12-2011

Effect of Type of Cue, Type of Response, Time Delay and Two Different Ongoing Tasks on Prospective Memory Functioning after Acquired Brain Injury [post-print]

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Keywords: prospective memory, memory for intentions, acquired brain injury

Acknowledgments

This research was supported, in part, by a grant from the James S. McDonnell Foundation and the Trinity College Faculty Research Committee. We would like to thank all of the individuals who served as participants and all of the Trinity College students who helped to collect data, including Brian Harel, Chloe Zaug, Sara Levy and Laura O'Sullivan. We also thank two anonymous reviewers for their very helpful comments.

Abstract

Failures of prospective memory are one of the most frequent, and least studied, sequelae of brain injury. Prospective memory, also referred to as memory for intentions, is the ability to remember to carry out a future task. Successful completion of a prospective memory task requires the ability to monitor time, keep the action to be performed periodically in awareness, remember the task to be performed, and initiate the action. Although prospective memory has been shown to be a common difficulty after brain injury, it remains unknown which aspects of performance are impaired. In this study, the performance of 25 individuals with brain injury and that of 25 healthy participants were measured separately on the following variables: time until completion of the task, difficulty of the ongoing task being performed while waiting, whether the task to be performed is an action or is verbal, and whether the cue to perform the task is the passing of a particular amount of time (e.g., ten minutes) or is an external cue (e.g., an alarm sounding). Individuals with brain injury demonstrated impairment compared to healthy adults on virtually all variables. Prospective memory performance was also compared to a battery of standard neuropsychological measures of attention, memory and executive functions, and to self-report measures of prospective memory functioning, in order to determine the underlying cognitive deficits responsible for poor prospective memory performance, if any. Prospective memory performance was correlated with measures of executive functioning but not to self-report measures of prospective memory functioning. Implications are discussed in terms of cognitive rehabilitation recommendations.

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Introduction

Of the many cognitive and emotional changes associated with brain injury, individuals report prospective memory failures (e.g., I forget to take my medicine) as their most frequent memory problem (Mateer, Sohlberg, & Crinean, 1987). Performance on prospective memory tasks is also more highly correlated with everyday functioning than performance on traditional memory tasks (Wilson, 1987). However, despite its importance in everyday functioning and its susceptibility to brain dysfunction, there have still been relatively few studies investigating prospective memory deficits in this population (see Henry, Phillips, Crawford, Kliegel, Theodorou, & Summers, 2007 and Shum, Fleming, & Neulinger, 2002).

Definition of Prospective Memory.

Prospective memory is defined as the ability to remember at a particular moment that one had previously decided to carry out a particular action at that moment (Kvavilashvili, 1992). Prospective memory may require uncued or self-cued remembering (e.g., remembering to return a phone call at 3:00 pm) (Levy & Loftus, 1984; Wilkens & Baddeley, 1988), or may be prompted by an external event (e.g., remembering to take a roast out of the oven in response to the oven timer) (Einstein & McDaniel, 1990; Harris & Wilkens, 1982; Kvavilashvili, 1992). Event-based tasks have consistently been found to be easier for individuals to perform, most likely because time-based tasks require the person to perform more self-initiated monitoring and retrieval in order to bring the intention to mind and check a clock or watch (Glisky, 1996; Park, Morrell, Hertzog, Kidder, & Mayhorn, 1997; Sellen, Louie, Harris, Wilkins, 1997).

Investigations of Prospective Memory Ability.

Studies of healthy adults have focused on determining the differences between prospective and retrospective memory functions (Koriat, Ben-Zur, & Nussbaum, 1990; Uttl, Graf, Miller, & Tuokko, 2001). Cockburn (1995) points out that successful prospective memory performance encompasses many cognitive processes, including the retrieval of the content of the to-be-performed task, the ability to initiate the action, planning, and the inhibition of inappropriate actions. In addition, there needs to be ongoing activation and retrieval of the intention to perform the task (Marsh, Hicks, & Bink, 1998).

Certain attributes of a prospective memory task have also been shown to affect healthy adults differentially. For example, the need to recall an action has been found by some investigators to facilitate performance compared to recall of verbal information (Goschke & Kuhl, 1993; Koriat, Ben-Zur, & Nussbaum, 1990), or watching actions be performed by a model (Engelkamp & Zimmer, 1989). This finding is not found consistently, however (Schaefer, Kozak, & Sagness, 1998). Differences in performance have also been demonstrated depending on the complexity of the task to be completed (Einstein, Holland, McDaniel, & Guynn, 1992; Kidder, Park, Hertzog, & Morrell, 1997) and the attentional demands of the ongoing secondary task (Einstein & McDaniel, 1990; Marsh & Hicks, 1998; McDaniel, Robinson, Riegler, & Einstein, 1998; Taylor, Marsh, Hicks, & Hancock, 2004). Therefore we will investigate two ongoing tasks with differing levels of difficulty

Many previous studies of prospective memory satisfy the criteria set out by Ellis and Kvavilashvili (2000). These criteria specify that tasks need to have a delay between encoding and retrieval of the prospective task; that there must be no explicit prompt when the occasion to act occurs; and that there must be a separate ongoing activity (e.g., Einstein & McDaniel, 1990). However, it is not entirely clear that these tasks measure the same kinds of problems reported by individuals with brain injury. Moreover, many tasks are unidimensional, such as performing a single task over time (e.g., Maylor, 1996) and repeating tasks may involve learning a routine rather than prospective memory (Cockburn, 1996). Similarly, some studies use the two prospective tasks in The Rivermead Behavioral Memory Test (RBMT) (e.g., Huppert & Beardsall, 1993). Types of skills that may be compromising performance (i.e., length of delay, difficulty of ongoing task, type of response required) are not analyzed. Thus, rather than use measures such as those described by Einstein et al. (1992) or the RBMT, the current study measured each of these variables within the two groups.

Prospective Memory and Brain Injury

Until recently, relatively few inquiries into prospective memory functioning after BI had been performed (Cockburn, 1996; Groot, Wilson, Evans & Watson, 2002; Kinsella, Murtagh, Landry, Homfray, Hammond, O'Beirne, Dwyer, Lamont, & Ponsford, 1996; Shum, Valentine, & Cutmore, 1999; Sohlberg, White, Evans, & Mateer, 1992). More recently there has been a increase in interest in this area of research (Kliegel, Eschen & Thone-Otto, 2004; Mathias & Mansfield, 2005;

Maujean, Shum, & McQueen, 2003; Raskin, 2009; Roche, Moody, Szabo, Fleming, & Shum, 2007; Schmitter-Edgecombe & Wright, 2004).

As would be expected, many of the initial studies were largely descriptive in nature and focused on demonstrating that prospective memory deficits exist in this group (Schmitter-Edgecomb & Wright, 2004). No previous studies, to our knowledge, have dealt systematically with individual aspects of prospective memory functioning (e.g., type of cue, or length of delay) in a BI population. Although it is acknowledged that individuals with BI have damage to large cortical regions, most demonstrate prefrontal cortical dysfunction. Previous authors have suggested that prefrontal cortical regions likely mediate prospective memory (Kliegel, Jager, Altgassen, & Shum, 2008) and shown that those individuals with poor executive function performance show greater prospective memory impairment (Kliegel et al., 2004). Thus, a careful examination of the performance of individuals with BI on a measure that allows for a separation of prospective and retrospective components of a task may yield valuable information.

Studies using questionnaires have yielded mixed results. Hannon et al. (1995) found that individuals with BI reported difficulty with short-term habitual tasks but not with more long-term remembering. Roche, Fleming, and Shum (2002) reported that individuals with BI did not report more prospective memory problems than healthy adults, although observers did report that the individuals with BI had more problems than healthy adults. Using section C of the Comprehensive Assessment of Prospective Memory (CAPM), Roche, Moody, Szabo, Fleming and Shum (2007) reported that persons with BI encounter difficulty specifically with encoding, formation and initiation of prospective memories.

Using naturalistic measures of activities of daily living, Fortin, Godbout & Braun (2002, 2003) reported that individuals with BI had difficulty due to trouble with organizing and planning intended activities, such as preparing a meal. These authors concluded that deficits in strategic planning and event-based prospective memory are responsible for difficulties completing activities of daily living in these patients. Knight, Harnett & Titov (2005) created a novel videotape task of a person driving and walking through an unfamiliar city. In this study, the group with BI was impaired compared to healthy adults, but demonstrated low awareness.

Time Delay

Although not too many studies have included varying time delays, individuals with BI have previously been shown to be able to successfully complete intentions for short time delays but not for long ones (Raskin & Sohlberg, 1996; Raskin, 2009).

Time-based versus Event-based cues

Cockburn (1996) used a single time-based activity (described in Baddeley, 1981) and a single event-based activity. She found that healthy adults performed better than a group of people with BI on both tasks and did not find a relationship with performance on executive function tasks. Mathias and Mansfield (2005) used event-based tasks from the Rivermead and time-based tasks adapted from Einstein et al. (1995). Individuals with BI in this study performed poorly compared to healthy adults on time-based tasks of both short and long interval. The people with BI also performed poorly when compared to healthy adults on event-based tasks judged to have low personal saliency. Performance on the prospective memory tasks was not found to be significantly related to performance on measures of attention, executive functions or declarative memory.

Groot et al. (2002) used the Cambridge Behavioural Prospective Memory Test with people with BI. This test includes four time-based and four event-based tasks. They reported again that individuals with BI were superior at event-based tasks compared to time-based tasks and that this group was able to benefit from compensatory strategies, such as writing things down.

Shum et al. (1999) separated tasks into time-based, event-based, and activity-based (a task that does not require any interruption in a secondary ongoing activity). These authors reported that the time-based task was more difficult than the event-based task for both individuals with BI and healthy adults. Both groups also performed superior to either the time- or event-based tasks on the activity-based task. The people with BI performed significantly more poorly than the healthy adults on all tasks. Again, however, interactions of other variables, such as time delay, with type of cue could not be measured. In order to plan appropriate treatment or management strategies prospective memory failures in people with BI might be better specified.

Using the Memory for Intentions Screening Test (Raskin, Buckheit, & Sherrod, 2010), we found specific effects of BI on prospective memory (Raskin, 2009). This test has two-minute trials and 15-minute trials, both event-based and time-based tasks as well as a 24-hour delay item and a recognition trial. Individuals with BI showed superiority for event-based versus time-based cues. There was no difference between people with BI and healthy volunteers on the recognition or 24 hour recall trials. In terms of errors, individuals with BI differed from healthy adults only on the numbers of prospective memory errors, that is, trials in which they gave no response at all. This suggests a specific difficulty in the initiation of the intention.

Effect of ongoing task

There has also been interest in the effect of BI on controlled attentional processes required for successful prospective memory. Maujean, Shum and McQueen (2003) directly measured the effect of the cognitive demand of the ongoing task. Participants in the BI group performed more poorly than participants in the healthy adult group in the condition of high cognitive demand but not the condition of low demand. This suggests that prospective memory performance is differentially affected by the cognitive demand of the ongoing task in individuals with BI. It is not known from this study whether this is due to reduced attentional capacity or reduced ability to allocate cognitive resources to the prospective memory task. Thus, we predict that people with BI in the current study will perform more poorly compared to healthy adults in the condition with the more attention-demanding ongoing task.

Effect of type of response

To our knowledge, this has not been previously studied in people with brain injury (BI). If this action superiority is due to subcortical contributions, these functions may be intact in a BI population. It would be interesting to determine if individuals with BI show superiority for action intentions, as this might point to possible rehabilitation strategies.

Effect of task complexity

Henry et al. (2007) looked at BI performance for a computerized prospective memory task and varied the number of target events (in essence the load on prospective remembering). Individuals with BI were impaired on both the one target task and the four target task compared to controls. The authors concluded that increasing the number of targets does not, therefore, increase demands on controlled attentional processes.

In terms of underlying cognitive processes, most studies have focused on prefrontal or executive functions. Maujean et al. (2003) demonstrated a relationship between an event-based prospective memory task and tests of prefrontal functioning (Letter-Number Sequencing, Tower of London, Controlled Oral Word Association Test). Knight et al. (2005) reported a relationship with not only a task of executive functioning (verbal fluency) but also one of retrospective memory

(Logical Memory). Thus, it was predicted that individuals with BI in the current study would show greater impairment on time-based tasks when compared to healthy controls than on event-based tasks.

A primary aim of the current study was to measure variables that may be important in yielding clues about prospective memory in individuals with BI. Variables were chosen that would help determine whether prospective memory relies on adequate prefrontal functioning in these people. These variables were length of delay (2 minutes versus 15 minutes), type of cue (time versus event), difficulty of ongoing task, and type of response (action versus verbal). We hypothesized that those with BI will perform worse than healthy adults overall. We further hypothesized that those with BI will show a greater decrement on longer time delays compared to short time delays, a greater decrement on time-based cues when compared to even-based cues, a greater decrement on verbal items than action items when compared to healthy adults and a greater decrement when given the difficult ongoing task than the simple ongoing task. A secondary aim was to investigate underlying cognitive processes that underlie prospective memory in these individuals. Performance on prospective memory measures was compared to performance on a standard set of neuropsychological measures. It was hypothesized that the prospective memory errors would be related to poor functioning on measures of executive functions but not on measures of retrospective memory. Finally, a laboratory measure of PM was compared to self-report measures. We hypothesized that they would not be well correlated, indicating a need to move away from relying on self-report measures alone in this population.

Methods

Participants. *Inclusion criteria:* All participants were aged 20-55 and spoke English as a primary language. Individuals with BI were at least one-year post injury, had lowest postresuscitation Glasgow Coma Score (Teasdale & Jennett, 1974) of 8-12, and had obtainable medical records. Twenty-five people with BI were recruited through local hospitals and the local brain injury association. Twenty-five healthy adults were relatives of the people with brain injury or employees of Trinity College. Demographic data for the two groups is presented in Table 1. Descriptive injury information is presented for the group with brain injury in Table 2.

Insert Tables 1 and 2 about here

Exclusion criteria: Any potential participant that had previous neurological or psychiatric illness, history of substance abuse or diagnosed learning disability, visual impairment that would interfere with reading the test materials, and post-traumatic seizure disorder was excluded from the study.

Screening measures: All participants were administered the Brief Psychiatric Rating Scale (Overall and Gorham, 1962) to screen for psychiatric illness. No individual with severe depression (≥ 21 on the Beck Depression Inventory) (Beck, 1987) or anxiety (Beck Anxiety Inventory) (≥ 30 on the Beck, 1990), global cognitive dysfunction (severe impairment on four or more of the subscales of the Neurobehavioral Cognitive Status Examination) (Kiernan, Mueller, Langston, & Van Dyke, 1987) was included.

Materials. *Assessment of Intentional Memory.* Prospective memory tasks on the Assessment of Intentional Memory (AIM) tasks all consisted of simple commands composed of three words (e.g., “touch your nose”). Half of the commands involved an external object and were created by combining one of five verb terms (touch, lift, turn, move, tap) with one of five objects (pen, paperclip, cup, key, scissors) and an appropriate article (e.g., “touch the pen”). The other half of the commands did not involve an external object, but were simple gestures. Two digital clocks were on the desk at all times, one facing the examiner and one facing the participant.

The test was essentially divided into two halves, based on the secondary ongoing task. The simple ongoing task was a single letter cancellation task. The second ongoing task was an alphabetizing sentences task (Sohlberg, Johnson, Paule, Raskin, & Mateer, 1994). The examiner read a sentence of five words. The examinee was required to repeat the words, placing them in alphabetical order. The test items given with the first ongoing task were designed to be comparable to those given with the second ongoing task. There were a total of eight trials with the first ongoing task and a total of eight trials with the second ongoing task.

For each of these sets of eight trials, the prospective memory tasks were presented on two separate three by five cards. One card indicated the cue, which was either time-based ("In exactly two minutes") or event-based ("When I show you a picture of a chair"). The time-based cues were all for either two minutes or 15 minutes. The event-based cues were all pictures of common objects (Snodgrass & Vanderwart, 1980). The cues were presented at either two or 15 minutes after presentation of the task. Thus, a card was presented which has printed on it, "In exactly two minutes" or alternatively "When you see the picture of the sailboat" with the task to be performed beneath. For each half of the test there were four time-based cues and four event-based cues. Of the four time-based cues, two were at a two-minute delay and two are at a 15-minute delay. The same was true for the four event-based cues. All pictures presented are valid cues.

In addition, there were two sets of responses that the participants were asked to make. For one set participants were asked to verbally report the task written on the card whereas for the other set participants were asked to perform the action. Participants were told at presentation which form of recall is to be performed. The full set of objects was in full view at all times in the center of the table.

Each participant received two trials of each of the time delays for each type of cuing, for each level of ongoing task, and for each type of recall. This made a total of eight two-minute trials (event-based cue, time-based cue, simple ongoing task, difficult ongoing task, verbal retrieval, action retrieval). Each participant also received eight fifteen-minute trials identical to the two-minute trials above. At the end of the test, participants were given instructions for a 24-hour probe. The participant was asked to call the investigator at a specific time the next day. Voice mail allowed for an accurate assessment of completion of the task at the correct time. If a participant missed any items during the test there was a multiple-choice probe to determine if they were able to recognize the item missed. The complete test took approximately one hour to administer.

In all conditions, performance was scored on a two-point scale. One point was given for either recalling the correct task or for recalling that a task needed to be performed at the correct time (allowing $\pm$ 10% of the time to allow for lack of synchronization of the clocks). Thus, recalling the correct task at the wrong time (for the time-cued tasks) was awarded one point. Recalling the incorrect task at the correct time (either at the elapsed time or at the cue) was awarded one point. Recalling both the correct task and at the correct time was awarded two points.

Additionally, six types of errors were analyzed (e.g., Cockburn & Smith, 1994). The first, prospective memory errors, were scored if a participant did not give any response. Task substitution errors were scored when the participant performed an action for a verbal item or a verbal response for an action item. Loss of content errors were scored when the participant recalled that a task needed to be performed at the correct time but either could not recall the task or recalled the incorrect task. Loss of time errors were scored when a participant recalled a task correctly but did so at the incorrect time. Place losing errors indicated that the participant performed only part of the task, or repeated a previous task. Finally, random errors were scored when the participant's error did not fit into any discernable category.

In addition, a battery of standardized neuropsychological tests was administered to all participants. Tests were chosen because it was judged a priori that they measured one of the underlying cognitive processes that might be essential for successful prospective memory performance.

Neuropsychological Battery

Prospective Memory

Rivermead Behavioral Memory Test (Wilson et al., 1985) as a measure of every day functional memory. For this study, the two prospective memory items were used as the criterion standard for prospective memory assessment. These were remembering to deliver a message at a particular time and remember to ask for a belonging that was hidden at the start of the session.

Retrospective Memory

Story recall and picture recognition from Randt Memory Test. (Randt & Brown, 1986) as a measure of retrospective recall. Participants are read a short story and asked to recall the details in the story recall subtest. In the picture recognition subtest, participants are required to study a series of pictures and then perform a forced choice visual recognition.

Working Memory

Paced auditory serial addition task (PASAT) (Gronwall, 1977) as a measure of working memory. Trial four (1.2 seconds interstimulus interval) was administered. Participants were presented with an audiotape in which numbers were presented. The participant must add together each successive two numbers and report the sum verbally to the examiner.

Consonant Trigrams Test (Peterson & Peterson, 1959) as a measure of working memory. This test required the participant to retain three consonants in mind while performing a distracting task.

Fluency

Controlled Oral Word Association Test (Benton & Hamsher, 1989) as a measure of generative ability. This test required the participant to generate as many words as possible in 60 seconds beginning with the letter “F” then again with the letter “A” and then again with the letter “S.”

Animal Naming from the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983) as a measure of generative ability. This test required the participant to generate as many animal names as possible in 90 seconds.

Shifting Mental Set

Trail Making Test (Lewis, Kelland & Kupke, 1990) as a measure of sequencing and set-shifting. Trail Making Part A is a test of visual scanning that required the participant to “connect the dots” by connecting a series of circles that each have a number in sequential order. Trail Making Part B required the participants to alternate between circles with letters and circles with numbers.

Attention

Revised Attention Process Test (RAPT) (Raskin et al., 1994) as a measure of divided attention. This unpublished test is based on the Attention Process Training materials, a series of audiotapes measuring aspects of auditory attention (sustained, selective, alternating, divided) and a series of letter cancellation tasks measuring visual attention (sustained, selective, alternating, divided). Each task was scored out of a possible 30.

Planning

Tower of Hanoi (Davis et al., 1994) as a measure of planning. Participants were presented with three trials via computer. For ease of data analysis, only trial three was analyzed and presented here. Participants were presented with a series of three pegs and five disks of descending size. The disks are all on the disk to the far left. Participants were required to move all disks to the peg on the far right within two constraints. No disk can be placed on a smaller disk, and only one disk can be moved at a time.

Time Estimation

Time estimation (Cool Spring Software, 1989) as a measure of time estimation. Participants were presented with a flash of light on a computer screen. This was followed by a series of numbers. Participants must click when a number was presented. Then there was a second flash and the participant must indicate the time that passed between flashes.

Measures of self-report

To measure whether the experimental paradigm correlates with the participant's experience of prospective memory performance in daily life, three self-report measures were used. The first was the Prospective Memory Questionnaire designed by Hannon et al. (1995). In addition, an everyday memory questionnaire was employed (Mateer, Sohlberg, & Crinean, 1987) to measure all aspects of memory functioning in daily life. The Community Integration Questionnaire (Willer & Corrigan, 1994) was used to determine the impact of prospective memory performance on daily living. Finally, a diary study of prospective memory functioning was used. The diary study involved keeping data for one week on ten prospective memory tasks which are part of the participants' regular daily routine and which are identified by the participant, significant other and examiner prior to the measurement week (described in Raskin & Sohlberg, 1996). Two points were given for completing each of the 10 prospective memory tasks, using the scale described previously, with a total score possible of 20 points. In most cases, a significant other was responsible for data keeping.

Procedure

After obtaining informed consent, all participants were given the neuropsychological test battery, and the self -report measures in two two-hour sessions. The order of tests was counterbalanced across participants. The AIM was given in a separate one-hour session. Breaks were given if participants complained of fatigue. All tests were administered using standard procedures.

Results

Data analysis proceeded from the three specific aims of the study; namely, to determine (1) specific aspects of prospective memory that are impaired after brain injury, (2) cognitive functions underlying prospective memory failures in brain injury, and (3) the relationship between prospective memory failure on the AIM and self-report measures of prospective memory.

Descriptive statistics for the two groups are presented in Table 1. There are no significant differences between the groups (tested by Student's t-test or chi-square as appropriate) for age, years of education, highest occupational level held, IQ as measured by the North American Reading Test-Revised (Blair & Spreen, 1989), sex, or handedness.

The means and standard deviations with t-tests are presented in Table 3 for all parts of the AIM for the two groups, separately for type of ongoing task. The healthy adult (HA) group was significantly superior to the group with BI on virtually all measures.

Insert Table 3 about here

A series of two-way analyses of variance (ANOVA) were computed for the two groups on the measures of the AIM. These data are presented in Figures 1-4. First, a two-way 2x2 ANOVA was computed for Group (BI, HA) X Time (2 minute, 15 minute) and significant main effects were found for both Group (F=35.89, p<.01) and Time(F=42.11, p<.001). The interaction was not significant. For both groups, performance at a 2-minute delay was significantly superior to performance at a 15-minute delay.

Insert Figures 1-4 about here

Second a two-way 2x2 ANOVA was computed for Group (BI, HA) X Cue (Time, Event) and the main effect of Cue (F=36.18, p<.01) was significant, however the main effect of group was not (F=1.11, p>.05). The interaction was not significant. For both groups, the data indicated that the event-based cues were performed significantly more successfully than the time-based cues.

Third, a two-way 2x2 ANOVA was computed for Group (BI, HA) X Response (Action, Verbal) with a significant main effect for Response (F=30.12, p<.01) and a significant main effect for group (F=33.11, p<.01). The interaction was significant (F= 101.22, p<.01). In this case, the healthy adult participants showed a significantly superior performance for action responses when compared to verbal responses. The participants with BI did not show a significant difference between these types of responses, although the pattern of performance was in this direction.

Finally, a two-way 2x2 ANOVA was performed for Group (BI, HA) X Ongoing task (simple, hard) and a significant main effect was demonstrated for Ongoing task ($F=21.89$, $p<.01$) but the main effect of group was not significant ($F=11.34$, $p>.05$). The interaction was also significant ($F=121.90$, $p<.01$). Again, the healthy adults showed a significant effect, with performance on the letter cancellation (simple) task being superior to performance on the alphabetizing sentences (hard) task. The group with brain injury did not show an overall significant difference for type of ongoing task.

On the 24-hour probe, the two groups did not differ significantly. The BI group demonstrated a mean score of 0.80, standard deviation 0.92; the HA group demonstrated a mean score of 1.20, standard deviation of 1.10 ($t=0.91$, n.s.).

During the course of the test, participants might have to hold up to five instructions in mind at the same time. The effect of this load was analyzed by comparing performance on items with a load of 1,2,3,4 or 5 for each group separately. There was no effect of load on error for either group.

A series of Student's t-tests were computed to compare the two groups on each of the error types. As shown in Table 4, prospective memory was the only type of error that significantly differentiated the two groups. Of note, while the healthy adults tended to make a small number of errors but make them across the range of possible error types, the individuals with brain injury made almost all errors of the prospective memory error type.

Insert Table 4 about here

To determine the potential underlying cognitive processes required for successful prospective memory performance, two sets of analyses were computed for the neuropsychological data. First, the neuropsychological test scores were correlated with the AIM Total Score and Prospective Memory Error Score using a Pearson product-moment correlation, for the BI group alone. This yielded significant correlations ($p<.05$) between the AIM Total Score and Rivermead Behavioral Memory Test prospective memory item, Consonant Trigrams Test, COWAT, Animal Naming, Trail Making Test Part B, the RAPT Divided Attention subtest, Tower of Hanoi, and the PASAT. The Prospective Memory Error Score was significantly correlated with the Rivermead Behavioral Memory Test, Consonant Trigrams Test, COWAT, RAPT Auditory Sustained Attention, and Tower of Hanoi. These correlation coefficients are presented in Table 6.

Then, the neuropsychological measures were separated into those judged a priori to be mediated by prefrontal functions (Tower of Hanoi, Consonant Trigrams Test, Trail Making Part B, COWAT, Animal Naming, RAPT Divided and Alternating Attention, PASAT, Time Estimation) and those judged not to be mediated by prefrontal functions (Randt measures, all other RAPT measures, Trail Making Part A, Rivermead BMT). Tests were analyzed using a multivariate Hotelling's T^2 test for two independent samples between groups. The groups were significantly different ($F=5.94$, $p<.01$) for the presumed prefrontal measures and not for the other measures.

Finally, a Pearson product moment correlation was computed for each of the total scores on the self-report questionnaire measures and the Total Score and error score on the AIM for the individuals with BI. These data did not yield any meaningful results. None of the scales of the PMQ correlated significantly with the AIM score, Total Error Score or Prospective Error Score. The only scale from the EMQ that correlated significantly with the AIM score was the face/place scale (and not the actions scale). The only scale from the CIQ that correlated significantly with the AIM score was the Productivity scale. No scale of the EMQ or CIQ correlated significantly with either error score.

However, total score on the diary measure did correlate significantly with total AIM score ($r=.745$) and error score ($r=.718$).

Discussion

Prospective memory and brain injury

Overall, this method of measuring prospective memory proved to be sensitive to deficits following brain injury. The individuals with brain injury performed more poorly than the healthy adults on virtually all aspects of the AIM. This supports the need for a standardized clinical test, such as the (MIST; Raskin, Buckheit, & Sherrod, 2010) or the Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2005) that is sensitive to brain injury, both to further understanding of this particular deficit and in planning appropriate treatment models (e.g., Raskin & Sohlberg, 1996; Raskin & Sohlberg, 2009). In addition to pointing out the need to assess prospective memory as part of a comprehensive clinical assessment of individuals with BI, this study suggests some novel understanding of PM after BI with regards to the individual variables measured.

Effect of time delay. Both groups showed a superior performance for a short time delay compared to a long time delay, as would be expected. A delay of 15 minutes was sufficient to significantly impair the performance of both groups compared to two minutes. This suggests the need to incorporate compensatory strategies that can be utilized within a 15 minute window for individuals with brain injury, including datebooks or electronic reminders, but that those with BI would be able to use such devices if they could utilize a shorter time span to input the data. Surprisingly, the groups did not differ at a 24 hour delay task. Possibly, the healthy adults did not feel as compelled to complete the task, due to other constraints on their time, or because they were not as motivated to demonstrate their memory performance. It is also possible that the instructions were not worded in a way that suggested the importance of completing the task. These findings could be interpreted within the literature that demonstrates that individuals who are older, while more impaired on laboratory tasks, actually show superiority for some naturalistic tasks (e.g., Eschen, Martin, Gassen, & Kliegel, 2009). In previous studies, the 24-hour delay item on the MIST has shown this effect whereby older participants perform better on this task than younger participants (Raskin, 2009). Future studies looking at performance over longer delay periods are needed to fully understand the difficulties encountered in daily life by individuals with brain injury.

Effect of type of cue. Again, not surprisingly, both groups performed significantly better with event-based cues than with time-based cues. This is consistent with previous literature on prospective memory (e.g., Einstein & McDaniel, 1990) and PM in BI (Shum et al., 1999) and with well-known phenomena of the superiority of recognition to recall. These findings highlight the need, both when making recommendations to individuals with brain injury and when planning treatment strategies, to maximize the number of event-type cues that can be embedded in daily functioning. Examples include the use of electronic datebooks that beep at particular times, or structuring travel during the day so that salient cues (such as passing the grocery store) become apparent when they are needed or hanging cues (such as a large calendar) in well-traveled areas of the home or workplace. Voice-activated technology also holds promise as a memory cue.

Effect of type of response. Healthy adults demonstrated the previously documented superior performance for responses that are action-based rather than verbal. Some researchers have speculated that this is due to increased activation at the time of planning-encoding (Mantyla, 1996). It is somewhat disappointing that the participants with BI did not show the same effect, as this might have been another important area to target in terms of remediation strategies. The reason why these participants did not show this effect is unclear. Traumatic brain injury may in some way disrupt either prefrontal networks connected to subcortical motor systems needed for planning-encoding (Cohen & O'Reilly, 1996) or subcortical rehearsal loops from the cortical memory and planning systems. However, further study is needed to be sure that it is not, instead, some characteristic of this particular test. One particular area of study might be to have individuals with BI act out the task first and then see if intention retrieval is improved.

Effect of type of ongoing task. Again, the healthy adults showed the expected superiority for prospective memory performance when the ongoing was the simple task rather than the difficult task. However, the individuals with BI did not show this effect. Each person was carefully monitored while taking the test so it is not possible that the people with BI were not fully engaging in the difficult task. The two tasks were chosen because they were judged a priori to have two distinct levels of difficulty, with the alphabetizing sentences task being more difficult than the letter cancellation task. However, because a task is more difficult in isolation, it may not necessarily be more distracting to ongoing prospective memory performance. In fact, because the sentences in the alphabetizing task had distinct starting and stopping points, this might have served as cues to the individuals with brain injury to check the clock. Conversely, the letter cancellation tasks took several minutes to complete and so the individuals with brain injury might not have remembered to check the clock until the entire page was finished.

It is, perhaps, not surprising that those with BI did not show a unique pattern of deficits compared to healthy adults on some of the variables measured. Although a specific deficit on time-based tasks has been demonstrated in some populations, such as Parkinson's disease (Raskin et al., 2011) it has not been shown in others, such individuals with HIV (Zogg et al., 2011). We also did not find such a pattern here between time-based cues and event-based cues in the current study. Perhaps this is because the networks involved in event-based PM performance are impacted by BI but not by other disorders, such as Parkinson's disease. Thus in Parkinson's disease, time-based PM may differentially affected, whereas in BI both are affected. Further study is needed to determine if this is the case.

Underlying cognitive processes

One of the goals of this study was to investigate the underlying cognitive processes that are necessary for successful prospective memory performance. As demonstrated by other authors, many functions underlying prospective memory are related to the functioning of prefrontal cortex. These include working memory, planning, set-shifting, divided attention, and fluid generation of information. Retrospective recall was not significantly related to prospective memory and the groups did not differ on retrospective recall performance. Rather, the striking difference between the groups was the ability to bring to mind an intention. This would appear to have important implications for both the assessment and treatment of PM deficits after BI that need to focus specifically on the ability to initiate an intention, rather than the other aspects of PM.

It is, however, unanticipated that the groups did not differ in time estimation. One possible explanation for poor prospective memory performance could be a faulty time sense. However, the individuals with BI did not differ significantly from the healthy adults on time estimation. In fact, at all time delays (30, 60, 90, and 120 seconds) the mean estimates of the brain injury group were closer to the actual time passed than the healthy participants. One difficulty with this task was that it required retrospective time estimation. In other words, a period of time passed and then the participant was asked how long the interval had been. It would be preferable for a study of prospective remembering to use a more prospective task, in which the participants must let the examiner know when a prescribed period of time has passed.

Relationship between self-report measures and prospective memory performance

Consistent with previous studies, self-report of prospective memory ability did not correlate with performance on the AIM (e.g., Roche et al., 2002; Roche et al., 2007). It is not clear whether this is due to poor insight, whether the real-world tasks are so different from the laboratory tasks that they measure two different functions, or whether performance over short intervals (up to 15 minutes) is qualitatively different from performance over days or weeks. Further study using laboratory tasks that have real-world components and longer delays is needed.

In contrast, the use of a diary study continues to demonstrate validity as a measure of PM in daily life (Raskin & Sohlberg, 2009).

There are many limitations to this study. The first is the rather small sample size that may be the reason for the lack of other interactions between the groups. The second is the heterogeneity of the sample in terms of etiology. While we realize that this limits the ability to interpret the findings purely in terms of individuals with traumatic brain injury and in terms of brain regions implicated, we felt that the inclusion of a variety of etiologies might make the findings more relevant to a typical clinical population. The most important limitation might be the AIM. It is not clear that ongoing tasks really reflected two levels of difficulty. In the future it would be worth including both focal and nonfocal cues. In addition, the AIM is lengthy and although individual participants were monitored for fatigue, a shorter test might be more appropriate.

Table 1. Means, standard deviations and t-tests for demographic information on the two groups.

	BI		HA		
	Mean	s.d.	Mean	s.d.	t[1]
Age (years)	44.47	14.71	37.27	15.62	1.29
Education (years)	13.80	2.93	16.00	2.51	2.21
Occupation[2]	5.60	2.41	6.93	2.93	1.93
NART-R IQ[3]	105.84	9.29	111.99	9.63	1.49

		BI	HA	
		N	N	χ^2
Sex	Male	18	15	4.82
	Female	7	10	
Hand	Right	24	24	0.00
	Left	1	1	

[1] No significant differences found for any measures (p>.05)
[2] Highest occupation held, using Hollingshead scale (Hollingshead, 1977)
[3] Estimate of IQ from North American Adult Reading Test-Revised (Blair & Spreen, 1989)

Table 2. Descriptive injury information for the brain injury group.

	N	Mean	s.d.	Min	Max
Glasgow Coma Scale	12	8.50	4.04	5.00	14.00
Days loss of consciousness	9	15.00	29.01	0.00	90.00
Days post-traumatic amnesia	1	8.00	N/A	8.00	8.00
Traumatic brain injury	19				
Cerebral vascular accident	2				
Anoxic encephalopathy	3				
Normal pressure hydrocephalus	1				

Table 3. Performance of the two groups on the Assessment of Intentional Memory.

	BI		HA		
	Mean	s.d.	Mean	s.d.	t
Letter Cancellation					
2 minute delay	4.67	1.44	6.47	1.36	3.34**
15 minute delay	1.92	1.56	4.27	1.22	4.39***
Event cue	3.58	1.51	5.67	1.11	4.13***
Time cue	2.92	1.38	5.07	1.22	4.29***
Action response	4.17	1.47	6.20	1.26	3.89**
Verbal response	2.42	1.00	4.53	1.25	4.78***
Summary score	19.67	6.05	32.20	6.10	5.33***
Alphabetizing Sentences					
2 minute delay	3.00	1.00	5.40	1.68	4.21***
15 minute delay	2.64	0.92	3.67	1.29	2.25*
Event cue	4.27	0.90	4.93	1.28	1.46
Time cue	1.45	1.44	4.13	1.96	3.83**
Action response	2.82	0.98	4.80	1.61	3.60**
Verbal response	2.91	1.04	4.27	1.49	2.59*
Summary score	17.09	4.39	27.20	8.37	3.64**
Total Score	37.18	9.21	59.40	11.96	5.14***

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

Table 4. Errors demonstrated on the AIM by the two groups as percentage of total errors.

	BI Mean	BI sd	HA Mean	HA sd	t
Prospective Memory Errors	32.82	19.61	12.00	10.04	3.54**
Task Substitution					
Action for Verbal	11.09	6.12	9.00	6.52	0.83
Verbal for Action	2.91	4.30	8.33	8.14	2.01
Novel	8.09	4.99	13.20	11.49	1.37
Loss of Content					
Action	9.27	8.58	12.00	9.76	0.74
Verbal	8.82	8.93	13.00	12.90	0.92
Loss of Time	1.09	2.43	4.73	6.18	1.84
Place Losing	0.64	2.11	0.00	0.00	1.18
Random	3.82	5.56	3.27	4.37	0.28

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

Table 5. Performance of the two groups on the standard neuropsychological measures.

	BI Mean	BI s.d.	HA mean	HA s.d.	t
Rivermead Behavioral Memory Test Standardized Profile Score	14.10	6.64	22.30	1.77	3.77**
Two Prospective Items	2.90	1.52	5.56	0.88	4.57***
Consonant Trigrams Test	34.82	6.81	45.67	6.52	3.61**
COWAT raw score	28.40	7.73	44.80	8.87	4.41***
Animal Naming	18.20	5.07	27.00	4.32	4.18**
Trail Making Test Part A (secs)	45.82	19.70	30.10	12.12	2.17*
Part B (secs)	119.45	51.86	50.70	32.37	3.60**
RAPT Auditory Sustained	29.20	1.48	29.80	0.42	1.24
Auditory Selective	28.90	1.29	30.00	0.00	2.70*
Auditory Alternating	19.80	9.38	27.40	4.27	2.33*
Visual Sustained	26.60	1.84	27.90	1.97	1.53
Visual Selective	54.90	6.01	57.00	2.26	1.03
Visual Alternating	24.90	8.10	29.50	1.27	1.77
Divided	20.20	5.37	24.20	6.01	2.01*
Randt Story Recall	5.60	1.58	10.67	2.92	4.78***
Picture Recognition Hits	6.90	0.32	7.00	0.00	0.95
Tower of Hanoi (Moves, Trial 3)	89.70	35.87	68.20	28.70	1.48
Time Estimation (120 secs)	109.42	67.27	91.22	22.61	0.73
PASAT (Trial 4)	30.84	14.32	44.11	6.31	2.56*

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

Table 6. Pearson product moment correlations for the AIM and the neuropsychological measures for the group with BI.

	AIM Total Score	AIM Prospective Errors
Rivermead BMT Total	.71**	-.54*
RBMT Prospective Items	.68**	-.51*
Consonant Trigrams Total	.51*	-.50*
COWAT	.72**	-.54*
Animal Naming	.65**	-.35
Trail Making A	-.42	.19
Trail Making B	-.63**	.32
RAPT Auditory Sustained Attn	.20	-.62**
RAPT Auditory Selective Attn	.48*	-.36
RAPT Auditory Alternating	.44	-.39
RAPT Visual Sustained Attn	.24	- .01
RAPT Visual Selective Attn	.33	-.31
RAPT Visual Alternating Attn	.13	.02
RAPT Divided Attention	.46*	-.12
Randt Story Recall	.44	-.41
Randt Picture Recognition	.30	-.08
Tower of Hanoi (moves, Trial 3)	-.62**	.64**
Time Estimation (120 secs)	.08	- .25
PASAT	.64**	- .27

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

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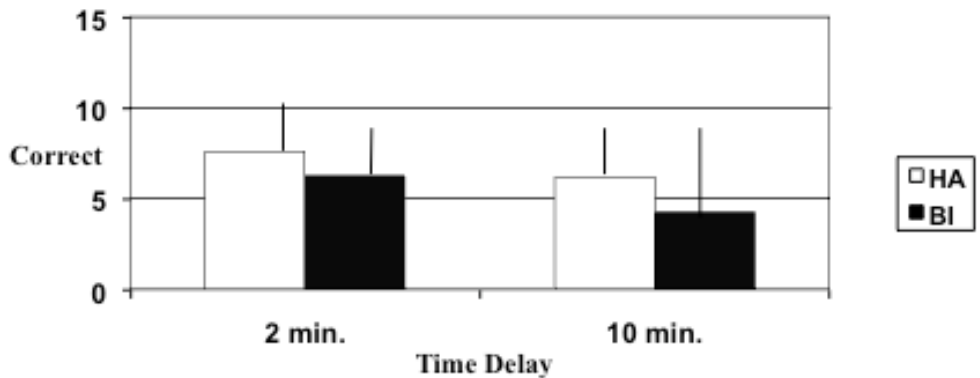
Figure 1.

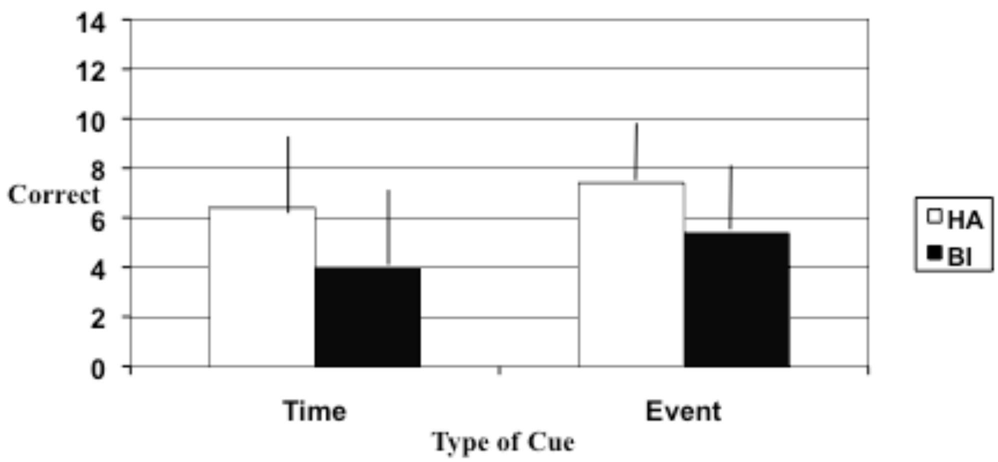
Performance of the two groups for each time period.



Both groups main effects p<.01, no sig. interaction

Figure 2.

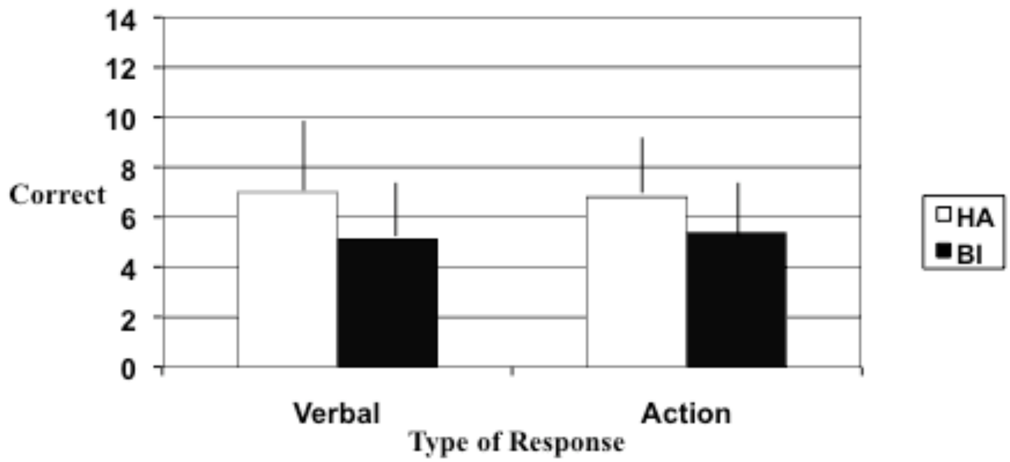
Performance of the two groups by type of cue.



Main effect of cue sig p<.01, no sig interaction

Figure 3.

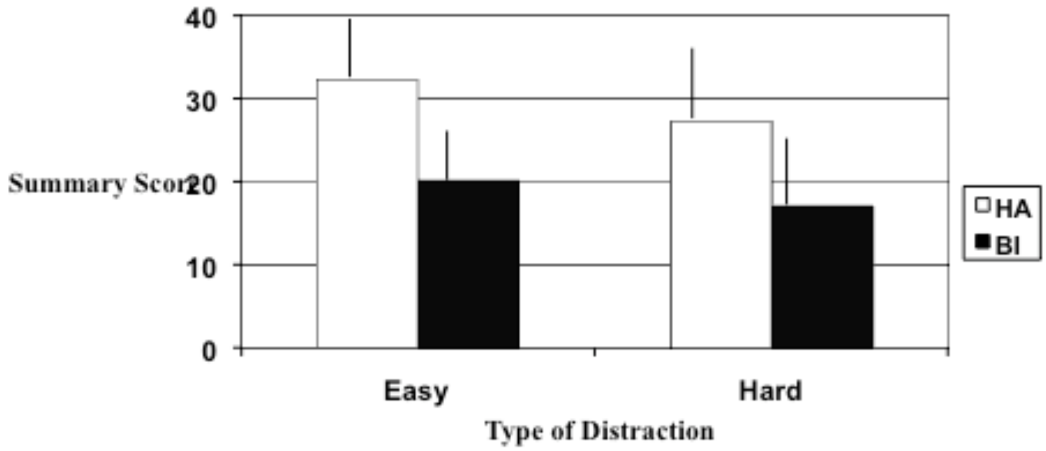
Performance of the two groups on the two response types.



Significant main effects for group (p<.01)
and response (p<.01), and interaction (p<.01)

Figure 4.

Performance of the two groups for each type of distraction.



Main effect of distraction $p<.01$, no main effect of group, interaction significant $p<.01$