showing the group with

TBI to be more accurate at item by item predictions than the healthy controls in the CUE component only. Table 17 includes the ANOVA summary.

Regression Models Over Time

JOLs.

Linear regression was carried out to determine the effect of time, measured as increasing item number or progress through the experimental task, on JOL ratings in each component and group. In the CUE component, the model for the entire group was significant [F (2,37) = 63.27, $p < .001$] with an adjusted R^2 indicating that 72.6% of the variance in the model is explained by the variance in group and item number (see Table 18). When examining the two groups independently, the HC group model was not significant, indicating no change in ratings as item number increased [F (1,18) = 3.62, $p < .07$, $R^2 = .12$], although the TBI group model was significant [F (1,18) = 54.18, $p < .001$, $R^2 = .74$], so that the group with TBI reduced JOL ratings as the game progressed (see Figure 18). Comparison of beta coefficients reveal that the HC and TBI lines also differ significantly from one another, so that the group with TBI reduced judgments at a larger rate than healthy controls; t (36) = 2.67, $p = .01$.

In the TASK component, the model for the entire group was again significant [F (2,37) = 77.43, $p < .001$, $R^2 = .80$], as were individual models for the group of healthy controls [F (1,18) = 5.21, $p < .04$, $R^2 = .18$] and TBI [F (1,18) = 38.39, $p < .001$, $R^2 = .66$]. Both groups reduced their JOLs as they played the game and had experience with the task (see Table 19). However, in this component, there was no difference between the two groups in terms of the rate of decrease; t (36) = 1.63, p = .11 (see Figure 19).

Novel PM recall accuracy.

Similar to the analysis performed on the JOL ratings over time, recall accuracy for each item was averaged for the two groups. Linear regression of novel CUE recall accuracy revealed the large difference between groups [F (2,37) = 14.27, p < .001] as indicated by the significant difference by group (β = -24.35) but not item number (β = -0.11). Examining CUE performance over time for the two groups separately showed no effect of time on accuracy (see Table 20). Although Figure 20 shows the HC group regression line increasing and the TBI group decreasing, neither of these lines differed from zero, or from each other, t (36) = 1.23, p = .23.

Similarly, for novel TASK accuracy, the combined model [F (2,37) = 81.34, p < .001] revealed large differences by group (β = -56.44) but not item (β = -0.90), and models of the two groups revealed no effect of time on accuracy, or difference between the two groups; t (36) = 0.91, p = .37 (see Table 21 and Figure 21). These results indicate stable performance across groups at alerting to novel PM CUEs and recalling novel PM TASKs as the game progressed.

Recurring PM recall accuracy.

Participants completed three recurring tasks each of the five days of the game. To consider accuracy at these recurring items across time, performance accuracy was averaged for each of the 15 data points in the two groups. There was a large difference between the two groups for accuracy at alerting to the CUE [F (2, 27) = 6.09, p = .007], but no effect of time when the two groups were considered in the same model (see Table 22). However, when comparing the two groups, the group with TBI did show decreasing performance as the game progressed (β = -1.44, p = .03), while the HC group did not (see Figure 22). Although there was a trend toward the TBI group decreasing their performance at a rate greater than controls, the two lines did not significantly differ; t (26) = 1.83, p = .08.

For recurring TASKs, the combined model again revealed large differences in accuracy between the two groups but no difference by item number [F (2, 27) = 9.78, p = .001]. When considered separately, both the HC (β = -.80, p = .02) and TBI (β = -2.20, p = .02) groups performed more poorly as the game progressed (see Table 23 and Figure 23). The rate at which performance decreased did not differ across the two groups; t (26) = 1.64, p = .11.

Ongoing Task Performance and Ratings

Independent sample t-tests assuming unequal variances compared total money found across groups (see Table 24). Both groups engaged in the task, but as expected, the group of healthy controls found significantly more money that the TBI group; t (26.83) = 5.76, p < .001. Participant WHERE JOL ratings of the likelihood of recalling money locations after a delay were not significantly different between groups; t (35) = -1.69, p = .10, so that both groups gave similar ratings. However, the pattern of response was different than JOLs about the PM tasks, so that participants with TBI tended to give higher ratings than HC, whereas the TBI group gave lower ratings on JOLs for both the CUE and TASK compared to the group of HC (see Figure 24).

Correlation Matrices

Correlation matrices for the two groups were generated separately to examine the relationship between JOLs and recall performance on the experimental task and basic demographics. Time post onset (TPO) was also considered for the group with TBI. As shown in Table 25, age correlated with CUE JOL for the HC group only. No other experimental variables correlated with participant demographics. Healthy controls' JOLs for the CUE and TASK were highly correlated. Participants in this group tended to give similar ratings across the two JOLs for the PM tasks. In contrast, WHERE JOLs that probed participants about recall of the distractor task (money finding) were not correlated with these judgments, suggesting that the HC group was considering these judgments differently than the PM recall. Comparing judgments to recall, CUE JOLs correlated with CUE recall performance, although this was not the case for TASK JOLs and recall.

When comparing experimental task performance with neuropsychological descriptors (see Table 26), both PM JOLs correlated with the PRMQ questionnaire of metamemory beliefs, so that participant judgments correlated with self-reported pre-existing beliefs about retrospective and PM abilities. The TASK JOL also correlated with strategy use on the CAMPROMPT standardized test of PM, indicating a relationship between metamemory monitoring and attempts to manage memory demands. Although participants did not have access to strategies during the experimental task, both CUE and TASK recall were also positively correlated with CAMPROMPT strategy use.

For adults with TBI, TPO did not correlate with any dependent variables (see Table 27), although it was negatively correlated with performance on the CAMPROMPT. The two PM JOLs, CUE and TASK, as well as the WHERE JOLs were highly correlated, so that participants gave similar ratings across all three judgments. CUE JOLs were also related to category fluency scores from the DKEFS. Both PM JOLs correlated positively with immediate memory measures on the RBANS. Recall performance accuracy across the two PM components was also related, so that recall on the TASK was associated with CUE performance. RBANS attention scores and total scores on the CAMPROMPT were also correlated with CUE performance, while TASK performance was associated with event and total scores on the CAMPROMPT, providing preliminary evidence of the validity of the experimental task.

Regression Models of JOLs and Performance on Experimental Task

Backward stepwise regression was used to examine the relative influence of neuropsychological factors to JOLs and recall performance on the PM task. Because correlation matrices indicated differing relationships of variables to the dependent variables across the two groups, regression models were created for each group and each of the primary dependent variables (e.g CUE and TASK JOLs, CUE and TASK recall accuracy for the HC and TBI groups). Significant correlates from the exploratory matrices were selected as predictors and were removed stepwise by *t*-value, so that a non-significant predictor with the *t*-value closest to zero was removed in each step until all remaining predictors continued to be below an alpha of .05. In cases of possible collinearity, such as CAMPROMPT Time and Total scores or MPAI and TPO, the predictor with the higher correlation was retained for modeling.

Healthy control JOLs.

Regression tables for healthy controls are located in Tables 28 and 29. In Table 28, only the PRMQ total remained a significant predictor of CUE JOL (β = .50, R^2 = .25, F = 6.08, p = .024). Immediate memory, attention, and performance on the standardized test of PM did not explain variance in these judgments beyond self-reported beliefs on the PRMQ. The PRMQ was also a significant predictor of TASK JOL (β = .63, p = .001), in addition to working memory span (β = .42, p = .014; see Table 29). As with the CUE JOL, immediate memory, attention, and CAMPROMPT scores did not add to the variance of the model (R^2 = .61, F = 13.06, p < .001). The contribution of metamemory beliefs as measured by the PRMQ to both JOLs suggests that healthy controls were using pre-existing judgments about recall ability rather than basing judgments on intrinsic features of the PM items. The addition of working memory to the TASK JOL may indicate that healthy controls were also mentally rehearsing studied items for later recall.

TBI JOLs.

For the adults with TBI, only immediate memory as measured by the RBANS significantly contributed to the variance in CUE JOLs (β = .54, R^2 = .29, F = 6.44, p =

.02). Working memory, life participation as measured by the MPAI, verbal category fluency, CAMPROMPT and PRMQ were removed from the model as non-significant predictors (see Table 30). TASK JOL variance was also explained by immediate memory alone (β = .59, R^2 = .35, F = 8.52, p = .01), but not by attention or the predictors listed above (see Table 31). That both JOLs were predicted by scores of immediate memory suggests that the group with TBI was performing a covert retrieval to determine if the information studied continued to be recalled once it was no longer present.

Healthy control recall accuracy.

Modeling for CUE recall found that scores on the time-based tasks of the CAMPROMPT (β = .55, R^2 = .30, F = 7.84, p = .012) were the only significant predictor of healthy controls' performance at recognizing when a task needed to be completed during the experimental task (see Table 32). Although the experimental PM task was event-based, recognizing the CUE does rely on recognizing an external cue at when it occurs. During the game, scenes advanced every 30 seconds so that PM cues occurred at regularly timed intervals. This regularity in the occurrence of events may have led to time-based scores being more closely related to CUE accuracy than the event-based measure. Strategy use on the CAMPROMPT (β = .63, R^2 = .39, F = 11.58, p = .003), but not event-based scores on that test, PRMQ, or immediate memory measures, predicted TASK recall for this group (see Table 33). Participants did not use strategies during the experimental task, so that strategy use may be a proxy for conscientiousness in completing PM tasks.

TBI recall accuracy.

Variance in CUE recall performance for adults with TBI was accounted for measures of attention (β = .59, R^2 = .35, F = 8.47, p = .01). Higher scores from the RBANS attention subscale were associated with higher accuracy at recognizing when a PM task needed to be performed. Immediate memory, event-based CAMPROMPT scores, and verbal letter fluency from the DKEFS did not explain additional variance in performance at CUE recall (see Table 34). For TASK recall, both immediate memory (β = .48, p = .02) and CAMPROMPT event-based memory scores (β = .43, p = .03) contributed to variance in performance accuracy (R^2 = .56, F = 9.50, p = .002). Because the experimental task was event-based, the contribution of the CAMPROMPT event subscale adds validity to the current task for the experimental group. Immediate memory as a predictor suggests the role of retrospective memory in encoding items to be remembered at a later time. Attention and category fluency were removed during modeling as non-significant predictors (see Table 35).

Discussion

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 daycare, and social commitments such as meeting for dinner or remembering special events like birthday cards. Some PM tasks are critical, such as adhering to medication schedules, so that PM is a key predictor of independence in pharmacologically dependent populations such as HIV positive adults (Woods et al., 2008). Because individuals with TBI frequently require pharmacological management of seizure or mental health disorders, the management of PM disorders is an important avenue of inquiry to support independent living in this population. The breadth of PM applications leads clinicians to frequently target PM during intervention, particularly if an individual with TBI has a goal discharge disposition that includes independence.

Although previous research has established the ubiquity of impairments to PM after TBI, less research has addressed the effectiveness of intervention approaches or packages (Evans, Wilson, Needham, & Brentnall, 2003; Shum, Fleming, Gill, Gullo, & Strong, 2011). In recent years, the majority of intervention work has examined training in the use of external aids, particularly high-tech devices with automatic alerts (Kim, Burke, Dowds, Boone, & Park, 2000; Lemoncello, Sohlberg, Fickas, & Prideaux, 2011; LoPresti, Bodine, & Lewis, 2011; Mioni, McClintock, & Stablum, 2014; Sohlberg et al., 2007). However, generalization and maintenance continues to be rarely reported, so that it is unclear how such training relates to real-world use. Extensive research has demonstrated that it takes time after a TBI for individuals to adapt to cognitive changes and accurately monitor memory ability (O'Keefe, Dockree, Moloney, Carton, & Robertson, 2007). Limited literature has explored metamemory monitoring and beliefs about PM in individuals with PM. With that in mind, the current study sought to expand this avenue of research by developing a tool to assess metamemory for PM and testing it with a group of adults with and without TBI by addressing the research aims discussed below.

The current study investigated four research aims related to how adults with and without TBI think about their memory and how metamemory monitoring and beliefs relate to performance at tasks of PM. Overall findings showed that adults with TBI were less confident about the likelihood of future recall than healthy controls, but that this decreased confidence was not enough to account for poor performance at recalling tasks to be performed. Participant JOLs and recall accuracy produced different models across the two groups, so that individuals with TBI were using different processes to consider and implement PM tasks than non-injured, healthy controls.

Tying the String, a new tool to assess metamemory for prospective memory in adult populations was developed for the current study as an online game so that it could be shared easily with other researchers in a format familiar to adults who use the internet and standard internet browsers. The game was designed based on two existing tools. Knight et al. (2005) designed a PM video task so that participants could view a journey unfolding from a first-person perspective. PM targets were introduced and then embedded in the video environment, creating a laboratory setting that approximated the distractions of daily life in assessing PM performance. However, there were multiple possible targets for PM task completion, so that scoring was laborious. The ecological validity of the task benefited from being open-ended, but better experimental control could be achieved if the task recall windows were constrained for comparison across participants. Rendell and Henry (2009) developed *Virtual Week* as a tool to assess PM in a computer game setting. Participants roll virtual dice and move around the board. Each square represents 15 minutes in time, and PM tasks are to be completed as certain squares are reached. The game meets the goal of being adequately engaging so that attentional focus must shift between the game and PM tasks, but the game is self-paced and past use with individuals with TBI has resulted in extended testing times for limited targets. Mioni et al. (2013) tested a group of 18 adults with TBI and a comparison group using a brief version of *Virtual Week,* with only 3 of 7 virtual "days" completed. This testing took 70 minutes to complete on average for individuals with TBI resulting in 12 novel event targets. The addition of two judgments for each of these tasks, as well as judgments for the ongoing distractor task would have made the too lengthy and risked fatigue in both groups.

Therefore, the current game sought to combine features of each of these by creating an immersive virtual experience, but with specific PM targets and an engaging, but unrelated distractor task. During initial piloting (see Appendix A), participants in experiment one completed the game in an average of 73 minutes. Although greater than the initial target, the administration is consistent with that of *Virtual Week* but allows for JOLs and 20 novel targets across 5 virtual days. The initial target completion time had been 40 minutes, but the increase was deemed acceptable for a few reasons. First, the time for each scene to elapse was raised from 25 to 30 seconds, allowing additional time for participants to respond to PM tasks and perform the distractor money search task. Second, initial piloting resulted in participants reporting confusion as to whether or not items studied during practice days were novel or recurring tasks (see Appendix A for details of the pilot study). Therefore, an additional practice day was added so that participants first learned the three recurring tasks, then were introduced to novel items on the second practice day. This allowed participants to continue practicing the recurring tasks with cueing on day two, and to practice studying novel tasks, making JOLs about those tasks, and performing those in conjunction with the repeated tasks from practice day one.

Lastly, administration time increased because some components of the game are self-paced. The introduction to the game, matching recall, and recall of money are not timed. Some participants took longer to proceed through these tasks and others chose to briefly rest before continuing the game. User time on each page is logged, and revealed some players taking more time than others to proceed through these screens. This was deemed beneficial, so that individuals with TBI could pace themselves during these sections of the game if necessary.

Qualitatively, all participants reported being engaged with the game and interested in both recalling the tasks and finding money. Computerized testing is gaining popularity for its ease of administration and scoring, but from a user standpoint, research is revealing that individuals often prefer this format as well (Hansen, Haferstrom, Brunner, Lehn, & Håberg, 2015). A virtual environment makes success or failure at tasks neutral, so that participants being tested do not feel judged by the test administrator (Collerton et al., 2007). Virtual reality environments can also bridge the gap between controlled settings for research and complex, distracting environments in which to embed PM tasks (Banville & Nolin, 2012). Although qualitative responses were not collected for the main experiment, participants reported enjoyment of the game, even as they also stated that it was difficult. All participants in both the pilot and main experiment completed the game without prompting.

Research Aim 1: **Determine if adults with TBI make similar predictions to matched healthy controls on the prospective tasks.**

Analyses of results of the main experiment began with an examination of participant JOL ratings across the two components of the PM items: CUE and TASK. Participants with TBI gave lower ratings than healthy controls, indicating reduced confidence in the ability to recognize when to perform PM tasks, and recall of what those tasks might be. Both groups were slightly more confident about recall in the CUE over TASK, meaning both groups thought it was a little more likely that the time when a task needed to be performed would be easier to recall 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 TASK in a group of healthy young adults, but overall levels of judgment were commensurate with those observed here (respectively, M = 65, 68).

The current study differed from the Schnitzspahn et al. (2011) study in that participants made JOLs at the beginning of each of the five virtual days rather than making all judgments before PM recall began. Participants in the current study had the opportunity to observe performance and adjust judgments on subsequent trials, and linear regression of JOLs over time revealed TASK JOLs declining significantly as the game progressed for both groups, but only the group with TBI reduced JOLs on the CUE (see research aim 4 for complete discussion of JOL adjustments). Experience with the game may explain differences between the two JOLs, so that healthy controls maintained initial confidence in remembering when to perform a task, but became less confident about remembering what the task was. This change over time is aggregated in the mean levels of performance for the ANOVA comparison, so that the main effect of component with lower confidence in TASK recall is likely driven by later occurring items.

That there was a main effect of group revealing individuals with TBI to be less confident about 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 TPO of 9.48 years, while the TBI group in the current study had a mean of 15.88 years post onset. All participants in the current study had also completed some cognitive rehabilitation post injury. Experience living with cognitive changes after TBI has been shown to be related to increased accuracy at metamemory tasks (Hart, Seignourel, & Sherer, 2007; Prigatano, 2005), although TPO did not correlate with JOLs on the experimental task.

Despite the fact that participants with TBI made JOLs in a pattern similar to healthy controls, the TBI group departed strikingly from the healthy controls when making judgments about the ongoing distractor task (e.g. WHERE JOLs). This task required participants to make judgments about the likelihood of recalling where money was found in two randomly selected scenes each virtual day. Although recall requirements of this task differ by visual versus verbal domains, this task is made most difficult by the sequencing of the task. Whereas for the PM JOLs participants study self-paced items with the knowledge that these are to be encoded for future recall, for the WHERE JOLs participants do not know which scenes will be selected for JOLs and recall until after the scene advances. By the time participants make judgments about the likelihood of future recall, there is 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 in previous days in the same scene.

Healthy controls reduced JOLs immediately in response to the increasing demands of the task, assigning a mean rating of 34.35 to the first WHERE JOL, in contrast to mean JOL ratings of 77.65 and 79.84 for the first pair of PM JOLs. The TBI group was sensitive to the greater difficulty of the distractor recall task, but was more conservative in reducing JOLs. First item mean WHERE JOLS for the TBI group was 42.06, compared to initial PM JOLs of 68.07 for the CUE and 64.33 for the TASK. This rating also shows an inverse pattern from the PM JOLs, so that the group with TBI expressed greater confidence in recall than the controls. The difference in reducing JOLs may reflect intact metamemory processing in healthy adults, while adults with TBI may require additional cycles of performance observation before shifting judgments to more closely approximate recall.

Visual metamemory research has frequently used JOLs to predict the likelihood of future recognition of presented items, such as novel versus studied faces (e.g., Sommer, Heinz, Leuthold, Matt, & Schweinberger, 1995). Busey, Tunnicliff, Loftus, & Loftus (2000) describe 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 in discounted. 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; 2001).

Recall of the distractor in the current study required participants to freely select where items were found in images by clicking with the mouse. This presents a more challenging task than recognizing same/different comparisons, but the literature on visual metamemory supports similar processes in considering the contents of memory and likelihood of future recall. 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. 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. Participants with TBI could also be less flexible in making metamemory judgments, so that repeated exposure and explicit feedback is 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 in a relative, rather than absolute standpoint, so that the reduction in judgments to the WHERE JOL revealed an acknowledgement 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 healthy controls. In contrast, healthy controls 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.

In response to research aim two, participants with TBI make similar patterns of predictions to healthy controls across the CUE and TASK components of PM, but with an overall reduction in JOLs that reflects decreased confidence in the probability of recall. Both groups were slightly more confident about CUE than TASK recall. However, adults with TBI make similar predictions to healthy controls about visual memory recall. Although not statistically significant, the groups exhibit a reversed pattern of JOLs so that TBI ratings are higher than those of the HC group.

Research Aim 2: **To determine if participants with TBI perform similarly to matched healthy controls on the prospective memory tasks.**

As hypothesized, participants with TBI performed more poorly at all PM tasks. Recall accuracy was greater for recognizing *when* a task was to be performed than recalling *what* the task to be performed was. Adults with TBI recognized 63.03% of PM cues, but recalled only 26.11% of the total tasks. 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 healthy controls was stable across the PM components. Controls recognized 89.25% of cues and performed 87.75% of tasks. This group could largely rely on recalling an action if able to recognize and alert to the cue.

All participants also completed a matching task at the end of each day to assess if participants were encoding PM tasks into retrospective memory. The matching task required participants to select the scene from the left hand side of the screen, and then select the corresponding task to be completed from the right. Given this support, participants with TBI were able to increase accuracy at recalling the task, from 26.11% for free recall to 39.17% of matched items (see Figure 13). However, the matching task was not a recognition task in that participants needed to correctly align two items rather than alert to studied items and reject unstudied items. Participants could recognize scenes and tasks, but could not use cues from one to correctly select the other. Because of this, a third measure examined if participants were able to select the correct tasks, if not necessarily match those to scenes. The TBI group was able to recognize the PM tasks with 66.39% accuracy, so that the majority of PM items were identified. The remaining items missed could have been poorly encoded, forgotten over time, or missed due to interference. Participants with TBI were particularly susceptible to interference, selecting a total of 45 foils from the list of tasks (M = 2.5 foils per participant) while healthy controls selected only 2 (M = .10). Pavawalla, Schmitter-Edgecombe and Smith (2012) found similar deficits in adults with TBI at discriminating targets and non-targets on a PM task, suggesting impairments were related to deficits in allocation of attentional resources.

Examining Figure 13, the patterns of performance across group and recall types reveals the same pattern regardless of stringency of recall conditions. HC perform relatively similarly across all three measures, but significantly better than adults with TBI. TBI recall accuracy increases in stair step fashion with support, but continues to be below that of HC. Because HC performance is consistent across all three recall conditions, failure is likely due to retrospective memory rather than prospective errors. HC participants performed 87.75% of tasks during the game, matched 85%, and recognized 92.5% of items. If items were missed during free recall because of prospective errors, or not remembering to perform a task that had been adequately encoded, then participants should have recalled more items during matching and recognition.

By comparison, the TBI group increased performance across recall types, so that items were encoded that were not executed at the appropriate time. However, recognition well below ceiling, so that the group with TBI made both retrospective *and* prospective errors, i.e., not all items were encoded, and not all encoded items were performed. In that sense, the experimental task describes the double-deficit that individuals with TBI face in performing PM tasks.

The primary dependent variable of interest as described above was free recall on the 20 novel PM tasks because those items align with participant JOLs. However, participants also performed 3 recurring tasks across 5 days for 15 recurring targets (see Figure 12). Healthy controls performed at or near ceiling at free recall, matching, and recognition of recurring items. The group with TBI again showed increased recall as support increased, also performing near ceiling at recognizing recurring tasks (*M* = 93.52%). However, even though participants with TBI demonstrated adequate retrospective memory for recurring tasks, participants only performed 48.86% of these items 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 will be forgotten.

In summary, individuals with TBI performed more poorly than healthy controls of tasks of PM. The TBI group 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.

Research Aim 3: **To determine if participants with TBI perform similarly to matched healthy controls on measures of metamemory of prospective memory tasks.**

Absolute difference scores compare mean JOL predictions with mean recall accuracy, providing a measure of how participants are anchoring beliefs about future success (Lichtenstein et al., 1982). Because accuracy is subtracted from predictions, difference scores can be both positive and negative, ranging from -100 to +100. Negative scores indicate underconfidence, or that participants recalled more items than had been predicted. Positive scores reflect overconfidence, i.e. that predictions were greater than recall accuracy. Healthy controls 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.

Although the near zero difference score on the CUE component by the TBI group would appear to reflect good calibration, the underconfidence of the HC 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 (i.e., judgments made after recall about confidence that the response was correct). In that light, metamemory underconfidence appears to be a typical baseline state of healthy adults, and the overconfidence reflected in TBI TASK absolute difference scores in this investigation becomes even more striking. TBI TASK absolute scores were 46% above absolute scores for healthy controls. Even when comparing JOLs with the less difficult matching recall task, the TBI group continues to be overconfident by 18.17% in absolute difference terms (see Figure 25).

This overconfidence in absolute terms is in contrast to group comparisons of JOLs in isolation that showed adults with TBI to be less confident than healthy controls. It appears that the group with TBI has adjusted predictions downward to reflect memory changes after TBI, but that those predictions are not large enough to account for actual memory deficits, and certainly not enough to match metamemory expectations of neurotypical adults. In order to exhibit underconfidence similar to the control group, CUE predictions would have needed to be 46% and TASK 13%, whereas observed JOLs for the PM components were 62.81% and 57.34%, respectively.

Relative metamemory accuracy was described using gamma correlations, finding that the adults with TBI were more accurate at predicting performance on an item-by-item basis on the CUE only. No other comparisons were significant, and both groups exhibited large variability in performance. The increased accuracy by the TBI group in the CUE condition only is somewhat difficult to interpret, although metamemory accuracy has been found to be a relative strength in adults with TBI on tasks of retrospective memory (Schmitter-Edgecombe & Woo, 2004). The current pattern of gamma results does match a finding from Schnitzspahn et al. (2011). In that report, healthy undergraduates studied PM items either one or three times, and made either immediate or delayed JOLs about both PM components, CUE and TASK. The only significant gamma correlation was the immediate JOL from the one-encoding condition. Participants in that study were all young, healthy adults, so that it is unclear why the TBI group in the current investigation would perform similarly to that sample while the HC group did not.

Regardless, it is unsurprising that gamma correlations were inconsistent given that participants made immediate JOLs. Delayed JOLs are proposed to be more accurate than immediate JOLs because studied items are no longer in working memory. Instead, the request for a JOL after a delay triggers a covert retrieval attempt so that a person is able to determine if the information is now accessible in memory stores (Nelson & Dunlosky, 1991). Schnitzspahn et al. (2011) found significant gamma correlations for both CUE and TASK in the delayed JOL condition, although reported that these were much lower than those typically observed in the literature on retrospective metamemory. In his study of prospective metamemory after TBI, Knight et al. (2005) found no difference between the experimental and control group by gamma correlations on immediate JOLs, but that study did not consider the two components of PM separately. Both groups in Knight et al. also exhibited considerable variability (for the TBI group: M = .26, SD = .24; HC: M = .35, SD = .23). Because immediate JOLs tend to be less accurate and PM metamemory JOLs tend to be smaller in magnitude, it is unlikely that that an effect would be detected or expected in the current design.

As an additional measure of metamemory monitoring during the experimental task, JOLs in the two components were regressed over time using a procedure from Krause and Kennedy (2009). Results showed the group with TBI reduced CUE judgments and both groups reduced TASK JOLs as the game progressed. In both components, the group with TBI also reduced judgments at a rate greater than that of the HC. In contrast, Krause and Kennedy found in their study of paired associate learning that adults with TBI did not adjust immediate JOLs over time, and that delayed JOLs increased. Participants completed the paired noun study, JOL, and recall task in two blocks, but did not receive any feedback about performance between blocks. In the current study, participants did not receive explicit feedback, but the matching task at the completion of each virtual day did offer an opportunity for participants to view studied items and determine if those items were familiar, regardless of whether accurate recall was possible. It appears likely then that participants were using this as a form of feedback, adjusting JOLs in response to presumed performance based on familiarity of the matching task.

Feedback has been shown to be an important feature of intervention programs for individuals with TBI, although has generally been provided in explicit contexts (Giacino & Cicerone, 1998; Schlund, 1999). However, Anderson & Schmitter-Edgecombe (2009) found that adults with TBI become more accurate at judging performance after experience with a task. Finn and Metcalfe (2007) similarly found support for the effect of a “memory for past test heuristic,” in which healthy adults reduced judgments and metamemory monitoring became more accurate after test experience. Experience with the PM task layered between judgments in the current study, coupled with inferences about recall performance during matching may have combined to allow individuals with TBI to become more accurate as the game progressed. From an intervention standpoint, this points to possible uses of computerized paradigms to provide cycles of predictions, performance, and feedback to correct adjustments downward. Limited research has shown promise for this kind of procedure (Mioni et al., 2014), but also indicates the importance of a broader approach incorporating activity and life-participation so that gains made in controlled contexts transfer to real world activities (Yip & Man, 2013; Waldum, Dufault, & McDaniel, 2014).

For research aim 4, HC participants were underconfident about both PM components in absolute difference measures, while the group with TBI was well-calibrated about the CUE, but very overconfident about recalling TASKs. From a relative standpoint, the TBI group was more accurate than healthy controls at predicting performance on the CUE. Neither group was accurate at predicting TASK recall success and gamma correlations for both groups were extremely variable. Participants with TBI reduced judgments over time across both aspects of PM and did in increments larger than healthy controls.

Research Aim 4: **To determine if metamemory JOLs and recall for prospective memory as measured by the experimental task correlates with standard neuropsychological measures.**

Exploratory correlation matrices showed some similarities in neuropsychological factors between the two groups to JOLs and recall accuracy on the experimental PM tasks. In both groups, CUE JOLs correlated with TASK JOLs. Although ANOVA analyses revealed a main effect of PM component, so that CUE predictions were higher than TASK, this suggests that participants were likely considering the two judgments similarly. In the TBI group only, these JOLs also correlated with WHERE JOLs. This was not the case for the group of healthy controls, whose WHERE JOLs did not associate significantly with any other variables and were near zero. The healthy controls seem to be performing online monitoring assessments and determining that this task does not resemble PM. The TBI group, on the other hand, may be relying on broader metamemory beliefs and making general statements about recall likelihood rather than monitoring features of this particular task.

However, both CUE and TASK JOLs associated significantly with metamemory beliefs on the PRMQ for the healthy controls, but not for the group with TBI. Regression modeling confirmed the contribution of PRMQ to both JOLs for the controls, with the addition of working memory for TASK judgments. The TBI group instead showed a correlation between immediate memory and JOLs for both components of PM that remained significant in regression models. Healthy adults appear to have more congruence between monitoring and beliefs, although recall performance did not associate with the PRMQ for either group. This result is not surprising given that metamemory beliefs are not necessarily predictive of monitoring decisions, and vice versa (Flavell, 1979; Koriat, Bjork, Sheffer, & Bar, 2004); and monitoring decisions and metamemory beliefs do not necessarily predict performance. When monitoring, individuals may believe that an aspect of personal recall ability is “good” or “bad,” but make predictions about a specific scenario based on features of the item to be remembered that may not reflect information that is useful in determining recall likelihood. For example, participants may make judgments based on perceptual features of the stimulus, such as loud versus soft auditory presentations (Rhodes & Castel, 2009), or conditions of study, such as familiarity or fluency of learning (Koriat & Bjork, 2006; Koriat & Ma’ayan, 2005), that do not then correspond to recall performance. In regards to metamemory beliefs, Uttl and Kibreab (2011) found no relationship between self-report measures of PM, including the PRMQ, and objective measures of PM. Those authors argued that the PRMQ is therefore not valid, but the questionnaire purports to capture frequencies of complaints about memory failures and not recall performance.

CUE and TASK recall were correlated in both groups, although the association was stronger in the HC group, showing a tendency for participants to recall a TASK if a CUE was recognized. This is also reflective of the nature of the task, in that a participant must indicate that a task is to be performed (recognizing the CUE) in order to have the free recall box appear on the screen for task entry. Participants may recognize a CUE and not recall the task or enter an incorrect task, but participants cannot perform a task unless acknowledging that it is to be performed. Recall for both groups also correlated with subscales of the CAMPROMPT, providing preliminary validity that the experimental task was assessing PM.

Regression models further refined predictors of recall to time-based scores on the CAMPROMPT for CUE recall for HC, but measures of attention from the RBANS for the TBI group. The decision to use a strategy during the CAMPROMPT was a predictor of TASK accuracy in the HC group, despite the fact that strategy use was not allowed during administration of *Tying the Sting*. The most concise explanation for this is the link between monitoring, control, and performance as originally described by Nelson and Narens (1990), then refined to describe the self-regulatory loop by Kennedy and Coelho (2005). HC participants could be employing internal strategies to recall PM tasks after interference and delay. However, such strategy use was not directly observable in the current research design. In future work, qualitative inquires as to how participants were managing the PM load may be illuminating.

TASK recall for the group with TBI was predicted by immediate memory and also event-based scores on the CAMPROMPT. The latter of these again provides validity that the PM task is similar to other published tools, but the association of immediate rather than delayed memory suggests the task may benefit from greater delay between encoding an execution, although working memory was not associated with recall. It may be that participants with TBI had more difficulty with encoding than decay, so that some participants could adequately store PM tasks at the time of study, while others struggled to do so. If items were encoded, it was likely they would be retained and tasks would be performed when the time came.

Demographic variables did not significantly correlate with PM JOLs or recall. For participants with TBI, TPO did correlate with performance on the CAMPROMPT, although negatively, so that increasing time since injury was associated with a reduction in PM scores. This is counterintuitive, and so may reflect an additional variable not accounted for in a simple correlation. For example, participants further out from injury could have been those participants with the greatest severity of injury. The three moderate TBIs were relatively recent in this sample, with a mean TPO of 5.5 years. Removal of those participants from the analysis does reduce the strength of the correlation between TPO and scores on the CAMPROMPT, but does not change the direction of the relationship.

In summary, several standard neuropsychological measures correlated with JOLs and recall accuracy, although the two groups drew on different resources. Healthy adults made JOLs largely based on self-reported metamemory beliefs, while adults with TBI relied on immediate memory. Recall accuracy for healthy controls was predicted by performance and strategy use on standardized measures of PM. CUE recall for the TBI group was predicted by attention, and TASK recall accuracy for participants with TBI was predicted by the standardized test of PM as well as immediate memory.

Limitations

The current study does have a number of limitations. First, some participants with TBI performed at floor on task recall (n = 7) and a few healthy participants performed at ceiling (n = 2). Participants could study PM items at a self-selected pace, but participants with TBI may benefit from having additional study time or opportunities. For example, participants viewed the three recurring tasks three times to ensure adequate encoding. 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 retrospective memory deficits while revealing PM failures. Alternatively, participants could have the opportunity to use a strategy to recall PM items.

Several participants in both groups also used a limited range when selecting JOLs, so that gammas could only be calculated for 25 of the 38 participants. The sliding scale had integer values for each point on the line from 0 to 100 so that some participants were selective in repeatedly choosing the same number value on the line. Removing the value from the line may have allowed for participants to make more subjective judgments to particular items instead of choosing a number (e.g., “82”) as a target that was repeatedly selected across the course of the game. The indicator on the line was set at 50% when participants landed on the JOL page, but could be removed so that no indicator is on the line until the participant selects a location. In this way, the experimental task could be revised to support participants being more likely to choose a judgment based on a particular item instead of repeating a previous response or being biased by the game design.

Fifteen of the study participants had severe injuries and only three had experienced moderate injuries. Although the three individuals with moderate TBIs perform with greater accuracy across the PM tasks those with severe injuries, the small size of this group will not allow for subgroup analyses. Trends between the levels of severity do suggest that this group mixes features of the severe TBI and HC group. For example, the three participants with moderate injuries make JOLs very similar to healthy controls, recall the PM CUE with slightly lower accuracy than controls, but perform the TASK with accuracy that straddles the two groups (see Table 36 for summary). Those with moderate injuries exhibit a pattern of absolute difference scores that mimics healthy controls for the CUE, but TBI for the TASK. All three individuals with moderate injuries had returned to productivity and were managing daily tasks, but were clearly impaired on aspects of the experimental task and reported more difficulty with everyday ADLs on the PRMQ and the MPAI. This limited data suggests that the group with moderate injuries may particularly benefit from this line of research. Although the group had some difficulty with retrospective deficits, recognizing only 78% of PM items, the 55%

accuracy at recalling PM tasks points to impairments in PM as being particularly limiting to productivity. However, future work will have to confirm if this is indeed the case.

The current study was also limited to individuals who were comfortable using computers and able to type to enter PM tasks during the game. Some participants with TBI complained of feeling rushed, but responses were counted correct if three or more letters in the text entry box were specific to the task to be completed. For example, if the task was “Take vitamins,” a response of “vit” was counted as correct. This happened rarely, and it was most likely that responses contained typing errors, but were clearly on target (e.g. “tk vitmins”). Participants also completed the DKEFS Trail Making Motor Speed test and no correlation was found with performance on either PM task.

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 much closer to correct than entering that task during the scene “After Dinner” and would demonstrate that the task had been encoded. Currently near, far, and absent responses are given equal weight as errors.

There was little diversity to participants in the current sample. All participants were Caucasian, spoke English as a first language, and most were native or long-term Minnesotans. Participants with TBI were also far removed from the time of injury, providing a window into long term impairments associated with TBI, but less information about serving individuals who are in the chronic stage but still recovering and pursuing goals to return to productivity.

Future Directions

Future work will benefit from some design changes to the experimental task to address limitations noted above. More substantive directions will recruit participants with moderate and mild TBI to determine how those groups may or may not resemble healthy controls or those with more or less severe injuries. PM impairments occur in individuals with mTBI in both the acute and chronic stages (Tay et al., 2010), but little is known about how people think about their memory following such injuries. Many individuals with mTBI can become discouraged by headaches and fatigue, and some may develop long-term complaints that are related not to brain-based differences, but other co-occurring factors such as premorbidities, psychogenic or neurogenic disorders. Other reviews have noted impairments in attention, mental flexibility, delayed memory, and speed of processing in the chronic phase (Ruff & Jamora, 2009). Metamemory judgments could characterize important differences in how individuals with milder injuries consider their thought processes and the effects of TBI.

The other immediate avenue of future work should examine strategy use during the experimental task. The game can be modified so that participants can use a "notepad" feature to enter PM tasks if a participant chooses. The program will track notes taken, but also when participants access the notepad, allowing for tracking of not just the quality of notes, but online monitoring and strategy execution during PM tasks. For example, healthy adults may benefit from taking notes but have little need to access them during the PM game. On the other hand, individuals with TBI may need to both take detailed notes, but also access those on a regular basis in order to benefit from the strategy. Note-taking and strategy use might be abandoned as the game progresses and confidence about performance increases, or because the participant decides that accessing the notes is too cumbersome and therefore too costly to ongoing performance. Such competing hypotheses point to the need to assess the link between online metamemory monitoring and strategy deployment during a virtual task such as *Tying the String* used in the current study.

In another avenue, JOL paradigms typically ask participants about the likelihood of successful recall, but may be more illuminating if requesting the likelihood of forgetting (Koriat et al., 2004). Given that participants with TBI often commented during neuropsychological testing about poor recall (e.g., "my memory is really bad"), asking participants about the likelihood of recall may encourage participants to be overly optimistic. Rephrasing this query to ask about the likelihood of forgetting may allow participants the opportunity to respond to JOLs with greater honesty about memory ability as it currently stands. If the two questions resulted in unbiased responses, then it could be assumed that JOLs for likelihood of successful recall and a paired JOL for likelihood of forgetting would add to 100%. It seems unlikely that this would be the case, but it does raise an interesting empirical question about how the language we use to investigate and treat awareness deficits in adults with TBI may bias results.

Conclusions and Implications

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 TBI group 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). Anecdotally, participants with TBI frequently stated that PM performance would increase with strategy use (e.g., "I could have done all that if I could have written it down"). However, all participants completed standardized testing of PM using the CAMPROMPT, which allows and encourages strategy use. Despite having access to and using compensatory strategies at a rate similar to healthy controls, the use of self-selected strategies by the group with TBI was not effective in approximating the performance of healthy controls ($t = 5.05$, $p < 0.001$, $d = 1.67$). It appears then, that individuals with TBI have the metamemory awareness to use strategies, but that knowledge is incomplete, so that strategies used may not address memory needs.

From an intervention standpoint for PM impairments, training should focus particularly on the TASK, so that individuals accurately record what is to be completed, instead of relying on a CUE to trigger recall of a CUE-TASK sequence. Participants with

TBI were observed making notes during the CAMPROMPT that included a cue, but not the associated action, such as writing down "7 minutes" in response to the PM task, "In seven minutes I'd like you to hand me this book." Participants presumed because the book was in view on the table and the cue had been recorded that that would be sufficient for recall. As evidenced by the wide discrepancy in CAMPROMPT scores between the two groups, that was rarely the case. Participants with TBI appear to have a general belief in PM deficits, but little knowledge of what about PM is difficult. Intervention should target developing awareness of the particular demands of such PM tasks, as well as an individual's needs.

A few participants with TBI commented following completion of *Tying the String* that the game had reminded them of why they had not been able to return to work. The game uses a work setting and gives multiple PM targets to be completed each day. Even though the group with TBI performed much more poorly at the experimental PM task, only one participant in the TBI group did not arrive for their scheduled appointment, the same rate as the group of healthy adults. All participants received reminders 24-48 hours before the appointment, but otherwise, the adults with TBI managed their schedules to arrive on the appointed day. Managing a calendar and appointments is frequently a target of PM intervention post-TBI. Participants need to continue coming to therapy, and being able to schedule and keep appointments is functional across a variety of tasks.

PM tasks assessed in the current study target a different level of PM though. Appointments are highly structured and individuals with or without TBI are often given time to record these into the external device of choice (calendar, smartphone, 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 co-worker 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. Intervention should consider discharge disposition and how goals of return to productivity might point to more targeted training in less structured PM tasks that occur across daily life and work settings.

The scatterplots in Figures 15 and 16 comparing JOL predictions with observed recall performance point to another clinical implication of the current study and potential applications for the experimental task. Clinicians may be unsurprised to see that clients with TBI perform more poorly at tasks of PM, but those figures indicate that some individuals are better calibrated about their abilities than others. For individuals whose data points cluster near or below the calibration line, intervention can likely target PM strategy development and application directly. However, for those well above the line, and particularly for individuals clustering in the upper left quadrant, it is likely that intervention will need to address the development of accurate metamemory monitoring for either the CUE, TASK, or both prior to the onset of more traditional strategy training. Those individuals appear to be particularly unaware of the level of difficulty such PM tasks pose, so that strategies are likely to be incompletely applied (or may address only a single component of PM, likely the CUE, rather than both). Using the current experimental task in a clinical setting could allow a clinician to correctly target the level of impairment, so that training could target either memory or a combination of memory and metamemory deficits according to the client profile.

Prospective memory 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. Future work will address refining the experimental task toward clinical application and continued exploration of how metamemory monitoring relates to strategy use across severity of TBI.

Tables

Table 1. *Main Experiment Participant Demographics*

TBI Group					Control Group				
ID	Sex (M/F)	Age	Education	Verbal IQ	ID	Sex (M/F)	Age	Education	Verbal IQ
1	F	25	16	114	26	M	24	16	118
2	M	33	18	125	27	F	23	18	118
3	F	62	20	111	28	F	42	18	116
4	M	24	14	90	30	F	43	16	113
5	F	52	15	108	31	M	55	16	117
6	M	62	14	119	32	M	26	18	124
7	M	59	13	102	33	M	37	18	122
8	M	56	16	122	34	M	50	18	117
9	M	33	16	113	35	M	43	16	119
10	F	32	14	102	36	M	59	16	102
11	M	55	21	105	37	M	50	16	107
14	M	64	16	110	38	F	41	16	119
15	M	52	16	122	39	F	65	16	119
18	M	23	17	97	40	F	33	18	127
19	F	41	16	119	41	F	48	17	117
20	M	59	14	117	42	F	61	17	117
21	M	61	16	106	43	F	40	14	120
22	F	54	17	98	44	F	50	18	125
					45	M	50	15	104
					47	M	20	14	127
M	(12/6)	47.06	16.06	111.00	*M*	(10/10)	43.15	16.60	117.4
SD		14.77	2.07	9.87	*SD*		13.00	1.35	6.76

Table 2. *TBI Participant Injury Information*

ID	Time Post Injury (months)	LOC	Severity of Injury	Description of Injury
1	90	1 week	severe	MVA
2	101	6 weeks	severe	Bike accident
3	228	10 days	severe	MVA
4	77	2 weeks	severe	MVA
5	18	> 30 minutes	moderate	Fall; 2 days PTA
6	305	10 days	severe	Motorcycle accident
7	89	4 weeks	severe	Motorcycle accident
8	96	2 hours	moderate	Pedestrian, bit by car
9	127	4 weeks	severe	MVA
10	173	10 weeks	severe	MVA
11	92	2 weeks	severe	ATV accident
14	516	4 weeks	severe	MVA
15	323	8 days	severe	MVA
18	47	10 days	severe	Skiing accident
19	307	2 weeks	severe	MVA
20	390	3 days	severe	Airplane accident, 4 months PTA
21	367	3 weeks	severe	Motorcycle accident
22	84	2 hours	moderate	Fall; 2 days PTA
M	*190.56*			
SD	*143.18*			

Table 3. *Assessments and Estimated Time in Minutes (Hours and Minutes) for Each Component of the Experimental Session*

Assessment / Component	**Acronym**	**Estimated Time**	**Process Measured**
Consent		10	
Western Aphasia Battery Bedside Screener	WAB	5	Language
Discourse Comprehension Test (Baseball and Painter Stories)	DCT	5	Language
Tying the String*		75	Prospective Metamemory
Mandatory Break		10	
Mayo Portland Participation Index	MPAI	5	Self-Report of Participation
Prospective and Retrospective Memory Questionnaire	PRMQ	5	Self-Report of Prospective and Retrospective Memory Beliefs
Wechlser Test of Adult Reading	WTAR	5	Estimated Verbal IQ
Delis Kaplan Executive Function System – Trail Making, Verbal Fluency, and Tower Tests	DKEFS	30	Executive Function
Short Form of Reading, Operation, and Symmetry Spans*	WM	25	Working Memory
Mandatory Break		10	
Repeatable Battery for the Assessment of Neuropsychological Status	RBANS	20	Cognitive Status, subscales for Immediate and delayed memory, language, attention, and visuospatial processing
Cambridge Test of Prospective Memory	CAMPROMPT	25	Prospective Memory
Debriefing and Payment		10	
	Total Time	240 (4:00)	

*Items administered electronically.

Table 4. *Mean Performance on Standardized Tests of Cognition for Participants in Both Groups*

Test	TBI Mean (SD)	Control Mean (SD)	t-value	*d*
WAB				
Criterion scores, max of 100, >93 = no aphasia				
Aphasia Quotient	98.66 (1.82)	99.55 (1.02)	1.82	
DCT				
Raw, out of 16				
Baseball and Painter Stories	14.11 (1.75)	15.00 (1.41)	1.71	
MPAI				
T-scores, M= 50	40.44 (11.87)	23.75 (14.18)	-3.95***	- 1.27
PRMQ				
T-scores, M= 50				
Prospective	39.33 (13.69)	49.20 (9.16)	2.58*	0.86
Retrospective	40.56 (12.4)	52.40 (7.82)	3.48**	1.16
Total	39.83 (13.76)	51.75 (8.92)	3.13**	1.04
WTAR	110.00 (9.81)	117.40 (6.76)	2.68*	0.89
Standard Scores, M = 100				
DKEFS				
Standard Score, M = 10				
Verbal Fluency: Letter	10.56 (2.91)	12.70 (3.93)	1.92	
Verbal Fluency: Category	10.61 (3.18)	13.60 (3.72)	2.67*	0.98
Verbal Fluency: Switching	8.50 (3.38)	12.90 (3.70)	3.83***	1.24
Verbal Fluency: Switching Accuracy	9.44 (3.05)	12.80 (3.47)	3.17**	1.02
Tower Test Achievement Score	11.22 (3.61)	13.35 (2.91)	1.99	
Trail Making: Cancellation	8.17 (3.54)	10.85 (3.01)	2.50*	0.82
Trail Making: Number Sequencing	8.06 (3.83)	12.05 (1.90)	4.00***	1.34
Trail Making: Letter Sequencing	9.00 (3.11)	12.15 (1.98)	3.68***	1.22
Trail Making: Number and Letter Switching	8.61 (3.73)	11.70 (1.69)	3.23**	1.09
Trail Making: Motor Speed	9.89 (1.45)	11.55 (1.88)	3.07**	0.98
Trail Making: Speed/Switching	8.72 (3.77)	10.15 (2.32)	1.39	
Working Memory Spans				
Raw Partial Scores (36 total for each)				
Operation	14.17 (10.56)	19.45 (9.63)	1.61	
Reading	15.50 (9.67)	21.60 (6.44)	2.31*	0.75
Symmetry	8.72 (7.64)	14.55 (6.13)	2.61*	0.85
RBANS				
Index Scores, M = 100				
Immediate Memory	81.78 (16.05)	106.20 (12.12)	5.25***	1.73
Visuospatial	86.78 (17.30)	97.35 (18.06)	1.84	
Language	93.50 (10.11)	108.55 (12.09)	4.18***	1.34
Attention	91.44 (17.57)	106.40 (16.56)	2.69**	0.88
Delayed Memory	76.06 (23.98)	102.80 (9.47)	4.43***	1.50
Total Scale	81.56 (15.28)	105.95 (13.20)	5.24***	1.72
CAMPROMPT				
Raw Scores (18 on each subscale, 36 total)				
Time-Based	10.00 (4.87)	15.55 (3.30)	4.06***	1.35
Event-Based	10.44 (4.19)	16.05 (2.72)	4.83***	1.60
Total Raw	20.44 (7.87)	31.60 (5.35)	5.05***	1.67

Note: Cohen's d is provided as a measure of effect size for scores that significantly differ.

Table 5. *Schedule of Prospective Memory Targets*

Scene	*Cue*	Practice Day One	Practice Day Two	Monday	Tuesday	Wednesday	Thursday	Friday
1	*Wake Up*	**Let out Dog**	**Let out Dog**	**Let out Dog**	**Let out Dog**	**Let out Dog***	**Let out Dog**	**Let out Dog***
2	*Get Ready for the Day*						Clean bathroom	Sweep and mop floors
3	*Breakfast*	**Take Vitamins**	**Take Vitamins**	**Take Vitamins***	**Take Vitamins** Order Cake	**Take Vitamins** Rent party tent	**Take Vitamins**	**Take Vitamins***
4	*Go to Work*		Drop package at post office	Buy donuts for new employee	Fill up with gas		Buy plates and napkins	
5	*At the Office*			Send invitations			Reschedule Dentist Appointment	
6	*Lunch*	**Work Out**	**Work Out**	**Work Out**	**Work Out***	**Work Out** Get oil changed in car	**Work Out***	**Work Out** Pick up balloons
7	*Afternoon Meeting*		Set up projector		Give presentation	Sign card		
8	*Drive Home*			Buy birthday gift	Buy candles	Shop for snacks		
9	*Home*					Mow grass		Set up tables and chairs
10	*After Dinner*		Call mom		Wrap gift		Hang streamers	

All recurring targets indicated in bold were introduced during training. Novel targets were introduced just prior to the start of the day in which they were performed.
*Recurring target included in end of day recognition memory probe.

Table 6. *Means and Standard Deviations of JOL Ratings by Group and PM Component*

	PM Component	
Group	Cue	Task
TBI	62.81 (17.33)	57.34 (20.42)
HC	73.24 (17.43)	71.80 (15.04)

Table 7. *Summary of 2 x 2 ANOVA of JOL Ratings Across Groups and PM Component*

Comparison	Df	Mean Square	F	Sig.	η_p^2	Observed Power
Group: TBI and HC	1	2932.04	5.07	0.03	.12	.59
Error (Group)	36	658.16				
Component: Cue and Task	1	226.65	5.68	.02	.14	.64
Group x Component	1	76.83	1.93	.17	.05	.27
Error (Component)	36	39.88				

Table 8. *Means and Standard Deviations of Recall Accuracy Comparison of Group by PM Component for Novel Tasks*

	PM Component	
Group	Cue	Task
TBI	63.06 (28.91)	26.11 (30.61)
HC	89.25 (8.93)	87.75 (9.93)

Table 9. *Summary of 2 x 2 ANOVA of Free Recall Performance of Novel Tasks Across Groups and PM Component*

Comparison	Df	Mean Square	F	Sig.	η_p^2	Observed Power
Group: TBI and HC	1	36543.29	49.99	2.65 E-08	.58	1.00
Error (Group)	36	731.01				
Component: Cue and Task	1	7000.94	34.98	9.06 E-07	.49	1.00
Group x Component	1	5950.94	29.73	3.75 E-06	.45	1.00
Error (Component)	36	200.17				

Table 10. *Means and Standard Deviations of Recall Accuracy Comparison of Group by PM Component and Recurrence*

	Cue Component		Task Component	
Group	Recurring	Novel	Recurring	Novel
TBI	73.65 (24.33)	63.06 (28.91)	48.86 (33.88)	26.11 (30.61)
HC	97.33 (5.47)	89.25 (8.93)	94.66 (6.34)	87.75 (9.93)

Table 11. *Summary of 2 x 2 x 2 ANOVA of Recall Accuracy Comparison of Group by PM Component by Recurrence*

Comparison	Df	Mean Square	F	Sig.	η_p^2	Observed Power
Group: TBI and HC	1	58617.51	44.77	8.37 E-08	.55	1.00
Error (Group)	36	1727.42				
Component: Cue and Task	1	10285.44	36.97	5.43 E-07	.51	1.00
Component x Group	1	7848.62	28.21	5.78 E-06	.44	.99
Error (Component)	36	278.23				
Recurrence: Recurring or Novel	1	5535.92	36.89	5.54 E-07	.51	1.00
Recurrence x Group	1	797.20	5.31	0.03	.13	.61
Error (Recurrence)	36	150.08				
Component x Recurrence	1	286.03	5.48	0.02	.13	.62
Component x Recurrence x Group	1	420.39	8.05	0.007	.18	.79
Error (Component x Recurrence)	36	52.24				

Table 12. *Means and Standard Deviations of Recall Accuracy for TASK Component by Group, Type of Recall, and Recurrence*

	Recurring Category			Novel Category		
Group	Free Recall	Matching	Recognition	Free Recall	Matching	Recognition
TBI	48.86 (33.87)	74.07 (31.43)	93.52 (20.72)	26.11 (30.61)	39.17 (29.06)	66.39 (27.43)
HC	94.67 (6.34)	96.67 (8.72)	98.33 (7.45)	87.75 (9.93)	85.00 (16.30)	92.50 (10.20)

Table 13. *Summary of 2 x 3 x 2 ANOVA of Recall Accuracy Comparison by Group, Type of Recall, and Recurrence*

Comparison	Df	Mean Square	F	Sig.	η_p^2	Observed Power
Group: TBI and HC	1	67522.23	39.09	3.20 E-07	.52	1.00
Error (Group)	36	1727.42				
Type	1.69	12352.27	72.87	1.28 E-15	.67	1.00
Type x Group	2	6934.36	48.35	3.13 E-12	.57	1.00
Error (Type)	60.92	169.51				
Recurrence: Recurring or Novel	1	18830.30	43.56	1.11 E-07	.55	1.00
Recurrence x Group	1	5754.90	13.31	0.000828	.27	.94
Error (Recurrence)	36	432.31				
Type x Recurrence	1.84	412.82	2.54	0.09	.07	.47
Type x Recurrence x Group	1.84	75.78	.47	0.61	.01	.12
Error (Type x Recurrence)	66.36	66.36	162.28			

Table 14. *Mean Absolute Difference Recall Accuracy by Group and PM Component*

	PM Component	
Group	Cue	Task
TBI	.04 (32.20)	30.45 (33.03)
HC	-16.46 (16.76)	-13.46 (15.29)

Table 15. *Summary of 2 x 2 ANOVA of Mean Absolute Difference Recall Accuracy by Group and PM Component*

Comparison	Df	Mean Square	F	Sig.	h_p^2	Observed Power
Group: TBI and HC	1	17282.98	16.98	0.000211	.32	.98
Error (Group)	36	1017.72				
Component: Cue and Task	1	5291.09	20.44	0.0000641	.36	.99
Group x Component	1	3559.26	13.75	0.000699	.28	.95
Error (Component)	36	258.81				

Table 16. *Means and Standard Deviations of Gamma Correlations by Group and PM Component*

	PM Component	
Group	Cue	Task
TBI	0.36 (0.45)	0.02 (0.34)
HC	-0.03 (0.72)	0.10 (.58)

Table 17. *Summary of 2 x 2 ANOVA of Gamma Correlations by Group and PM Component*

Comparison	Df	Mean Square	F	Sig.	η_p^2	Observed Power
Group: TBI and HC	1	.31	.68	.42	.03	.12
Error (Group)	25	.47				
Component: Cue and Task	1	.13	.74	.40	.03	.13
Group x Component	1	.74	4.16	.05	.14	.50
Error (Component)	25	.18				

Table 18. *Regression Models for CUE JOLs Over Time Across Groups*

	Unstandardized Coefficients	Standardized Coefficients	*t*	Sig.
Both Groups				
Model				1.15 E-12
Constant	78.28		64.70	1.13 E-39
Item Number	-.48	-.41***	-5.28	5.50 E-12
TBI	-10.43	-.78***	-9.93	5.95 E-06
HC Only				
Constant	76.10		44.39	5.42 E-20
Item Number	-.27	-.41	-1.90	0.07
TBI Only				
Constant	70.05		62.50	5.42 E-20
Item Number	-.69	-.87***	-7.36	7.86 E-7

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

Table 19. *Regression Models for TASK JOLs Over Time Across Groups*

	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
Both Groups				
Model				5.98 E-14
Constant	78.12		52.59	2.24 E-36
Item Number	-.60	-.39***	-5.39	1.84 E-13
TBI	-14.45	-.81***	-11.22	4.21 E-06
HC Only				
Constant	75.86		37.33	1.68 E-18
Item Number	-.39	-.47*	-2.28	0.03
TBI Only				
Constant	65.93		41.71	2.17 E-19
Item Number	-.82	-.83***	-6.20	7.56 E-6

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

Table 20. *Regression Models for Novel CUEs Over Time Across Groups*

	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
Both Groups				
Model				.00003
Constant	89.88		17.08	2.24 E-36
Item Number	-.11	-.04	-0.29	0.77
TBI	-24.35	-.66***	-5.33	5.01E-6
HC Only				
Constant	84.82		12.30	3.41 E-10
Item Number	0.37	.15	0.64	0.53
TBI Only				
Constant	70.60		11.01	2.00 E-9
Item Number	-.60	-.25	-1.11	.28

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

Table 21. *Regression Models for Novel TASKs Over Time Across Groups*

	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
Both Groups				
Model				2.85 E-14
Constant	82.05		16.09	2.76 E-18
Item Number	0.005	.001	0.01	0.99
TBI	-56.44	-.90***	-12.75	4.09 E-15
HC Only				
Constant	78.37		10.50	4.20 E-9
Item Number	0.36	.13	0.57	0.58
TBI Only				
Constant	29.30		5.42	.00004
Item Number	-0.35	-.18	-0.77	0.45

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

Table 22. *Regression Models for Recurring CUEs Over Time Across Groups*

	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
Both Groups				
Model				.007
Constant	93.21		20.87	3.44 E-18
Item Number	.60	.24	1.37	.18
TBI	-17.80	-.62**	-3.49	.002
HC Only				
Constant	99.48		39.93	5.48 E-15
Item Number	-.27	-.26	-0.98	0.35
TBI Only				
Constant	87.51		16.47	4.35 E-10
Item Number	-1.44	-.59*	-2.48	0.03

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

Table 23. *Regression Models for Recurring TASKs Over Time Across Groups*

	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
Both Groups				
Model				8.20 E12
Constant	84.93		11.09	1.48 E-11
Item Number	1.47	.32	1.96	.06
TBI	-38.62	-.716***	-4.41	0.00014
HC Only				
Constant	101.10		36.25	1.90 E-14
Item Number	-0.80	-.59*	-2.62	0.02
TBI Only				
Constant	67.25		9.28	4.25 E-7
Item Number	-2.20	-.61*	-2.76	0.02

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

Table 24. *Means and Standard Deviations from Ongoing Distractor Task Performance and JOL Ratings*

Group	Money Found	WHERE JOLs
TBI	85.89 (66.28)	40.09 (27.67)
HC	188.80 (38.82)	26.03 (23.07)

Table 25. *Correlation Matrix of Demographics, JOLs, and Recall Performance for Both Groups*†

	TPO	Age at TBI	Age	Education	Gender	CUE JOL	CUE Recall	TASK JOL	TASK Recall	Where JOL
TPO	-	-	-	-	-	-	-	-	-	-
Age at TBI	**-0.21**	-	-	-	-	-	-	-	-	-
Age	**0.56***	**0.57***	-	*-0.13*	*-0.03*	*-0.49**	*-0.34*	*-0.44*	*-0.04*	*0.31*
Education	**-0.02**	**0.03**	**-0.04**	-	*-0.34*	*-0.24*	*-0.01*	*-0.05*	*0.09*	*-0.11*
Gender	**-0.23**	**0.15**	**-0.02**	**0.17**	-	*-0.09*	*0.00*	*-0.04*	*-0.10*	*-0.03*
CUE JOL	**-0.02**	**-0.12**	**-0.10**	**0.00**	**0.03**	-	*0.46**	*0.88***	*0.12*	*0.08*
CUE Recall	**-0.29**	**0.08**	**-0.08**	**0.15**	**-0.03**	**0.34**	-	*0.53**	*0.72***	*-0.08*
TASK JOL	**0.00**	**-0.08**	**0.00**	**-0.14**	**-0.19**	**0.82****	**0.29**	-	*0.33*	*0.18*
TASK Recall	**-0.41**	**0.17**	**-0.15**	**0.15**	**0.06**	**0.30**	**0.50***	**0.20**	-	*-0.21*
WHERE JOL	**0.01**	**0.10**	**0.03**	**0.36**	**0.34**	**0.55***	**-0.19**	**0.53***	**0.05**	-

†Data for HC is above the diagonal in italics; correlations for TBI group are below the diagonal in bold.
Note: $N_{TBI} = 18$, $N_{HC} = 20$
**p* < .05, ***p* < .01

Table 26. *Correlation Matrix: Spearman Rho Correlations of PM Recall Performance and JOLs with Neuropsychological Factors for HC Group*

	CUE JOL	CUE Recall	TASK JOL	TASK Recall	WHERE JOL	M2PI	Letter Fluency	Category Fluency	WM Span	RBANS Imm. Memory	RBANS Attention	RBANS Delayed Memory	CMPT Time	CMPT Event	CMPT Total	CMPT Strategy	PRMQ Total
CUE JOL	1.00																
CUE Recall	.46*	1.00															
TASK JOL	.88**	.53*	1.00														
TASK Recall	0.12	.72**	0.33	1.00													
WHERE JOL	0.08	-0.08	0.18	-0.21	1.00												
M2PI	-0.12	0.00	-0.02	-0.06	0.22	1.00											
Letter Fluency	-0.31	0.03	-0.19	0.06	0.10	-0.12	1.00										
Category Fluency	-0.34	-0.02	-0.35	0.12	0.08	0.07	.48*	1.00									
WM Span	0.28	0.29	0.41	0.02	0.18	0.04	0.08	-0.22	1.00								
RBANS Immediate Memory	0.04	0.11	0.14	0.16	0.30	0.04	0.10	0.03	0.23	1.00							
RBANS Attention	-0.39	-0.03	-0.22	0.09	-0.11	-0.29	.58**	0.15	0.05	0.32	1.00						
RBANS Delayed Memory	-0.11	-0.15	-0.17	-0.03	0.21	-0.08	0.18	0.29	0.02	.66**	0.38	1.00					
CAMPROMPT Time	0.30	.59**	0.35	0.42	-0.05	-0.20	0.09	-0.14	.66**	0.02	-0.01	-0.07	1.00				
CAMPROMPT Event	0.11	-0.01	0.01	-0.12	-0.13	-0.14	0.06	-0.19	0.33	-0.13	-0.10	-0.04	0.28	1.00			
CAMPROMPT Total	0.22	0.31	0.21	0.10	-0.09	-0.16	0.09	-0.21	.69**	-0.11	-0.04	-0.04	.81**	.75**	1.00		
CAMPROMPT Strategy Use	0.33	.59**	.57**	.55*	0.25	0.15	-0.01	-0.20	0.38	0.15	-0.15	-0.29	0.40	0.29	0.34	1.00	
PRMQ Total	.62**	0.44	.77**	0.37	0.23	0.09	-0.24	-0.34	0.15	0.03	-0.22	-0.20	0.31	-0.14	0.08	.57**	1.00

Table 27. *Correlation Matrix: Spearman Rho Correlations of PM Performance and JOLs with Injury and Neuropsychological Factors for TBI Group*

	TPO	CUE JOL	CUE Recall	TASK JOL	TASK Recall	WHERE JOL	M2PI	Letter Fluency	Category Fluency	WM Span	RBANS Immediate Memory	RBANS Attention	RBANS Delayed Memory	CMPT Time	CMPT Event	CMPT Total	CMPT Strategy	PRMQ Total
TPO	1.00																	
CUE JOL	-0.02	1.00																
CUE Recall	-0.29	0.34	1.00															
TASK JOL	0.00	.82**	0.29	1.00														
TASK Recall	-0.41	0.30	.50*	0.20	1.00													
WHERE JOL	0.01	.55*	-0.19	.53*	0.05	1.00												
M2PI	-0.07	-0.39	-0.08	-0.35	-0.04	-0.36	1.00											
Letter Fluency	0.01	0.06	0.44	-0.19	0.28	-0.20	-0.33	1.00										
Category Fluency	-0.05	.48*	0.30	0.18	0.46	0.11	-0.47	.75**	1.00									
WM Span	-0.31	0.19	0.23	0.32	0.13	-0.07	-.57*	0.30	0.35	1.00								
RBANS Immediate Memory	-0.26	.50*	0.14	.51*	0.43	0.25	-0.20	0.21	.533*	0.38	1.00							
RBANS Attention	-0.10	0.45	.67**	0.37	0.32	-0.21	-0.05	.55*	.55*	0.40	0.45	1.00						
RBANS Delayed Memory	-0.29	0.00	0.23	0.15	0.41	0.06	0.06	0.10	0.14	0.13	.67**	0.23	1.00					
CAMPROMPT Time	-0.47	0.37	0.45	0.35	0.25	0.37	-0.25	0.16	0.11	0.20	0.15	0.22	0.15	1.00				
CAMPROMPT Event	-.50*	0.34	0.39	0.10	.60**	-0.07	-0.28	0.42	.53*	0.45	0.36	.53*	0.23	0.42	1.00			
CAMPROMPT Total	-.56*	0.44	.51*	0.28	.47*	0.18	-0.35	0.36	0.36	0.43	0.28	0.42	0.18	.84**	.82**	1.00		
CAMPROMPT Strategy Use	-0.21	0.01	0.31	-0.03	-0.02	0.20	-0.18	0.07	-0.09	-0.16	-0.09	-0.09	0.10	.49*	0.12	0.38	1.00	
PRMQ Total	-0.23	-0.21	-0.20	-0.07	-0.15	0.30	-0.38	-0.10	-0.14	0.37	0.13	-0.36	0.28	0.13	-0.16	0.00	0.05	1.00

Table 28. *Backward Stepwise Regression Models of CUE JOL and Injury, Demographic, and Neuropsychological Factors for HC Group*

	Model 1			Model 2			Model 3			Model 4		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	8.96	43.39		21.56	41.60		-8.71	36.48		22.43	20.89	
PRMQ Total	0.62	0.44	0.32	0.80	0.40	0.41	0.96	0.40	0.49*	0.98	0.40	0.50*
Immediate Memory	0.43	0.30	0.30	0.41	0.30	0.29	0.30	0.29	0.21			
Attention	-0.33	0.22	-0.32	-0.31	0.22	-0.30						
CAMPROMPT Total	0.71	0.70	0.22									
R^2		0.41			.37			.30			.25	
F change for R^2		2.65			1.03			1.95			1.08	

Table 29. *Backward Stepwise Regression Models of TASK JOL and Injury, Demographic, and Neuropsychological Factors for HC Group*

	Model 1			Model 2			Model 3			Model 4			Model 5		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	10.56	34.87		11.42	27.61		11.42	27.61		9.06	23.84		-0.51	14.55	
PRMQ Total	-0.51	14.55	-0.51*	1.02	0.35	0.61**	1.04	0.31	0.62**	1.02	0.27	0.60**	1.06	0.26	0.63***
Working Memory Span	1.00	0.46	0.44*	1.00	0.42	0.44*	1.01	0.39	0.45*	0.99	0.36	0.44*	0.95	0.35	0.42*
Attention	-0.08	0.17	-0.08	-0.07	0.16	-0.08	-0.08	0.15	-0.08	-0.08	0.15	-0.08			
CAMPROMPT Total	-0.12	0.60	-0.04	-0.13	0.57	-0.05	-0.11	0.51	-0.04						
CAMPROMPT Strategy Use	0.89	9.82	0.02	0.93	9.42	0.02									
Immediate Memory	0.01	0.24	0.01												
R^2		0.61			0.61			0.61			0.61			0.61	
F change for R^2		3.44			0.00			0.01			0.05			0.26	

Table 30. *Backward Stepwise Regression Models of CUE JOL and Injury, Demographic, and Neuropsychological Factors for TBI Group*

	Model 1			Model 2			Model 3			Model 4			Model 5		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	57.88	29.08		63.51	28.97		52.55	27.40		33.54	23.84		15.51	18.97	
Immediate Memory	0.43	0.23	0.40	0.53	0.22	0.49*	0.55	0.22	0.51*	0.54	0.23	0.50*	0.58	0.23	0.54*
MPAI	-0.54	0.32	-0.37	-0.59	0.32	-0.41	-0.51	0.32	-0.35	-0.37	0.31	-0.26			
PRMQ	-0.35	0.27	-0.28	-0.37	0.27	-0.30	-0.36	0.27	-0.28						
CAMPROMPT Strategy Use	-10.99	7.61	-0.32	-7.89	7.18	-0.23									
CAMPROMPT Total	-10.99	7.61	-0.32												
R^2		0.52			0.47			0.42			0.35			0.29	
F change for R^2		0.51			1.28			1.21			1.73			1.48	

Table 31. *Backward Stepwise Regression Models of TASK JOL and Injury, Demographic, and Neuropsychological Factors for TBI Group*

	Model 1			Model 2			Model 3			Model 4			Model 5		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	27.53	32.59		12.96	29.66		4.65	29.84		16.97	26.79		-3.96	21.38	
Immediate Memory	0.75	0.31	0.59*	0.73	0.31	0.57*	0.56	0.30	0.44	0.71	0.25	0.56*	0.75	0.26	0.59**
MPAI	-0.76	0.39	-0.44	-0.63	0.37	-0.37	-0.42	0.35	-0.24	-0.43	0.34	-0.25			
Attention	0.39	0.28	0.33	0.39	0.28	0.34	0.26	0.27	0.22						
Verbal Fluency *Category*	-2.85	1.80	-0.44	-2.36	1.75	-0.37									
CAMPROMPT Strategy Use	-8.87	8.39	-0.22												
R^2		0.55			0.51			0.45			0.41			0.35	
F change for R^2		0.25			1.12			1.82			0.90			1.59	

Table 32. *Backward Stepwise Regression Models of CUE Recall and Injury, Demographic, and Neuropsychological Factors for HC Group*

	Model 1			Model 2			Model 3		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	54.84	11.18		55.62	10.78		66.09	8.45	
CAMPROMPT Time	1.05	0.60	0.39	1.11	0.58	0.41	1.49	0.53	0.55*
PRMQ	0.28	0.24	0.28	0.32	0.21	0.32			
CUE JOL	0.05	0.12	0.10						
R^2		0.39			.38			.30	
F change for R^2		3.43			0.20			2.22	

Table 33. *Backward Stepwise Regression Models of TASK Recall and Injury, Demographic, and Neuropsychological Factors for HC Group*

	Model 1			Model 2			Model 3			Model 4		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	61.39	26.12		64.76	22.24		55.94	16.08		73.33	4.60	
CAMPROMPT Strategy Use	16.89	7.32	0.62*	17.95	5.98	0.66**	16.12	5.00	0.59**	16.96	4.98	0.63**
Immediate Memory	0.15	0.17	0.18	0.14	0.16	0.18	0.17	0.15	0.21			
CAMPROMPT Event	-0.45	0.83	-0.12	-0.47	0.81	-0.13						
PRMQ	0.07	0.26	0.06									
R^2		0.45			.45			.43			.39	
F change for R^2		3.05			0.07			0.35			1.27	

Table 34. *Backward Stepwise Regression Models of CUE Recall and Injury, Demographic, and Neuropsychological Factors for TBI Group*

	Model 1			Model 2			Model 3			Model 4		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	-17.83	38.06		-25.60	32.35		-22.54	31.26		-25.46	30.94	
Attention	0.73	0.52	0.44	0.64	0.46	0.39	0.76	0.41	0.46	0.97	0.33	0.59*
CAMPROMPT Event	1.41	1.84	0.20	1.33	1.78	0.19	1.55	1.70	0.23			
Verbal Fluency - Letter	1.44	2.69	0.15	1.56	2.59	0.16						
Immediate Memory	-0.19	0.45	-0.11									
R^2		0.40			.40			.38			.35	
F change for R^2		2.21			0.18			0.36			0.84	

Table 35. *Backward Stepwise Regression Models of TASK Recall and Injury, Demographic, and Neuropsychological Factors for TBI Group*

	Model 1			Model 2			Model 3		
Variable	*B*	*SE B*	*β*	*B*	*SE B*	*β*	*B*	*SE B*	*β*
(Constant)	-73.71	33.47		-74.23	32.58		-81.83	27.54	
Immediate Memory	1.05	0.60	0.39	1.11	0.58	0.41	1.49	0.53	0.55*
CAMPROMPT Event	0.91	0.44	0.48	1.00	0.39	0.52*	0.92	0.35	0.48*
Attention	-0.23	0.43	-0.13	-0.19	0.41	-0.11			
Verbal Fluency *Category*	1.23	2.34	0.13						
R^2		0.57			.57			.56	
F change for R^2		4.39			0.28			0.22	

Table 36. *Comparison of HC, Moderate TBI, and Severe TBI Participant Performance on JOL and Recall Accuracy*

	Cue Component			Task Component		
Group	JOL	Recall	Absolute	JOL	Recall	Absolute
HC	73.24	89.25	-16.01	71.80	87.75	-15.95
Moderate TBI	74.29	78.33	-4.04	74.75	55.00	19.75
Severe TBI	60.39	60.00	.39	53.86	20.33	33.53

Figures

Figure 1. *Cognitive Processes of Prospective Memory*

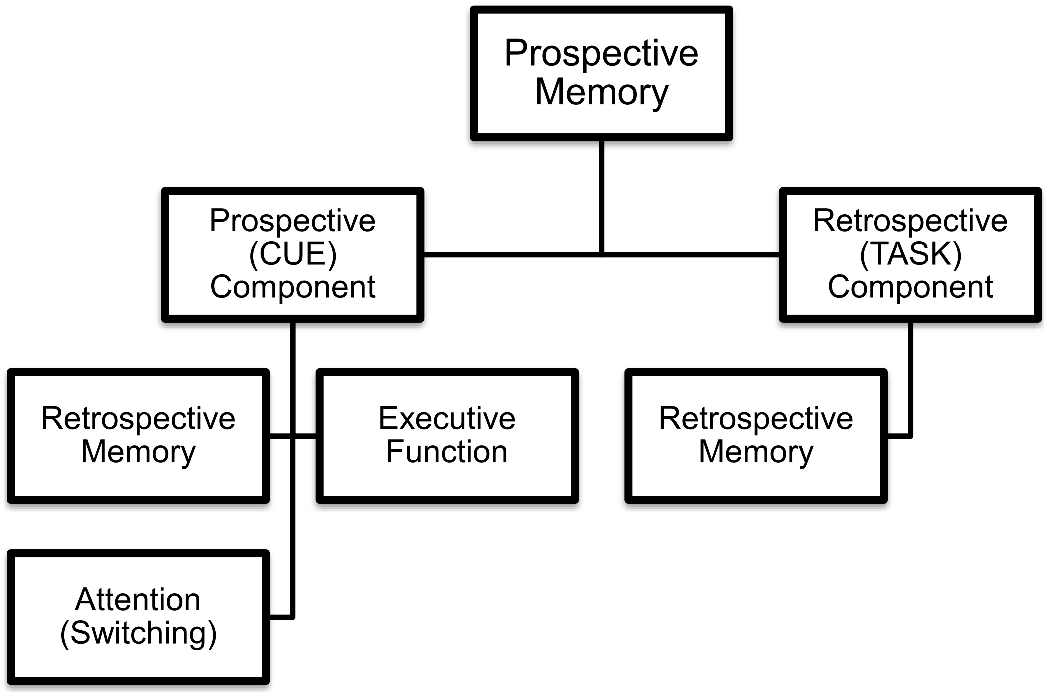


Figure 2. *Neurological Bases of Prospective Memory*

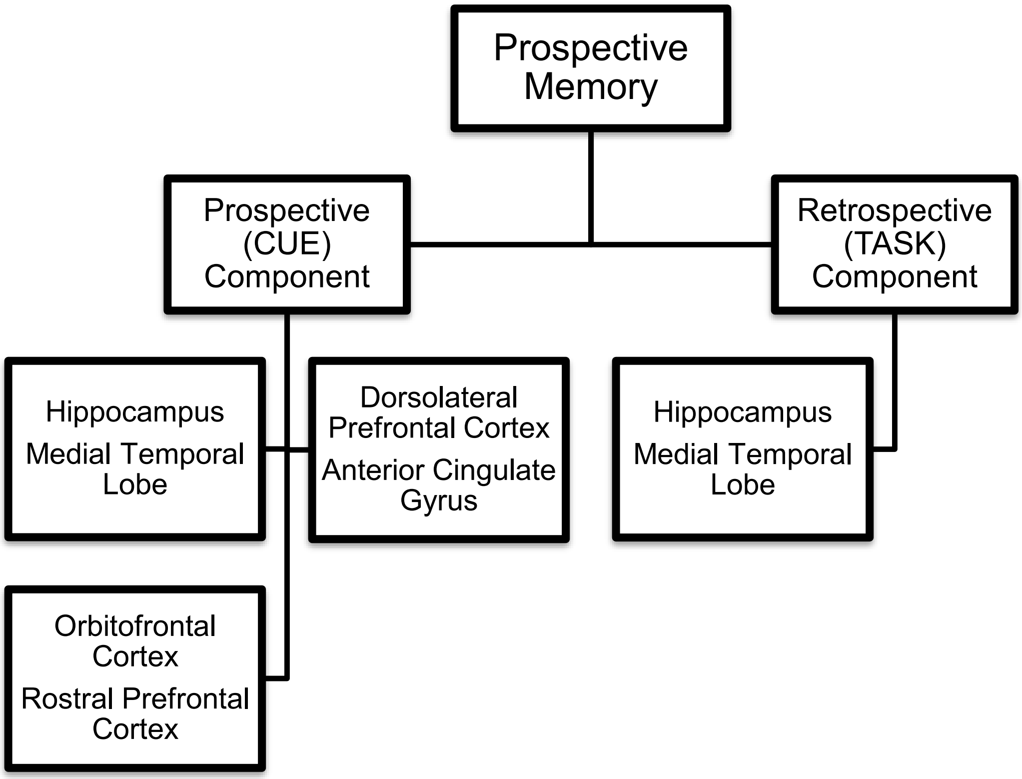


Figure 3. *Images and Titles for Ten Daily Scenes*

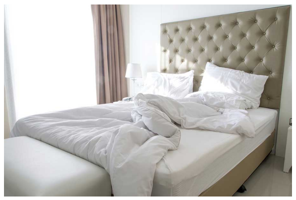
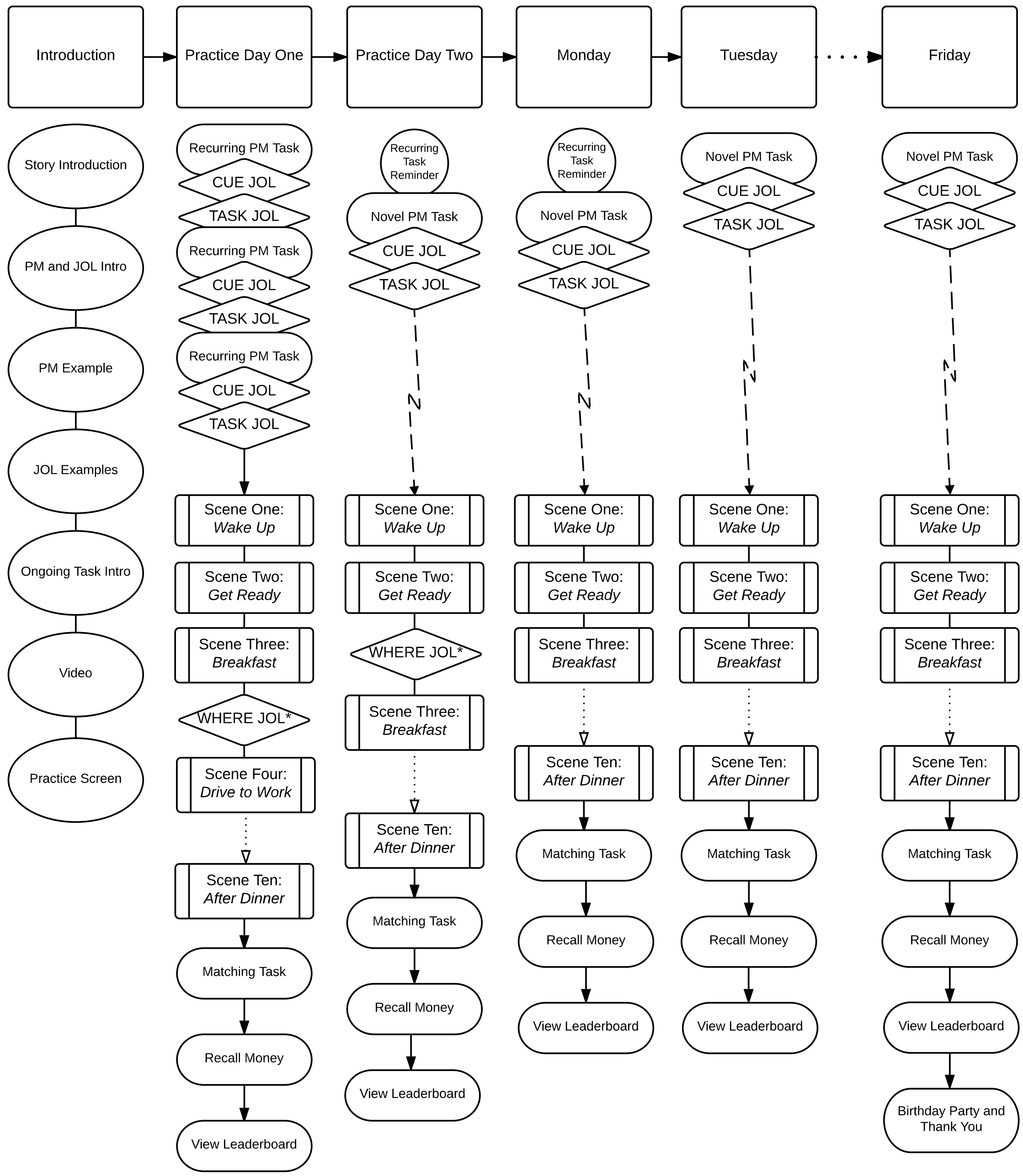
Wake Up	*Get Ready for the Day*	*Breakfast*	*Go to Work*	*At the Office*
				
Lunch	*Afternoon Meeting*	*Drive Home*	*Home*	*After Dinner*
				

Figure 4. *Schematic of Game Design*



*WHERE JOLs occurred twice each day in a randomized sequence and referred to the scene that had just passed (i.e., for practice day one, the WHERE JOL in the diagram refers to "Scene Three: Breakfast."

Figure 5. *Screen Capture of Experimental Scene*

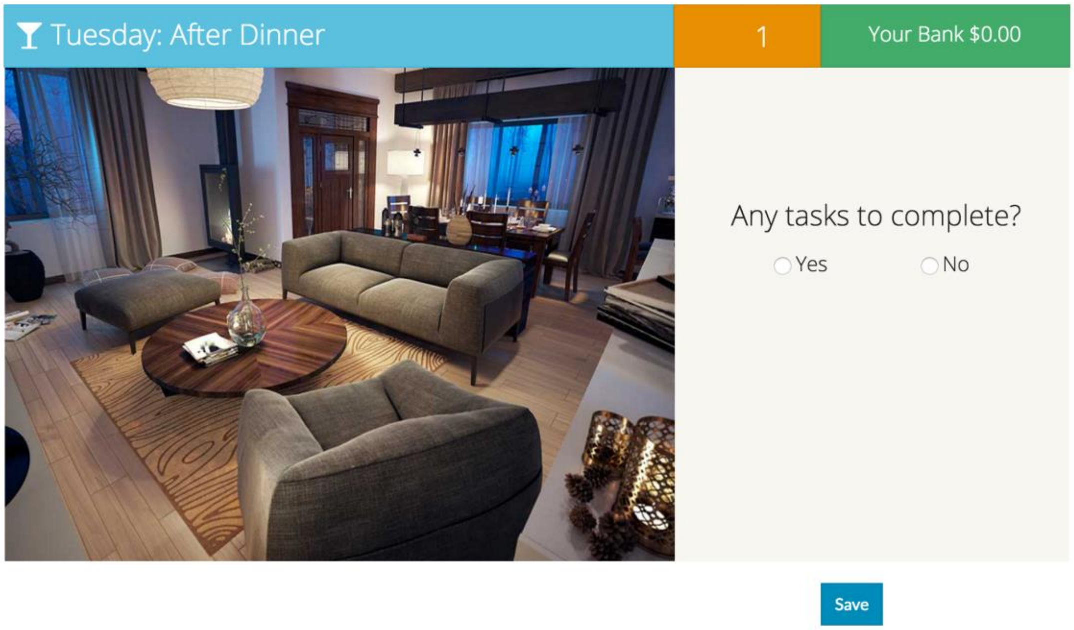


Figure 6. *Screen Capture of Task Study and JOL Sequence*

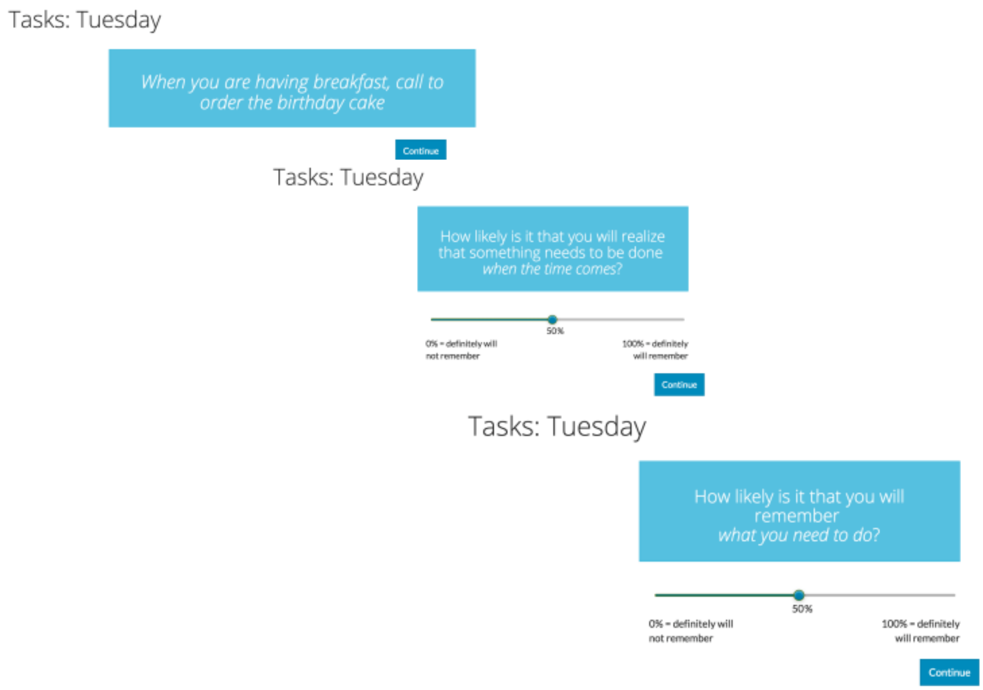


Figure 7. *Screen Capture of Matching Task*

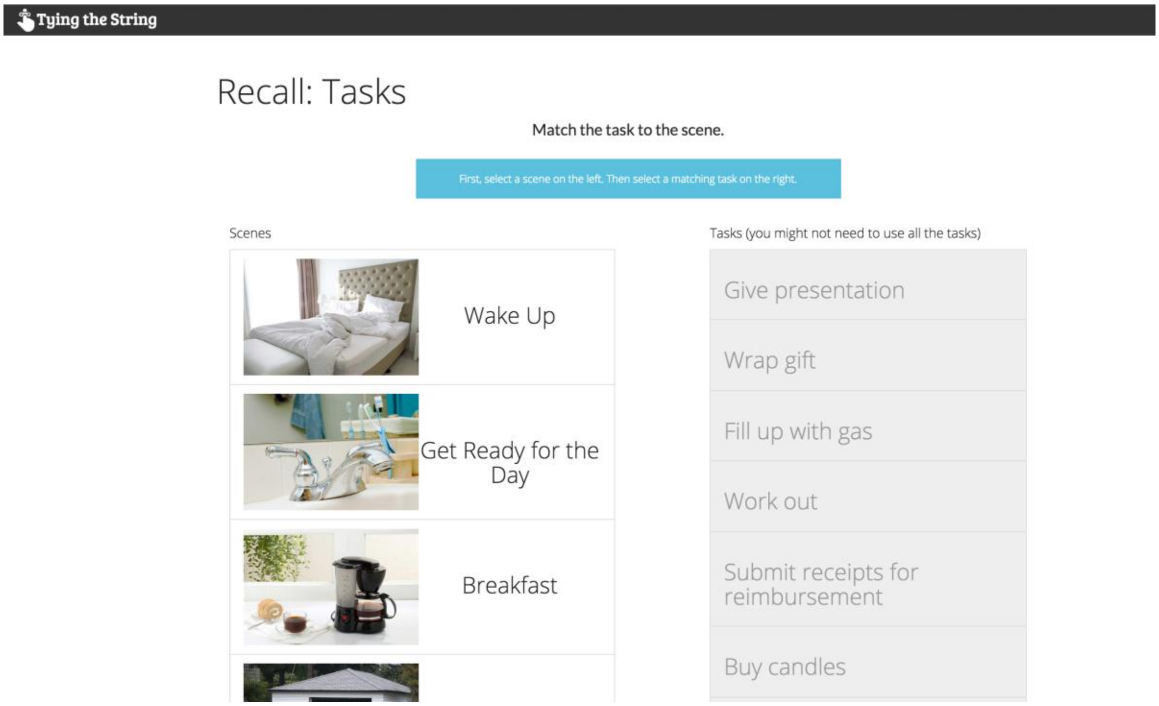
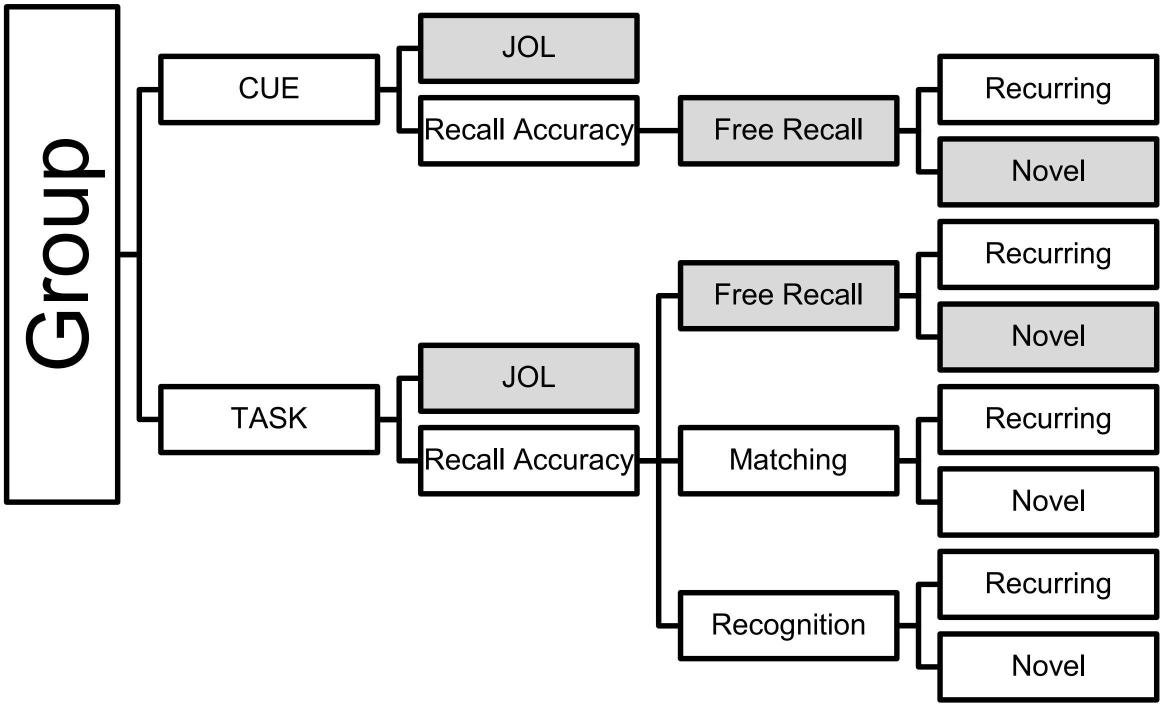


Figure 8. *Schematic of Primary Independent and Dependent Variables*



Note: Contrasts of interest for metamemory accuracy are highlighted in gray.

Figure 9. *Mean Judgments of Learning by Group and Component*

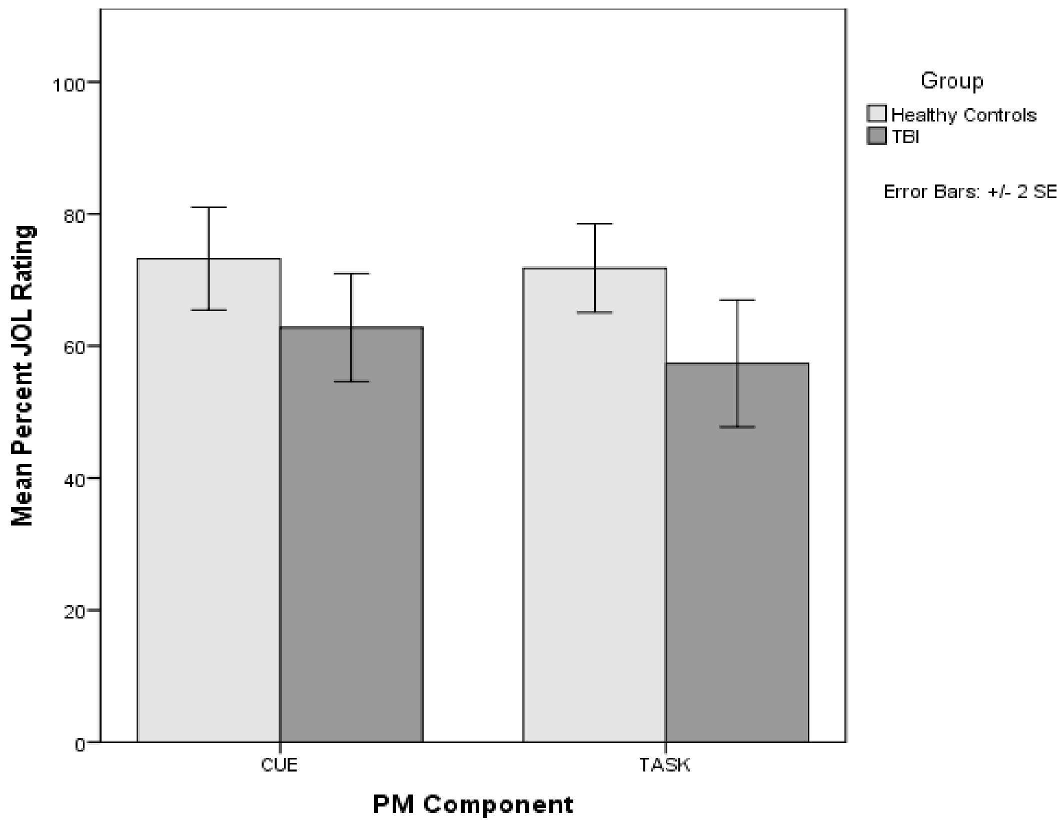


Figure 10. *Mean Free Recall Accuracy by Group and Component*

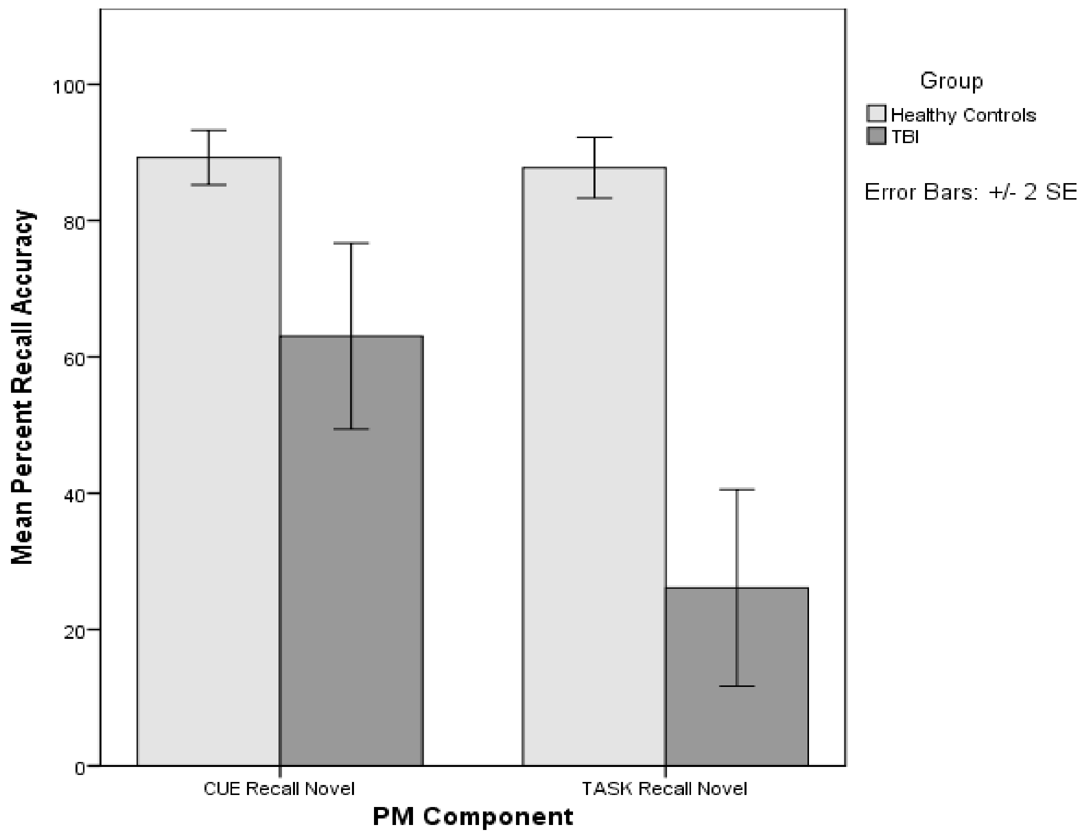


Figure 11. *Mean Accuracy by Group, PM Component, and Recurrence*

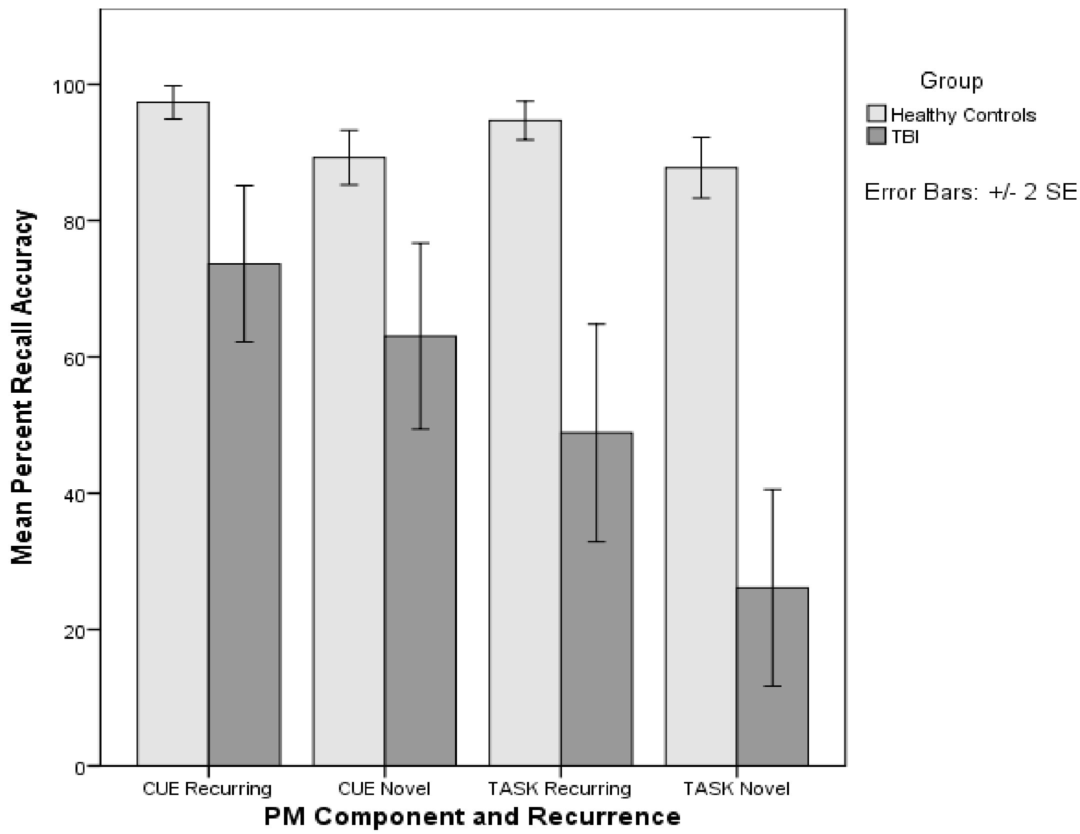


Figure 12. *Mean Recall Accuracy by Group and Type of Recall for Recurring Tasks*

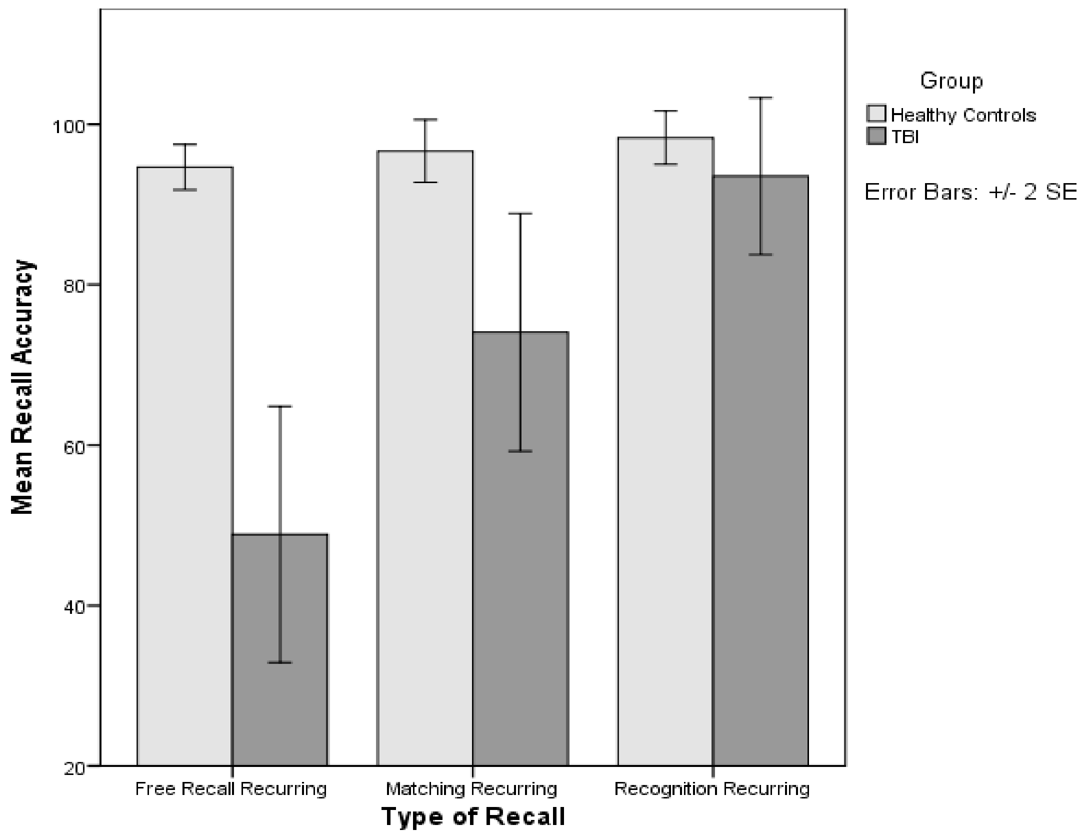


Figure 13. *Mean Recall Accuracy by Group and Type of Recall for Novel Tasks*

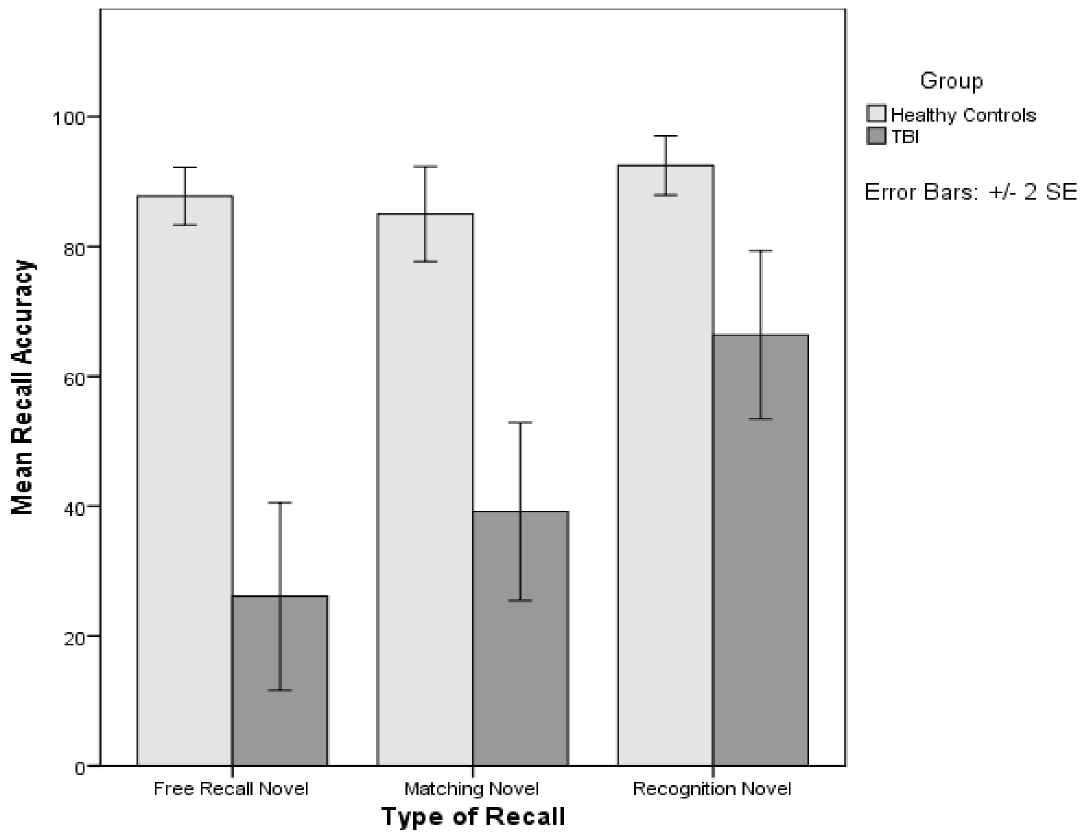


Figure 14. *Absolute Metamemory Accuracy by Group and PM Component*

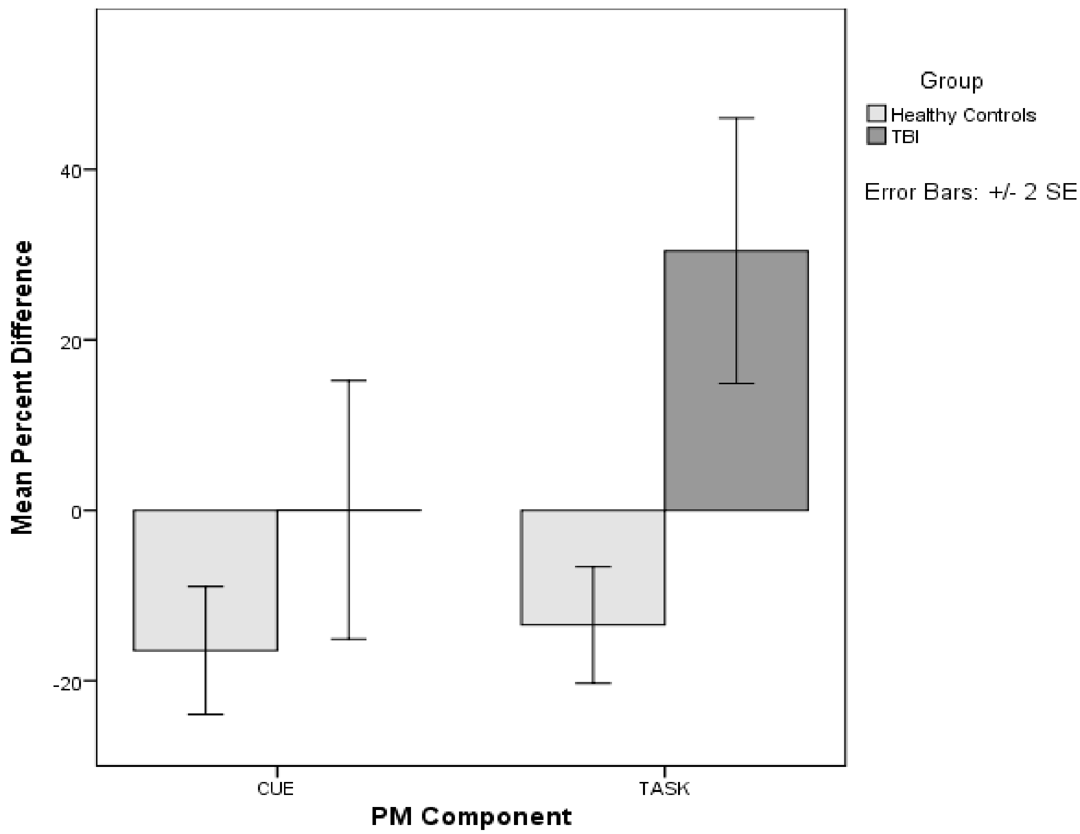
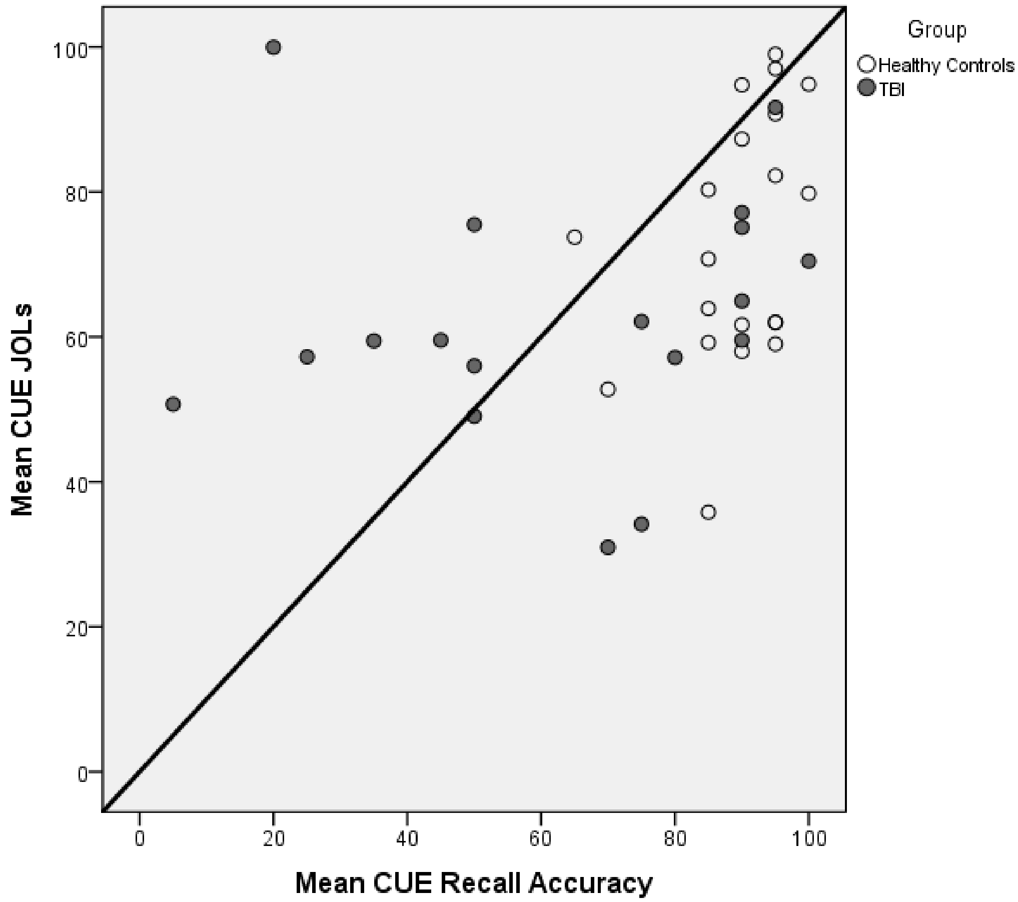
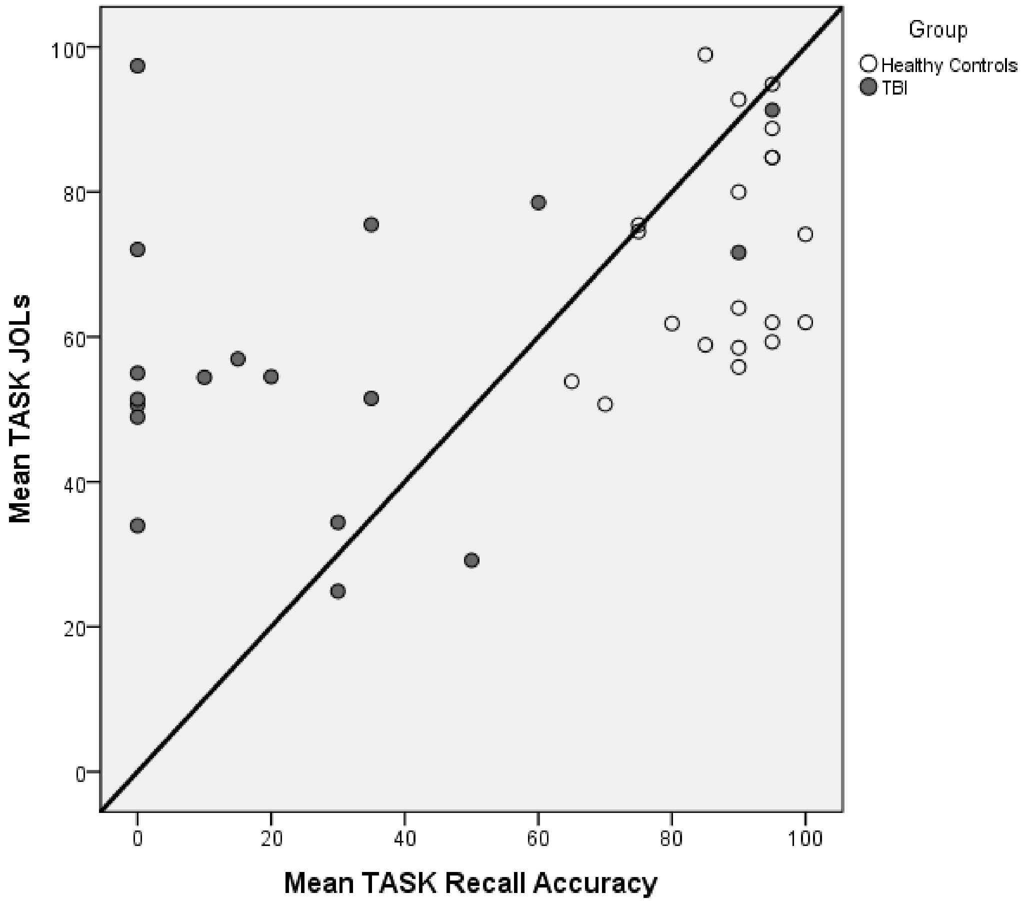


Figure 15. *CUE JOL Ratings Plotted by Recall Accuracy*



Note: Data points above the diagonal line indicate overconfidence; those under the line indicate underconfidence.

Figure 16. *TASK JOL Ratings Plotted by Recall Accuracy*



Note: Data points above the diagonal line indicate overconfidence; those under the line indicate underconfidence.

Figure 17. *Relative Metamemory Accuracy by Group and PM Component*

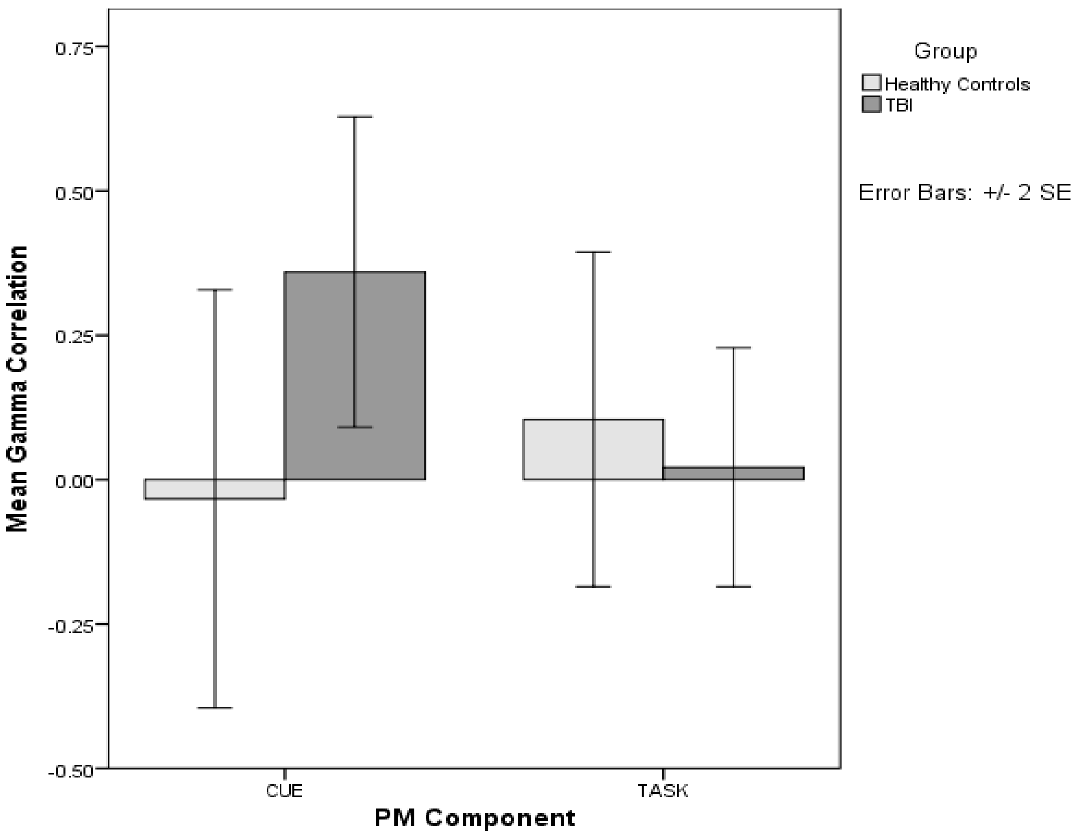


Figure 18. *Fitted Regression Lines by Group to Change Over Time on CUE JOLs*

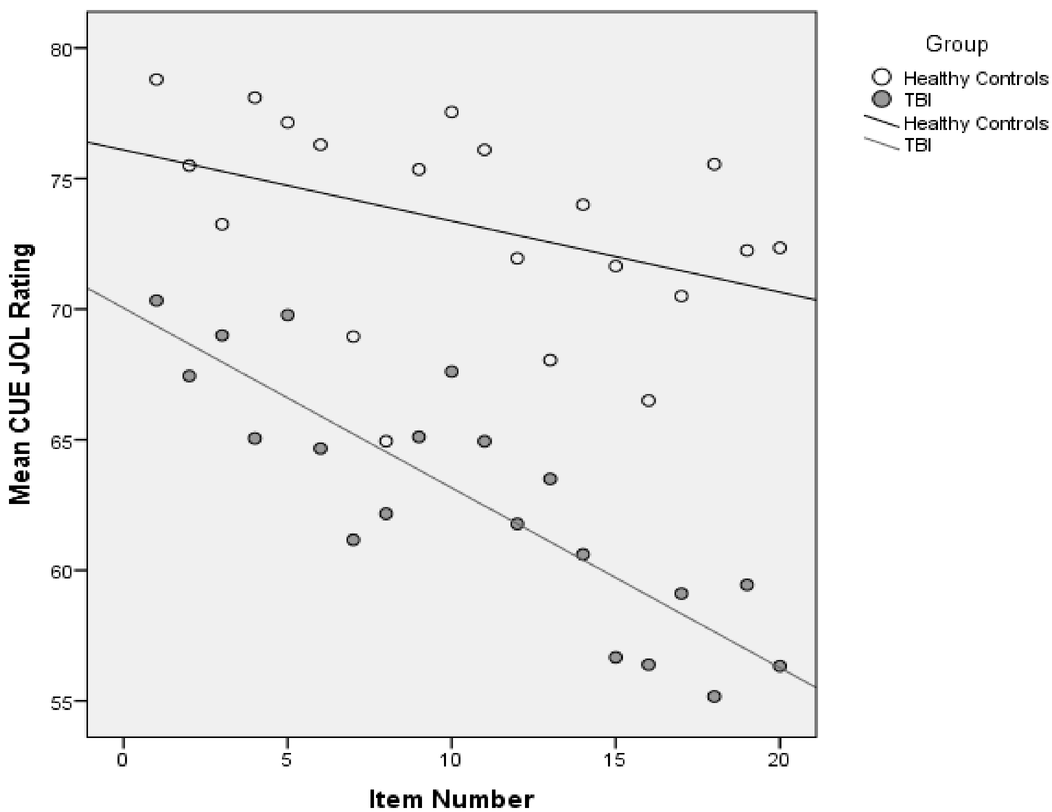


Figure 19. *Fitted Regression Lines by Group to Change Over Time on TASK JOLs*

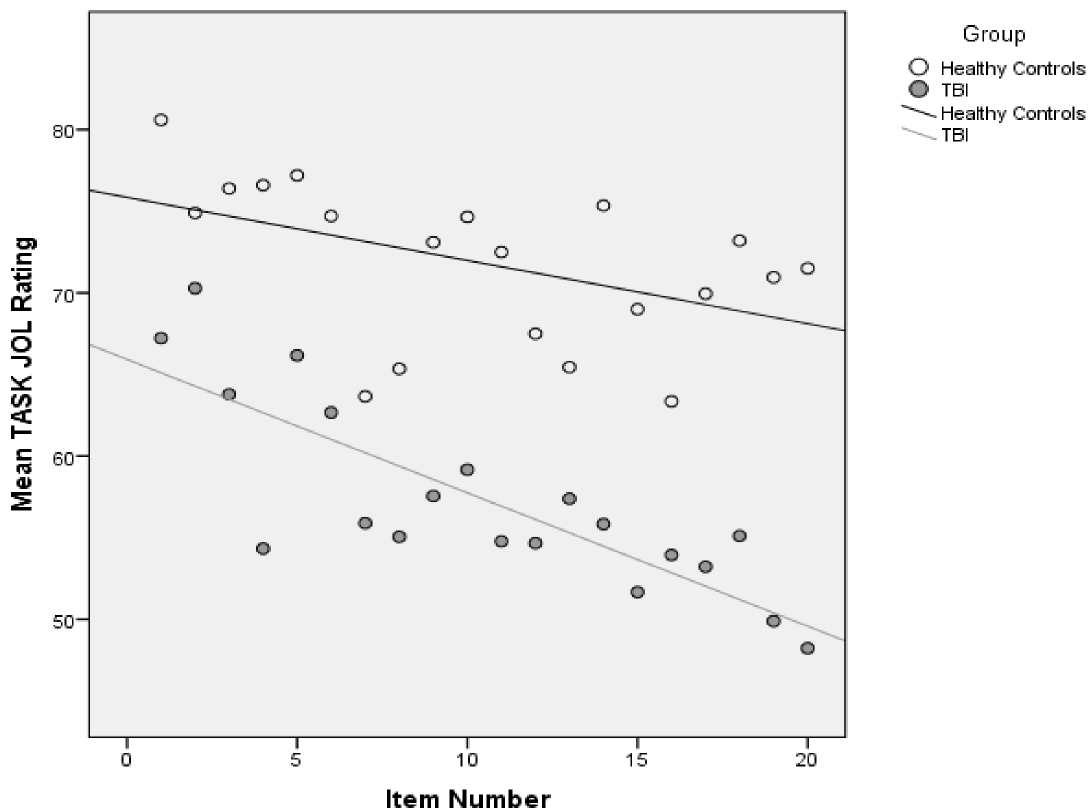


Figure 20. *Fitted Regression Lines by Group to Change Over Time on Novel CUEs*

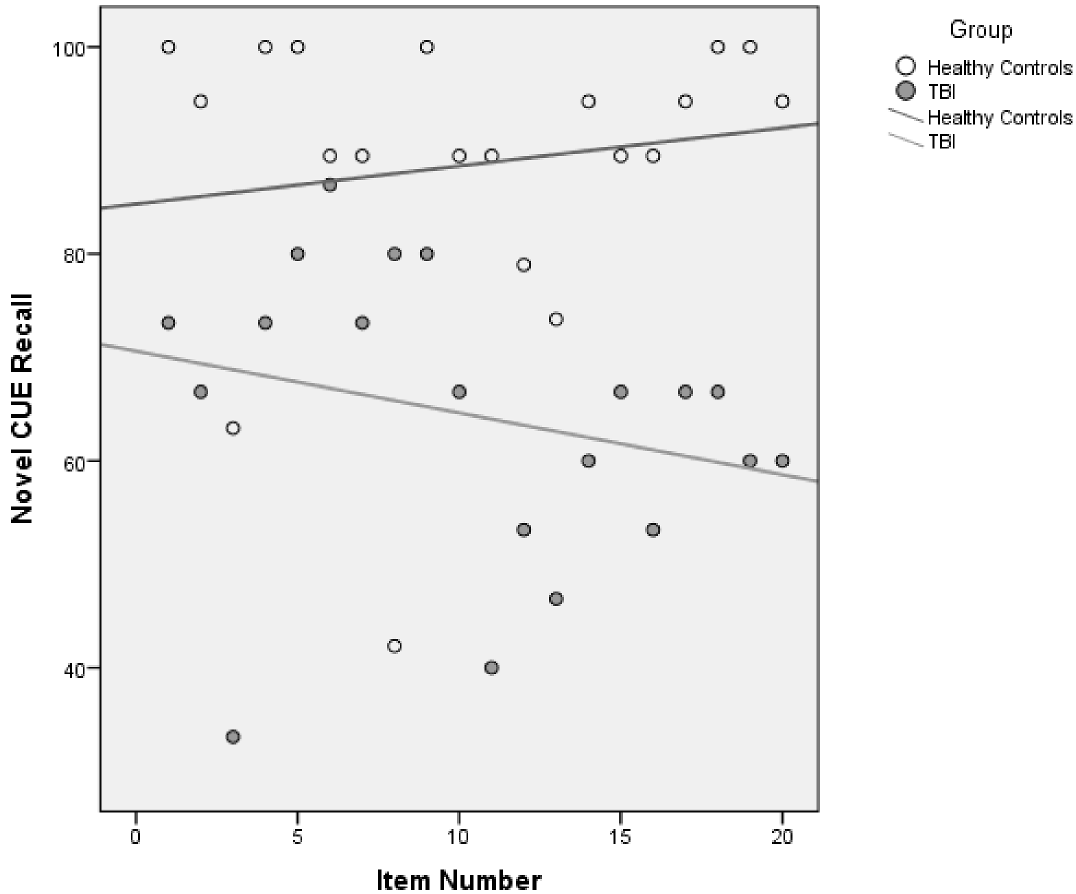


Figure 21. *Fitted Regression Lines by Group to Change Over Time on Novel TASKs*

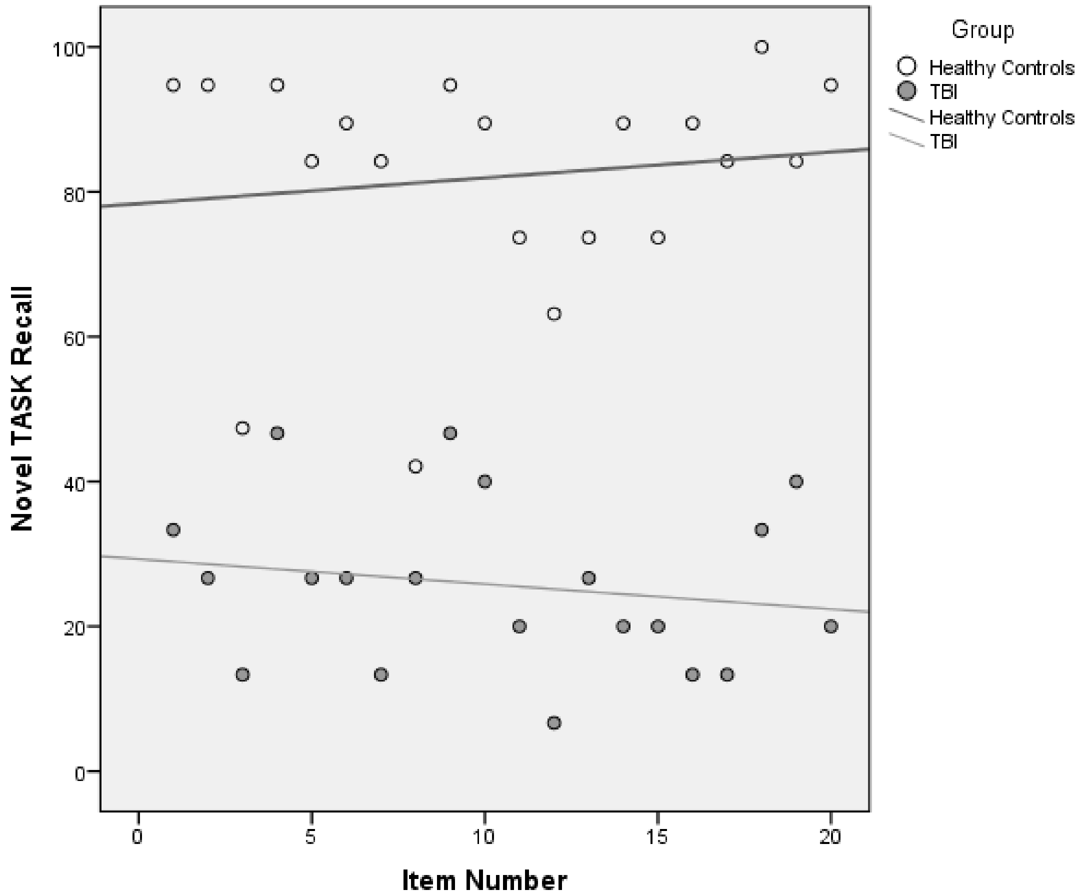


Figure 22. *Fitted Regression Lines by Group to Change Over Time on Recurring CUEs*

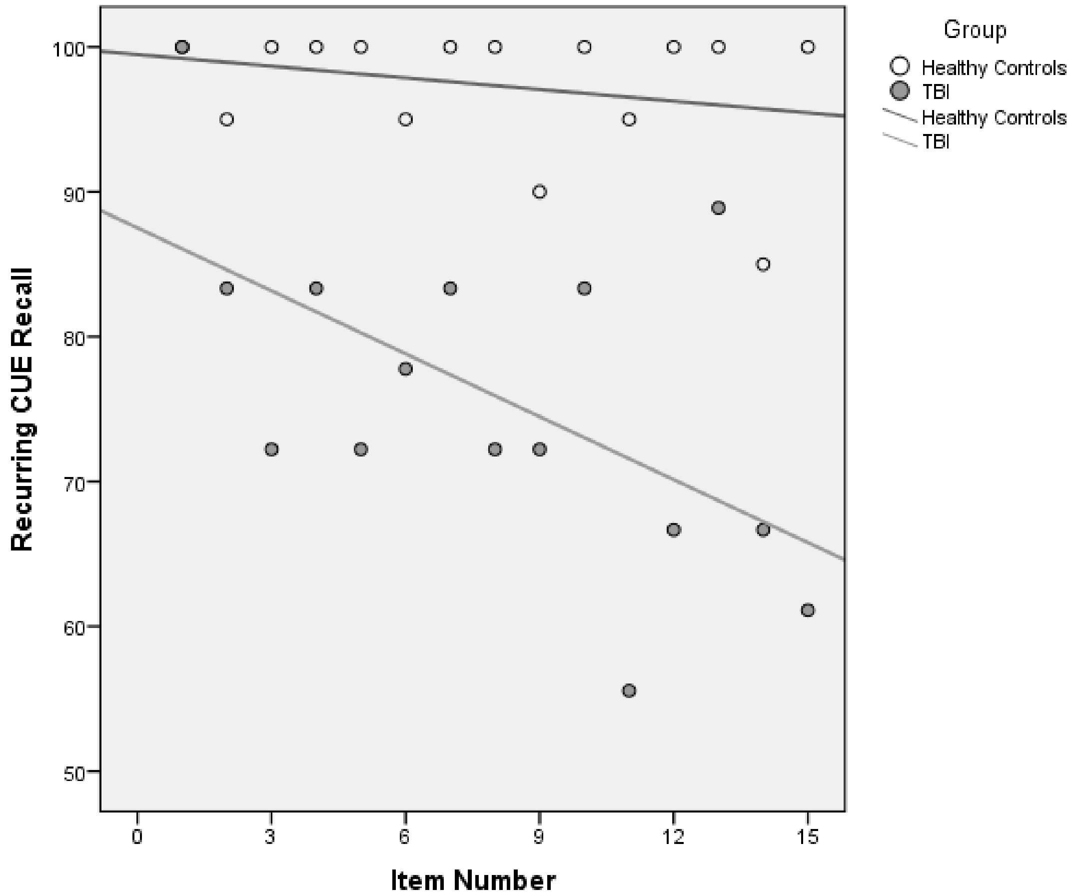


Figure 23. *Fitted Regression Lines by Group to Change Over Time on Recurring TASKs*

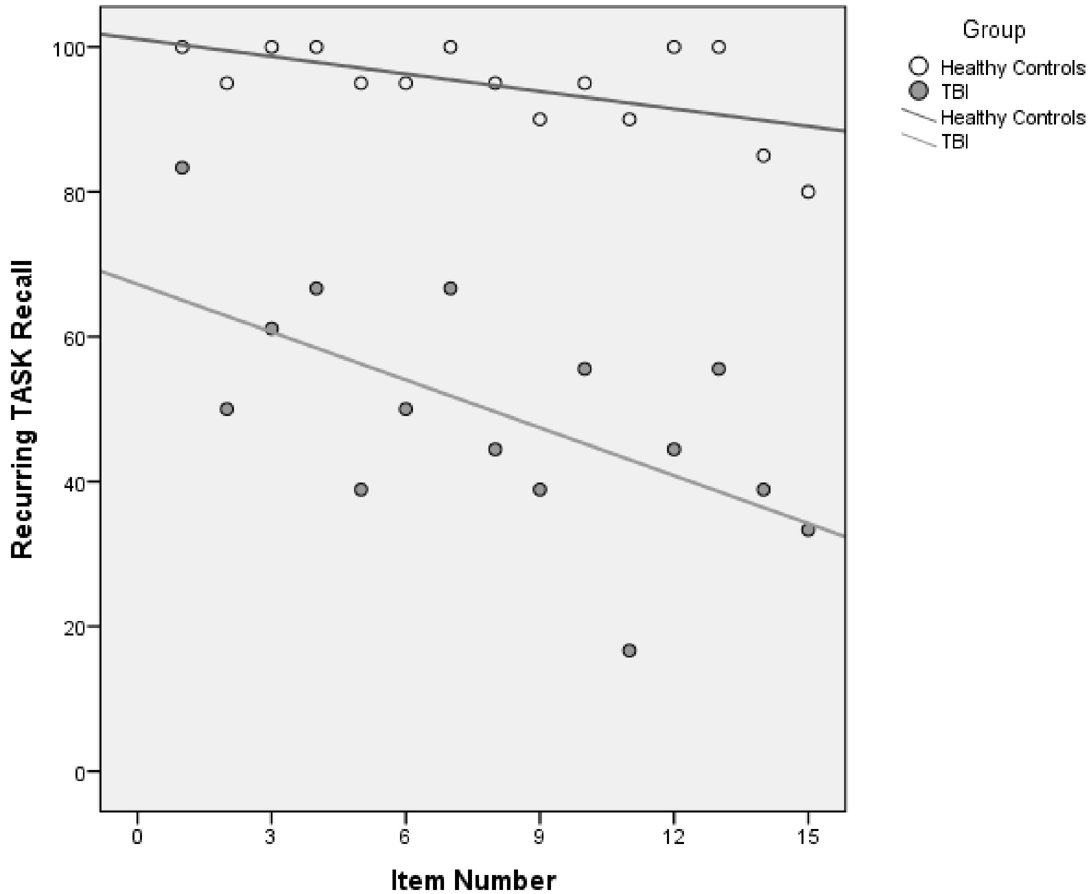


Figure 24. *Comparison of Mean JOL Ratings across PM Components and Distractor (WHERE) Tasks*

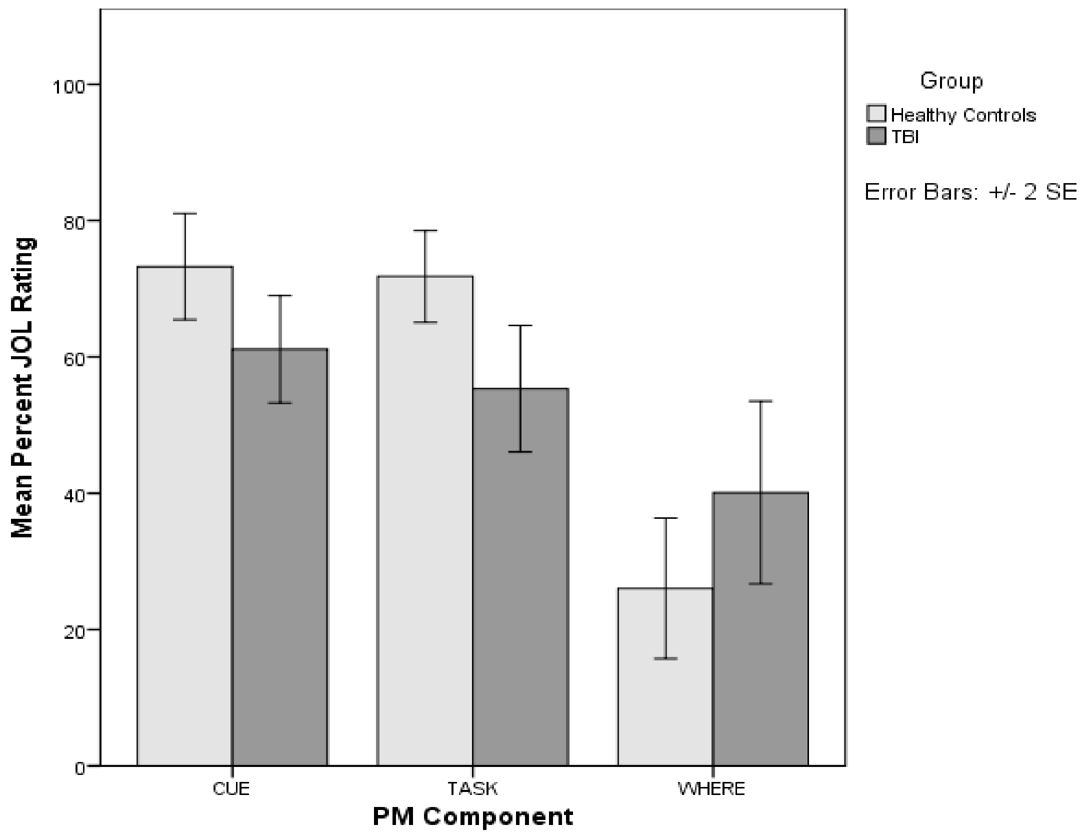
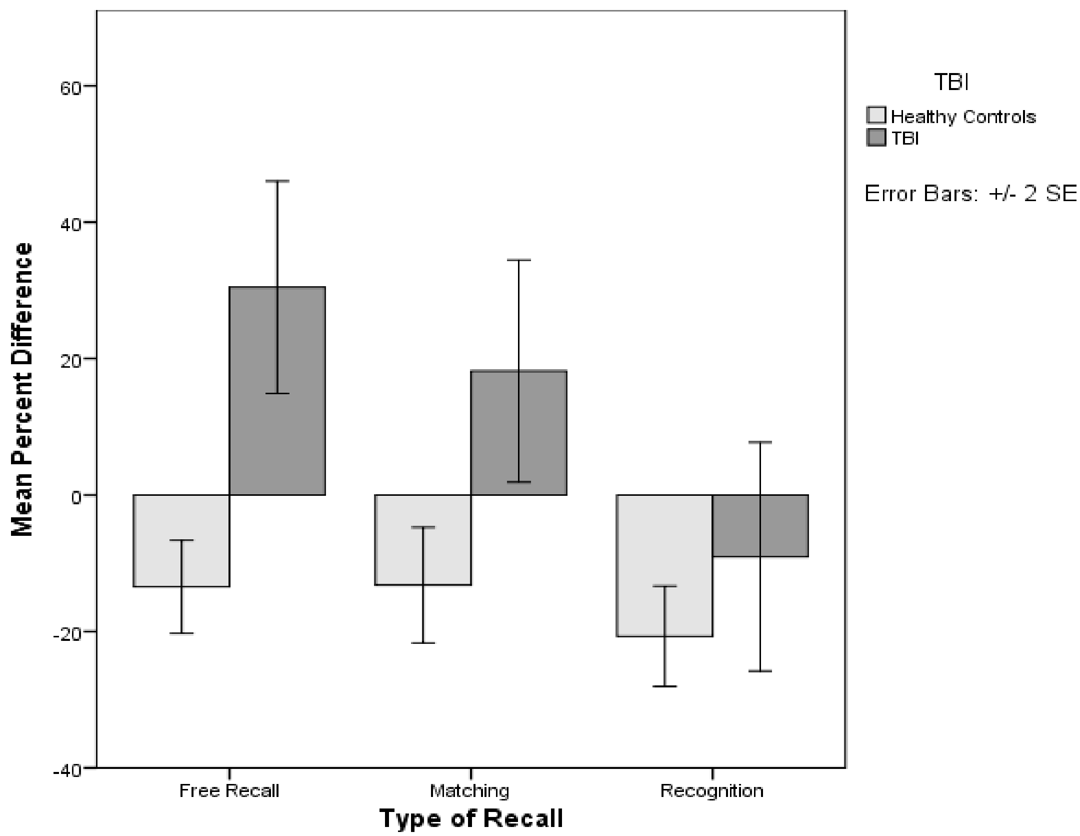


Figure 25. *Comparison of Mean Absolute Difference Scores for PM Task Across Type of Recall*



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Appendices

Appendix A: Pilot Study with Healthy Adults

Purpose and Methods

In a pilot study, a convenience sample of eight adults completed the experimental task, *Tying the String*, using personal computers. The PI contacted a convenience sample of adults via email asking if s/he would like to participate in piloting *Tying the String*. Participants replied to this email and if interested, the PI sent a 10-digit code that would allow the person to log on to the game at their convenience. The PI requested that participants allow 90 minutes to complete the game, that participants not take notes of tasks to be completed, and that headphones were used to maximize audio quality. Participants in Experiment One completed the game on their personal computers using headphones or ear buds of their choosing. Afterwards, participants provided feedback via email or in person with the PI. The purpose of the pilot experiment was to examine feasibility of the game administration and to gather participant reactions and feedback to experiencing the game.

Research Aims

- To develop a tool assessing metamemory for PM in adult populations that can be easily administered and completed in a reasonable time span by:
    - Analyzing completion rates with a goal of greater than 95% of participants completing the game.
    - Analyzing time to completion with a goal of less than thirty minutes for the experimental task.
    - Collecting and qualitatively reviewing requests for clarification during game administration to consider refinement of task instructions.
  - *Hypothesis:* Participants will complete the game and training in less than 40 minutes with few complaints about the complexity of the task
    - *Dependent Variable:* completion rates, time to completion, requests for clarification of instruction, comments about game
    - *Analysis:* Descriptive statistics for completion rate and time to completion for all participants will be calculated. Qualitative reports of difficulty or requests for clarification were collected.
    - *Implications:* Upholding the hypothesis would indicate that the game is comprehensible and participants are able to complete it independently or with minimal requests for clarification. If the hypothesis is not upheld, then adjustments to the timing component of the game or to the instructions and training may be indicated.

Results

The research question for experiment one focused on the feasibility of the game administration and completion in order to refine the game for use with adults with TBI in the main experiment. Quantitative dependent variables included rate of completion and time to completion and qualitative information was gathered on requests for clarification and feedback about the game.

Participants in the pilot experiment included eight adults aged 23 to 65 all without history of brain injury. All but one participant completed the game in a single sitting. The person who did not complete the game did not follow instructions to complete the game using a computer, instead attempting to use an iPad. The game requires the use of an external mouse in order to search the image for money. The participant who used the iPad offered to retake the game, but time did not allow for that person to do so. All other participants completed the game independently during the first attempt.

Game administration time ranged from 1:05:21 to 1:22:04 with a mean of 1:13:41. Although this exceeded the initial estimation of 40 minutes, all participants stated that two days of training were necessary at the beginning of the game. Training took an average of 00:29:06, so that the experimental task was completed in an average time of 00:44:35.

Requests for clarification clustered around the recurring tasks only. The majority of pilot participants reported confusion as to whether or not these tasks were only for training purposes or if they were to be performed during the experimental portion of the game. Participants requested no other clarifications. Other comments communicated enthusiasm about finding the money in the pictures and curiosity about performance on the PM tasks. Participants denied fatigue despite game length, reporting sufficient engagement to maintain focus.

Overall, the game was reported to be comprehensible with the exception of the recurring tasks. Explicit written and auditory instructions were added in to two places as a result of this feedback: at the beginning of practice day two and the beginning of the experimental task (i.e., “Monday”). In both cases, participants saw the three recurring items again, allowing for additional study time, and were instructed to continue performing these tasks every day.

Positive feedback from the pilot study included that the game was engaging, the tasks were comprehensible, and the time to completion was reasonable. Negative feedback included confusion as to whether the recurring tasks were used only for training or to be continued throughout the game. Participants also requested that the video more clearly state to close the screen to begin practice. Participants expressed concern about recalling money found in scenes, stating that the task was difficult. Feedback also requested that the money recall screen include a button to clear responses or select that no money had been found in the initial exposure to the screen.

Game Revisions

Based on feedback from experiment one, revisions were made to the game to increase clarity of the instructions, consistency across the game, and ease of interface for individuals with TBI. Revisions included:

1. Additional study opportunities and reminders to perform the recurring tasks were added during the second practice day and at the beginning of the game. Prior to beginning the game on “Monday,” a screen was added

with the three recurring tasks for restudy, again stating participants should remember to perform these tasks every day.

2. The video was edited to tell participants to close the window once the video was complete, and the text on the button was updated to match this instruction.
3. The recall money task was clarified in the instructions to tell participants that the location recalled did not have to be exact, but would be scored correct if the 3 x 3 quadrant location was correct. The additional instructions that recall could reflect a more general rather than specific location was added to encourage participants to persist at this task.
4. Additionally, a button was added to the money recall screen to allow participants to clear responses.
5. Additionally, a second button was added to the money recall screen to allow participants to indicate that no money had been found (and thus could not be recalled).

Appendix B: Consent Form for Group with TBI

Memory Study
Consent Form for Adults with TBI

You are invited to be in a research study looking at memory in adults with and without traumatic brain injury (TBI). Please take your time reading this form. Ask any questions you may have before agreeing to be in the study. This study is being conducted by Katy O'Brien, MA, CCC- SLP, and Dr. Mary Kennedy, Ph.D. in the Department of Speech-Language-Hearing Sciences, University of Minnesota

Background Information:
This study is looking at how well people are able to remember. Some questions will ask about things that have already happened. Other questions will ask you to remember to do something in the future. The purpose of this study is to compare how adults with and without TBI do when remembering different kinds of information. People with TBI often have difficulty with their memory. We are hoping to find better ways to help them with their memory.

Procedures:
If you agree to participate, you will attend one session. This session will last about 3 to 4 hours. You will play a game on a computer that takes through a typical workweek. You will have lots of errands to perform. You will also have to remember things that happen in the game.

After the game, you will complete a few tests. These tests will look at remembering, planning, and thinking of words. These tests will take about two hours to complete. You will be given breaks throughout.

You will be doing tests that include listening, following directions, remembering words, and talking. Some will require careful attention. We will be tape recording some of the tests. We will give you instructions for each of these tests. You can choose to NOT answer any question at any time.

Risks and Benefits of Being in the Study:
There is no known risk to your health in this study. There is a small risk of mental discomfort if you are worried about doing really well on the tests. If you would like to see your test results, we can mail them to you after they are scored. You also might not want to answer some personal questions. You do not have to answer anything you do not want to answer.

You may also become tired during testing. If you feel tired, you may take a break. If the researcher notices that you look tired or restless, we will offer you a break too.

There is no direct benefit to you for being in this study. This study will not make your memory better. Instead, we are hoping to find out more about how we can help people with TBI. Your participation will let us know more about how people with TBI remember information. There is no cost to you for participating.

Compensation:
You will be paid for the amount of time you participated in the study. You will receive $30 for completing this study. If you do not complete the study, you will be paid by how much you completed. Your completion will be rounded to the nearest quarter. For example, if you complete about half of the study, you will receive $15. If you complete about three quarters, you will be paid $22.50.

Confidentiality:
The records of this study will be kept private. When we provide results to this study, we will not include any information that could identify you. All of the test scores and records will be kept in a locked file cabinet. These records will be destroyed after ten years. Your identity as a participant will remain confidential throughout the study. Only the researchers will have access to identifying information. Your responses to these activities will be used only for research.

Any personal health information (PHI) created or received for this study is protected under the federal law known as HIPAA. That form has more details about how that information will be used.

Voluntary Nature of the Study:
Participation in this study is voluntary. You may decide to stop your participation in this study at any time. It will not affect your relationship with the University of Minnesota or the researchers.

Contacts and Questions:
The researchers conducting this study are: Katy O'Brien, MA CCC-SLP and Mary Kennedy, PhD. You may ask any questions you have now. If you have questions later, **you are encouraged** to contact Ms. O'Brien at the Speech-Language-Hearing Sciences Department, 612-626-9756 or obrie765@umn.edu.

If you have any questions or concerns regarding this study and would like to talk to someone other than the researcher(s), **you are encouraged** to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware St. Southeast, Minneapolis, Minnesota 55455; (612) 625-1650.

You will be given a copy of this information to keep for your records.

Statement of Consent:
I have read the above information. I have asked questions and have received answers. I consent to participate in the study.

*Signature:*____________________________________ *Date:* __________________

____
Print full name

*Signature of Investigator:*_______________________ *Date:* __________________

____
Print full name

COMPREHENSION QUESTIONS:

1. Will you receive any money to pay you for participating in the study? Y or N
2. Name two activities that are part of this study.
   1) ______________________________
   2) ______________________________
3. Can you decide to stop being in the study at any point in time? Y or N

Briefly, what is this study about?
____
____
____
____

Appendix C: Initial Intake Interview for Healthy Controls and Adults with TBI

ID: ______________________

Today's date: ______________

Interviewer's Initials: __________

INITIAL INTAKE PROTOCOL: EXPERIMENTAL PARTICIPANTS

Remembering to Remember: Prospective Memory after Traumatic Brain Injury

After researchers have been contacted by a potential participant indicating their interest and willingness to discuss possible participation in this study, the following is the initial intake protocol that will be used to during this first contact.

Greetings and Introductions

"Hi, I'm ____________, from the Speech-Language-Hearing Sciences at the University of Minnesota. I received a phone message (or email) recently indicating that you would be willing to discuss possible participation in our study. Are you still interested in hearing more about this study? I would like to discuss that with you now. Is this a good time to talk? Or should I call you back at a later time?"

Brief Description of the Study

Assuming they indicate willingness to continue, a description of the study would follow.

"In this study we are interested in how people think about their memory, for example, if they are "terrible with names," or "a quick learner." Studies have shown that it often takes time for people with brain injuries to adjust to cognitive changes they may have experienced. While this is happening, they may have a hard time knowing how "good" their memory is. However, no studies have looked to see how people do at the various kinds of memory, like remembering your last birthday party versus remembering to buy milk on the way home from work. Typical adults tend to be sensitive to these kind of differences – that some are harder than others – but it is not known how adults with TBI might respond to different kinds of tasks like this. We are hoping to look at this carefully to help plan better treatment for individuals with memory impairments. This study will require you to come in for one session that will last approximately three to four hours. During that time, you will have opportunities to take breaks throughout. First, we'll go through the consent form for the study and make sure all of your questions are answered and that you would like to participate. If so, in the second part, you'll play a computer game that uses lots of different kinds of memory. In the third part, we'll have you complete standardized testing that gives an overview of cognitive function."

"If you are still interested, I'd like to spend about 5 minutes asking you some questions, for which you are free not to answer any of the questions you do not wish to answer. Some questions have to do with your prior experiences in school, but others are more personal, like 'When you were in school, did you ever have difficulty learning how to read or write?', and 'Have you ever experienced an extended period of alcohol abuse?' All your answers are confidential. Shall I proceed?"

If the individual indicates that the investigator can continue, the following questions will be asked by phone; all questions will be reviewed again at the initial face-to-face meeting.

Demographic information

1. How old are you?________________
2. What is your birthday?____________________
3. Are you a high school graduate? Yes or No
4. What is the last grade you completed? _______________
5. Is English your first language? ________________________

   If NO: when did you learn English ______________________________________
6. Do you sign legal documents yourself? (power of attorney) Yes or No

   If no, who does? ____
7. When you were in elementary school, did you have any difficulty learning how to read or write?

   Yes or No

   If yes, please explain:____

____
8. When you were in elementary school, were you ever identified as being academically gifted?

   Yes or No

   If yes, please explain:____

____
9. Did you ever receive assistance in school in the form of speech therapy, or remedial help for anything else? Yes or No

   If yes, please explain:

____

____

10. To the best of your knowledge, is your hearing adequate? Yes or No

If no, please explain:

____

11. To the best of your knowledge, is your vision adequate or corrected to adequate? Yes or No

If no, please explain:

____

12. Are you currently on any medications that could alter your thinking? Yes or No

What medications are you on?

____

____

Injury information:

13. When and how were you injured?

____

14. Were you hospitalized after your injury?

____

15. Were you unconscious after your injury? Yes or No

If yes, for how long?

____

What is the first thing (situation, people, etc) you remember after your injury?

____

____

16. Were you working or in school at the time of your injury? Yes or No

If yes, what kind of work/school?

____

17. Did you take time off of work/school after your injury? Yes or No

If yes, how much?

____

18. Have you returned to work/school? Yes or No

19. Are you working at the same job and the same amount? Yes or No

Explain:

____

____

20. Is TBI your primary disability? Yes or No

21. Do you have any other disability, such as blindness, prior learning disability or a mental health disability? Yes or No

If yes, please explain:

____

____

Other Medical Information:

22. Have you ever been diagnosed with the following?
    - Stroke
    - Cancer or tumor
    - Multiple sclerosis
    - Parkinson's disease
    - Dementia
    - Hospitalized for psychological difficulty
    - Periods of unconsciousness
    - Previous head or brain injury
    - Any other neurological problem

23. Do you drink alcohol? Yes or No

    If yes, how much and how often?

    ____

    Have you ever received rehabilitation or help for alcohol abuse?

    ____

24. Do you use recreational drugs? Yes or No

    If yes, how much and how often?

    ____

    Have you ever received rehabilitation or help for drug abuse?

    ____

For participants who are screened out:

Should any participants not meet the selection criteria or be excluded based on identified exclusion criteria, indicated by their answers to the above questions, they will be informed of this over the phone in the following manner. This will vary slightly, depending on which selection criteria they do not meet. Examples of how this would be communicated are provided below:

> "You indicated that the primary language you speak is ___________ (e.g. Spanish). However, **in this particular study** all the activities involve remembering and telling stories in English. So, I appreciate your willingness and I want to thank you for your interest, for this study we need participants who speak English as their first language.
>
> "You indicated that you had encephalitis when you were 11 years old. Because the purpose of this particular study is to look at how people tell stories after a TBI, we

are looking for participants who have medical histories involving only TBI. Individuals who have had encephalitis are likely to have other, additional cognitive and learning problems in addition to those associated with brain injury. So, I appreciate your willingness and I want to thank you for your interest."

For subjects who pass the initial screening and express interest in participating

"When would you be to meet to sign the consent forms, discuss the program in more detail and get started with the evaluation phase?

(Date and time)____

"Do you have any questions you would like to ask? If you should have any questions before we meet, feel free to call me (the investigator) at (612) 276-2250.

Name:
Address:
Phone:
e-mail:

Closing Remarks
"Do you have any questions you would like to ask? If you should have any questions before we meet, feel free to call me (the investigator) at (612) 276-2250. This is the Dept. of Speech-Language-Hearing Sciences where I work. You may have to leave a message on Voice Mail, but I will return your call as soon as I get it. Also, I will send you a letter or email confirming the date, time and location for our next appointment. I want to thank you for your time, and I look forward to our meeting. Good Bye."