PROSPECTIVE MEMORY FOLLOWING MODERATE TO SEVERE TRAUMATIC BRAIN INJURY: A FORMAL MULTINOMIAL MODELING APPROACH

By

SHITAL PRABODH PAVAWALLA

A dissertation submitted in partial fulfillment of
the requirements for the degree of

Doctor of Philosophy in Psychology

WASHINGTON STATE UNIVERSITY
Department of Psychology

AUGUST 2009

To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of SHITAL PRABODH PAVAWALLA find it satisfactory and recommend that it be accepted.

Maureen Schmitter-Edgecombe, Ph.D. (Chair)

G. Leonard Burns, Ph.D.

Lisa Fournier, Ph.D.

Acknowledgements

Gratitude is due to my academic advisor and dissertation chair, Maureen Schmitter-Edgecombe, Ph.D., as well as my research assistants, Rebecca Auger, Sheena Green, and Jessica Summerville. I would also like to thank Rebekah E. Smith, Ph.D. for her extensive collaboration and invaluable assistance over the course of this project.

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Abstract

Shital Prabodh Pavawalla, Ph.D.
Washington State University
August 2009

Chair: Maureen Schmitter-Edgecombe, Ph.D.

Prospective memory (PM), which can be understood as the processes involved in realizing a delayed intention, has been found to be impaired following a traumatic brain injury (TBI). Although PM can be empirically dissociated from retrospective memory, it inherently involves both prospective and retrospective components. This study utilized a formal multinomial processing tree (MPT) model that was developed and validated by Smith and Bayen (2004) to disentangle the prospective and retrospective recognition components underlying PM following TBI. Fifteen participants with a moderate to severe TBI and 15 age- and education-matched control participants completed an event-based PM task that was embedded within an ongoing computer-based color-matching task. Results of the MPT modeling revealed a trend towards group differences in the prospective component and significant group differences in the retrospective recognition component of PM, despite intact post-test recall of the PM task and target words. More traditional data analyses revealed a significant cost to ongoing task performance with the inclusion of the PM task. Overall, our data suggested that our event-based PM task was resource demanding, and TBI participants tended to have difficulty with both the prospective and retrospective recognition aspects of PM.

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Dedication

This dissertation is dedicated to my family who provided to me their unconditional support.

CHAPTER ONE

INTRODUCTION

Our ability to remember to carry out an intended action in the future, such as stopping at the store to buy bread on our way home from work, is an important component of our daily lives. This type of memory, called prospective memory (PM), can be dissociated from retrospective memory (RM), or memory for past events (e.g., Bisiacchi, 1996; Maylor et al., 2002; Palmer & McDonald, 2000; West & Craik, 2001; West & Krompinger, 2005). Failures in PM have been found to be a significant concern for individuals, as both neurologically healthy individuals and persons with a traumatic brain injury (TBI) have noted the impact of PM failures in their daily lives to be greater than that of RM failures (Mateer, Sohlberg, & Crinean, 1987). Although PM and RM are now considered distinct forms of episodic memory, it is important to understand that all PM tasks inherently involve a retrospective component. The prospective component of PM can be conceptualized as remembering *that* an action needs to be carried out, while the retrospective component involves remembering *what* action needs to be executed (e.g., Einstein et al., 1992; Ellis, 1996) and *when* it must be carried out (i.e. accurately discriminating between cues and non-cues; Smith & Bayen, 2004). In this study, we further examine the prospective and retrospective recognition components of PM performance in individuals with moderate-to-severe TBI.

In terms of PM assessment, a distinction has been made between three fundamental types of PM tasks: time-based, activity-based, and event-based (Kvavilashvili & Ellis, 1996). A time-based PM task requires that the intended action be performed at a specified time or following a specified time interval (e.g., medication must be taken at 10:00 a.m. every day). Activity-based tasks require that the intended action be performed after the completion of another activity (e.g., turn off the computer after using it). Finally, in event-based PM tasks, the intended action must be performed when presented with a specific external cue (e.g., give a message to a coworker when seeing him/her at work). The primary difference among these intentions involves the level of external cueing and activity interruption. Activity- and event-based intentions involve some form of external cueing, while time-based intentions fail to provide such assistance because, in general, there is no obvious external cue for particular times or time frames (Kvavilashvili & Ellis, 1996). Finally, time- and event-based tasks tend to require the interruption of an ongoing activity, whereas activity-based tasks are executed following the completion of an activity.

A large number of studies have examined prospective remembering in various neurologically impaired populations, including TBI populations, and have consistently found significant PM impairments (e.g., Carlesimo, Casadio, & Caltagirone, 2004; Cockburn, 1996; Fortin, Godbout, & Braun, 2003; Groot et al., 2002; Henry et al., 2007; Kliegal, Eschen, & Thone-Otto, 2004; Kinsella et al., 1996; Knight, Harnett, & Titov, 2005; Knight, Titov, & Crawford, 2006; Mathias & Mansfield, 2005; Roche, Fleming, & Shum, 2002; Roche, Moody, Szabo, Fleming, & Shum, 2007; Schmitter-Edgecombe & Wright, 2004; Shum, Valentine, & Cutmore, 1999). For example, Cockburn (1996) examined the performance of individuals with TBI on a time-based PM task that required participants to start and stop a timer during an ongoing sentence verification task, as well as an event-based PM task that required participants to change pen colors upon being cued during an ongoing number cancellation task. Cockburn’s results indicated that participants with a TBI were significantly less accurate in overall PM performance compared to healthy controls. In a similar vein, Kinsella et al. (1996) utilized activity-based and time-based PM tasks to examine PM deficits in individuals with a TBI. Their tasks involved participants asking for a questionnaire at the end of the testing session (activity-based) and returning it by mail with the date written in the corner (time-based). Kinsella and colleagues' results revealed that individuals with a TBI exhibited greater PM deficits for the activity-based PM task compared to healthy controls, but performance on the time-based task was equivalent across groups.

Although most studies on PM functioning following TBI have found impairments in various types of PM tasks, it is important to note that few have attempted to differentiate between deficits in the prospective versus retrospective components of prospective remembering. Many studies examining PM following TBI tend to assume that if the participant can accurately recall what they are suppose to do, then the observed deficits in PM functioning are due to impairments in the prospective component of prospective remembering (e.g., Cockburn, 1996; Fish et al., 2006; Fortin et al., 2003; Groot et al., 2002; Kinsella et al., 1996; Knight et al., 2005; Knight et al., 2006; Mathias & Mansfield, 2005; Shum et al., 1999). Only a handful of studies examining PM in individuals with a TBI have attempted to tease apart such processes. For example, Carlesimo and colleagues (2004) utilized a unique performance scoring method to examine the prospective versus retrospective components of prospective remembering in a chronic (i.e., > 6 months post-injury) severe TBI population. While engaged in ongoing cognitive tasks, participants were required to make time-based and event-based PM responses. Participants were allowed a 2-min tolerance interval both before and after the performance interval during which they could carry out the PM task. If the participant failed to carry out the PM task without prompting, they were asked by the examiner, “Do you remember that at this point you were supposed to do something?” (p. 682), and if the participant provided an affirmative response, the number of correctly executed actions was recorded. Carlesimo and colleagues asserted that this technique would allow for the differentiation of the prospective component from the retrospective components underlying PM by allowing for the separate examination of spontaneous task initiation and the content of the intended action without spontaneous initiation. These authors found that in addition to the TBI group being significantly less accurate in spontaneously initiating the PM task compared to controls, TBI participants were also significantly worse at accurately recalling the content of the intention. Thus, TBI participants in this study exhibited deficits in the prospective component as well as and retrospective components of prospective remembering.

Kliegal and colleagues (2004) attempted to tease apart the prospective and retrospective components by examining four phases of PM in a severe TBI sample more than six months post-injury: (1) intention formation; (2) intention retention; (3) intention re-instantiation (i.e., performance interval); (4) and intention execution. According to these researchers, examining the intention retention phase of the PM task would allow for the assessment of the retrospective component of PM, while the intention re-instantiation would allow for the examination of the prospective component. In this study, participants were required to: (1) develop an explicit intention for how they were going to complete a set of six subtasks (intention formation); (2) recall the content of their intention following brief distractor tasks (intention retention); (3) initiate the intended action during further distractor tasks (intention re-instantiation); and (4) properly execute the intended actions according to the plan created during the intention formation phase (intention execution). While the TBI group demonstrated impaired performance in the intention formation, re-instantiation, and execution phases, the results failed to reveal significant group differences for the intention retention phase. These findings suggested that the

PM deficits found within the TBI group were not the result of retrospective memory impairments, but the result of impaired prospective processes underlying PM.

In a more recent PM study with a TBI population of varying severity levels (mild to severe) who were more than one year post-injury, Henry and colleagues (2007) manipulated the number of PM target events that needed to be remembered (i.e., 1 or 4). This manipulation was intended to vary the resource demands in order to examine hypotheses regarding the prospective component of PM put forth by the multiprocess framework theory (McDaniel and Einstein, 2000) and the PAM theory (Smith, 2003). The multiprocess framework theory posits that prospective remembering can rely on either a strategic cue monitoring and detection process or an automatic orienting and retrieval process, depending on task-specific factors (e.g., type of task, type of cue, type of ongoing activity, etc.). In contrast, the PAM theory (Smith, 2003) asserts that prospective remembering always requires capacity-demanding preparatory processes to maintain "a state of readiness to perform the [PM] task" (Smith & Bayen, 2005, p. 244), and which result in cognitive resources being taken away from the ongoing activity (Smith & Bayen, 2005). This process may or may not involve explicit checking, and may function "outside of the immediate focus of attention" (Smith, 2003, p. 245).

In order to assess the retrospective component of their PM task, Henry et al. (2007) administered a post-test recall task for the PM task instructions. Their findings relating to the prospective component revealed that while TBI participants were significantly impaired across both target manipulations as compared to controls, they were not differentially affected in their ability to respond to the four-target condition as compared to the one-target condition. These findings were interpreted to mean that the increase in targets did not cause an increase in strategic processing and monitoring because participants relied on more automatic and noneffortful processes when making the PM response, which is in line with the multiprocess framework theory. Regarding the retrospective component, the authors found that the TBI and control participants were equivalent in their post-test recall of PM task instructions and target events. Based upon these findings, the authors concluded that observed impairments in PM functioning following TBI were likely related to the prospective component rather than the retrospective component, and the prospective component of their task relied on more automatic processes.

The use of post-test recall and/or recognition tests such as the kind used by Henry et al. (2007) is a common method of controlling for the influence of retrospective memory deficits on PM performance with both clinical and neurologically intact populations (e.g., Altgassen, Kliegel, Rendell, Henry, & Zollig, 2008; Cohen, Jaudas, & Gollwitzer, 2008; Jager & Kliegel, 2008; McDaniel et al., 2004). However, this method fails to allow for examination of the retrospective recognition component of *when* the PM task must be executed (i.e. the ability to discriminate between targets and nontargets). As Smith and Bayen (2006) discuss, recall of the target(s) following the task does not necessarily ensure that the target(s) are recognized *during* the task. Thus, the use of post-test recall of PM targets and task may be an effective way of teasing apart the prospective component from the retrospective component of remembering *what* needs to be done, it does little to differentiate the prospective component from the retrospective recognition component of *when* the task must be executed. Because recognition failure for items that are successfully recalled at a later time has been demonstrated on other cognitive tasks (Tulving & Thomson, 1973), it is important to examine alternative approaches to teasing apart these components underlying prospective remembering.

One alternative approach to disentangling the effects of prospective and retrospective recognition processes on PM impairment is through the use of statistical modeling. Smith and Bayen (2004) introduced an event-based PM multinomial processing tree (MPT) model based on the PAM theory as a means to differentially examine the retrospective recognition component (i.e., discriminate between targets and non-targets) and the prospective component (i.e., remembering that something needs to be done) in neurologically healthy populations. The use of the MPT model has been validated in several studies using neurologically intact individuals (e.g., Smith & Bayen, 2004, 2005). In one set of experiments, Smith and Bayen (2004) manipulated several variables that were hypothesized to primarily affect either the prospective or retrospective recognition component of PM, including the importance of the ongoing or PM task, the distinctiveness of the PM targets, and the time available for encoding PM targets. As predicted by the PAM theory, MPT modeling results revealed significantly greater preparatory processing in conditions emphasizing the importance of the PM task (rather than the ongoing activity) and semantically similar target-nontargets (rather than semantically distinct target-nontargets). In contrast, conditions manipulating target encoding time significantly affected retrospective recognition processes but not preparatory attentional processes (Smith & Bayen, 2004). The findings from this set of experiments, as well as later experiments by these researchers (e.g., Smith & Bayen, 2005), provided validation for their MPT model as a successful method of disentangling the effects of the prospective and retrospective recognition components underlying prospective remembering.

Smith and Bayen (2006) later extended the use of their MPT model to examine PM functioning in healthy aging. They examined neurologically intact younger and older adults using a PM task that was embedded in an ongoing color-matching task across two experiments in which factors related to the retrospective recognition component of PM were varied (i.e., length of time for PM target encoding and familiarity of target words). Citing previous research indicating reduced cognitive resources in older adults, the authors argued that the PAM theory would hypothesize that older adults would exhibit reduced preparatory attentional processes as compared to younger adults. While traditional analyses on both experiments revealed that that older adults were less likely to make a PM response compared to young adults, results of the MPT modeling approach revealed that this finding was due to younger adults being more likely to engage in preparatory attention processing (i.e., prospective component) than older adults. The modeling analyses did not find any differences in the ability to discriminate between targets and non-targets (i.e., retrospective recognition component) between younger and older adults. Based upon the findings, the authors concluded that the findings supported the PAM theory of PM.

In this study with a moderate-to-severe TBI population, we used a MPT model to disentangle the influence of strategic prospective processes, or remembering *that* an action needs to be taken, from the retrospective recognition processes of remembering *when* the action needs to be executed (i.e., discriminating between targets and non-targets). Disentangling these processes better allows for evaluation of the extent to which each component contributes to residual PM failures commonly observed following a TBI. Similar to the experimental paradigm utilized by Smith and Bayen (2006), this study employed an event-based PM task embedded within an ongoing color-matching task.

Consistent with prior research (e.g., Carlesimo, Casadio, & Caltagirone, 2004; Cockburn, 1996; Fortin, Godbout, & Braun, 2003; Groot et al., 2002; Kliegal, Eschen, & Thone-Otto, 2004; Kinsella et al., 1996; Knight, Harnett, & Titov, 2005; Knight, Titov, & Crawford, 2006; Mathias & Mansfield, 2005; Roche, Fleming, & Shum, 2002; Schmitter-Edgecombe & Wright, 2004;

Shum, Valentine, & Cutmore, 1999), we expected that the moderate-to-severe TBI group would display greater overall PM deficits compared to healthy controls as indicated by fewer PM responses. Furthermore, based upon previous findings indicating that individuals with a TBI experience deficits in resource-demanding, strategic cognitive processes (e.g., Schmitter-Edgecombe & Beglinger, 2001; Schmitter-Edgecombe, Marks, & Fahy, 1993; Schmitter-Edgecombe & Rogers, 1997; Vakil, Blachstein, & Hoofien, 1991), it was hypothesized that analyses using the MPT model would reveal that individuals with a TBI show a significantly reduced likelihood of engaging in preparatory attentional processes compared to healthy controls. Furthermore, we hypothesized that if, as much of the previous neurological literature suggests, PM deficits following TBI are primarily due to impairments in the prospective component, then no group differences should be found for the retrospective recognition component of PM. We also examined relationships between the experimental PM paradigm findings and questionnaire data intended to assess for everyday prospective and retrospective memory functioning, neuropsychological measures of both prospective and retrospective memory, and neuropsychological measures of executive functioning.

CHAPTER TWO

RESEARCH DESIGN AND METHODOLOGY

Participants

A total of 21 individuals with moderate-to-severe TBI participated in this study. Of these, three TBI participants were excluded from analyses because they were unable to successfully encode the six PM target words prior to the PM block of the color-matching trials. Furthermore, two TBI participants were excluded because of the inability to understand task instructions, and one TBI participant was excluded after medical records revealed that the injury was primarily related to seizure and hematoma. This resulted in a remaining sample of 15 participants with moderate-to-severe TBI in the experimental group (8 males, 7 females). The comparison sample consisted of 15 neurologically healthy matched control participants (8 males, 7 females). Demographic comparisons indicated that the two groups were well matched in age (TBI: M = 36.00, SD = 11.17; control: M = 34.93, SD = 10.35), $t(28) = 0.27$, $p > .05$, and education level (TBI: M = 15.73, SD = 1.83; control: M = 15.73, SD = 1.53), $t(28) = 0.00$, $p > .05$.

Severity of TBI was defined by a Glasgow Coma Scale (GCS; Teasdale & Jennet, 1974) score, length of loss of consciousness (LOC), length of posttraumatic amnesia (PTA), neuroimaging findings, and/or neurosurgery. In those cases where medical records were unattainable ($n = 9$) or the depth and/or duration of coma were unclear from medical records ($n = 1$), participant and/or significant other reports of LOC and PTA were used to estimate severity. Participants were considered to have suffered a severe TBI if they experienced a depth of coma (as measured by the Glasgow Coma Scale) of 8 or less or coma duration of greater than 48 hours ($n = 11$). Moderate TBI was defined by a GCS score of 9 – 12 or higher if accompanied by positive neuroimaging findings and/or neurosurgery (*n* = 4; Dennis et al., 2001; Fletcher, et al., 1990; Taylor et al., 2002; Williams, Levin, & Eisenberg, 1990). Eighty-seven percent of participants reported a PTA estimate of greater than one day, with 54% of those reporting duration of PTA greater than five days.

Cause of injury for a majority of the TBI participants (*n* = 9) was a motor vehicle accident, while the remaining injuries were the result of a fall of 10 feet or greater (*n* = 3), a bicycle accident (*n* = 2), or an airplane accident (*n* = 1). To rule out developmental effects, TBI participants were at least 15 years of age at the time of injury and less than 55 years of age at time of initial testing. Because we were interested in the residual effects of TBI on PM performance, all TBI participants were assessed at least one year post-injury (range 1-27 years). Eighty percent were three or more years post-injury at the time of participation, and 25% were more than 10 years post-injury. Other exclusion criteria included: a prior history of non-TBI-related neurological disorders (e.g., stroke, attention-deficit hyperactivity disorder, etc.); a prior history of treatment for substance abuse; a prior history of multiple moderate-to-severe TBIs; a Snellen ratio of less than .50 (measured at a distance of 45 cm); a reading or comprehension impairment; a visual field deficit that would impair viewing of a computer screen; color blindness; any medical condition that precluded ability to participate in neuropsychological testing (e.g., dementia, aphasia); and an impairment in ability to respond with an upper limb during assessment. All participants received a brief report on their current cognitive functioning and were entered into a drawing to win a monetary prize as compensation for participating in the study. Written informed consent was obtained from all participants and protocol approval was obtained from the Institutional Review Board at Washington State University.

Materials

Questionnaire Measures

Following recruitment, participants received by mail a packet of questionnaires to be completed prior to the testing appointment. This packet included the following questionnaires:

Prospective-Retrospective Memory Questionnaire ([PRMQ] Smith, Della Sala, Logie, & Maylor, 2000). This self-report measure is a brief 16-item questionnaire that examines everyday prospective and retrospective memory functioning.

Dysexecutive Questionnaire ([DEX] Wilson et al., 1996). This self-report measure is a brief, 20-item questionnaire about executive-based behavioral changes and is designed to measure various aspects of executive deficits (e.g., perseveration, distractibility, decision-making, impulsivity, etc.).

Performance-Based Neuropsychological Measures

To characterize the TBI population, participants were administered a battery of performance-based neuropsychological tests. The following measures were individually administered to each participant:

Repeatable Battery for the Assessment of Neuropsychological Status – Form A (RBANS; Randolph, Tierney, Mohr, & Chase, 1998). This test battery is intended to be a brief (approximately 30 minutes) but comprehensive measure of performance in various areas of cognitive functioning. It produces scores within five indices: (1) immediate memory; (2) visuospatial/constructional; (3) language; (4) attention; (5) and delayed memory. The memory indices include a measure of list learning, story recall, and figure recall, which allows for the assessment of rote and semantic verbal learning, as well as visual learning and memory.

Trail Making Test (TMT; Reitan, 1992): This test, which involves two forms (TMT-A and TMT-B), is commonly used to examine attention, processing speed, and executive functioning (i.e., sequencing and cognitive flexibility). Part A requires individuals to draw lines connecting 25 encircled numbers in ascending order as quickly as possibly on a sheet of paper, while Part B requires individuals to draw lines alternating between numbers and letters in numerical and alphabetical order (i.e., 1-A-2-B-3-C, etc.). The score on each form represents the amount of time the individuals take to complete the task. Part A is commonly used to measure processing speed and visual tracking, while Part B is often used to measure aspects of executive functioning.

Delis-Kaplan Executive Function System – Design Fluency Subtest (D-KEFS; Delis, Kaplan, & Kramer, 2001). This individually-administered test battery is designed to measure various types of executive functions. The Design Fluency subtest is comprised of three parts requiring individuals to connect a varied number of dots to create as many unique designs as possible within a given time limit. It is intended to assess planning and flexibility in thinking in a visuospatial modality.

Experimental Prospective Memory Test

Similar to Smith and Bayen (2006), we administered an event-based PM task embedded within an ongoing color-matching task in order to examine PM functioning.

Ongoing Color-Matching Task: The materials for the ongoing color-matching task with the embedded PM targets were obtained from Smith (Smith & Bayen, 2006) to be adapted to the current study. The task included five colors: blue, red, green, yellow, and white. Colored rectangles (1.5 X 1.3 in.) were individually displayed in the center of a black computer screen.

Eighteen-point font words were also individually displayed in one of the above colors in the center of the black computer screen.

Prospective Memory Task: As described in Smith and Bayen (2004, 2006), this portion of the experiment was developed by randomly selecting 124 medium-frequency words from the Kucera and Francis (1967) norms. From these, two sets of six words were chosen as prospective memory targets. The remaining 112 words were randomly assigned to one of two filler word lists to be used for the ongoing color-matching task. This resulted in two 6-item target word lists and two 56-item filler word lists, with four possible combinations. These combinations were counterbalanced across participants so that each list served equally often as the baseline and experimental blocks.

Procedure

General Procedure. Participants were provided with questionnaires prior to their testing session, which they were required to complete and bring to the experiment session. The full testing session lasted between approximately 150 – 180 minutes. Each session began with a brief neuropsychological intake to obtain demographic information, followed by the testing procedures. The experimental prospective memory test was embedded within the neuropsychological test battery. Rest breaks were offered to each participant as needed.

Experimental Prospective Memory Test Procedures. Procedures for the experimental PM paradigm closely modeled those used by Smith and Bayen (2004, 2006). Instructions for the ongoing color-matching task were displayed on the computer screen and emphasized both speed and accuracy. As part of each trial, four colored rectangles were individually displayed in the center of a black computer screen for 500 ms each. A blank screen appeared for 250 ms in between the presentation of each colored rectangle. Following the final rectangle and blank screen, a word was displayed in lowercase letters. In half of the trials, the word was displayed in one of the four colors presented in the preceding rectangles (match trials) and in the other half, the word was displayed in a color different from any of the preceding rectangle colors (non-match trials). This study utilized a response box with five horizontally-lined response keys to collect response data. The middle three keys of the response box were labeled “1”, “2”, and “3”, which were used for making responses in this study. For right-handed participants, the “1” key corresponded to a “yes” response, the “2” key corresponded to a “no” response, and the “3” key was designated for the PM response key. For left-handed participants, the “3” key corresponded to a “yes” response, the “2” key corresponded to a “no” response, and the “1” key was designated for the PM response key. Participants were required to press the “yes” key (“1” or “3”) with their index finger on the response box for match trials and the “no” key (“2) with their middle finger for non-match trials. Specific key assignment instructions were varied depending on the handedness of the participant. For match trials, the color of the word was randomly selected amongst the four preceding rectangles, and the order of match and non-match trials were randomized with the constraint that no more than three match or non-match trials in a row occurred. Following a response, a screen appeared which instructed participants to press the spacebar in order to progress to the next trial, which allowed for participants to control the pace at which they completed the experiment.

Participants completed one set of 12 practice trials, and no practice trial sets had to be repeated as all participants included in the final analyses (*n* = 30) demonstrated understanding of the task. This was then followed by the first block of 62 color-matching trials, which did not include instructions for the embedded PM task. This non-PM baseline block was used to compare performances on the ongoing task alone versus the ongoing task with an embedded PM task. At the end of this baseline block, participants were provided with PM task instructions and each of the six PM target words on the computer screen. The PM task instructions informed participants that they must press the third key ("3" or "1") with their ring finger whenever one of six target words appears in the color-matching task. The instructions were neutral in regard to the importance of either the PM task or the ongoing task in that participants were not told that one task was more important than the other. Furthermore, they were not provided with specific instruction on whether they should execute the PM task before, instead of, or after responding to the ongoing task (Smith & Bayen, 2006). After receiving the PM task instructions, all six target words were presented simultaneously on the computer screen. Participants were allowed as much time as they need to study the PM target words, and were told to inform the examiner when they were finished studying the words. The examiner then lowered the computer screen and initiated a 30 s delay in which the participants were asked to count backward by fours starting with a given number to prevent target word rehearsal and maintenance. Participants were then asked to recall the target words in any order to ensure that the words had been adequately encoded. When any target items failed to be recalled, the participant was again shown the list of PM target words and again allowed to study the list for as long as needed. This procedure was repeated until the participant was able to successfully recall all six target words twice in a row. Although it did not reach statistical significance, a one-tailed Independent *t*-test revealed that the TBI group (M = 2.40, SD = 1.55) required on average one more repetition of the word list to learn the target words compared to the control group (M = 1.67, SD = .90), $t(28) = 1.59$, $p = .06$, $d = .58$.[1]

Prior to the start of the PM block of trials, a 10-minute delay period occurred in which the participants completed a fine motor skills task. Following the 10-mintue delay, participants

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[1] All reported effect sizes and power analyses were performed with the GPOWER program by Erdfelder, Faul, & Buchner (1996).

returned to the ongoing color-matching task without being reminded of the PM task instructions. Target items appeared on trials 10, 20, 30, 40, 50, and 60, and the order of the target words was randomized for each participant. Following the PM block of trials, participants were asked to recall the six target words. If a participant failed to recall any of the target words, a recognition trial was provided (TBI: $n = 9$; control: $n = 4$). They were also asked to recall the PM task instructions, which was followed by a recognition trial in the case that a participant failed to accurately recall the task (TBI: $n = 1$; control: $n = 0$). Each block of the experimental PM task lasted approximately 5-8 minutes.

CHAPTER THREE

ANALYSES

Neuropsychological Variables

Clinical data on cognitive functioning collected at the time of study participation were analyzed to further characterize our sample. As can be seen in Table 1, with the exception of measures of rapid visual scanning and tracking (RBANS Coding subtest; TBI: $M = 47.33$, $SD = 12.45$; control: $M = 60.27$, $SD = 6.93$), $t(28) = -3.51$, $p < .01$, and flexible thinking and planning (D-KEFS Design Fluency subtest scaled score; TBI: $M = 10.92$, $SD = 3.43$; control: $M = 13.40$, $SD = 2.69$), $t(26) = -2.14$, $p < .05$, group differences on most measures did not reach statistical significance. However, analyses revealed medium to large effect sizes (i.e., *d'*s > .44) for most cognitive measures, suggesting that the results were impacted by a lack of power. Questionnaire data indicated that, compared to controls, TBI participants were self-reporting significantly greater impairments in everyday prospective (PRMQ – Prospective Scale; TBI: $M = 26.67$, $SD = 7.84$; control: $M = 16.67$, $SD = 5.58$), $t(28) = 4.02$, $p < .01$, and retrospective memory abilities (PRMQ – Retrospective Scale; TBI: $M = 21.07$, $SD = 6.79$; control: $M = 14.13$, $SD = 5.57$), $t(28) = 3.06$, $p < .01$, as well as in executive abilities (DEX; TBI: $M = 29.67$, $SD = 10.30$; control: $M = 13.33$, $SD = 9.76$), $t(28) = 4.46$, $p < .01$.

Experimental Prospective Memory Task Performance

All participants were required to learn the target words and the PM task prior to starting the second block of trials. Furthermore, only those participants who were able to accurately recall or recognize all six target words and accurately recall or recognize the PM task at the end of testing were included in the final analyses.

PM task Accuracy. To determine whether the TBI and control groups differed in the amount of PM responses made during the experimental PM task, we used a one-tailed *t*-test to examine accuracy of PM responding. We found that the difference in the proportion of accurate responses to PM targets between the TBI group ($M = 0.47$, $SD = 0.39$) and control group ($M = 0.66$, $SD = 0.37$) approached but did not reach statistical significance, $t(28) = -1.35$, $p = .09$, $d = .50$, $(1 - \beta) = 0.38$. Examination of the means suggests a trend in the hypothesized direction, with the control group making more PM responses than the TBI group.

Ongoing Color-Matching Task

For color-matching task analyses, the PM target trials and two trials following the appearance of each target in the experimental block were excluded in order to avoid finding an artificial cost associated with PM responses. Similarly, we removed the baseline trials that were in the same position as those that were removed from the experimental block.

Accuracy. A Group (TBI vs. control) X Block (Baseline Block 1 vs. Experimental Block 2) X Trial Type (match vs. non-match) mixed-model ANOVA was conducted on the accuracy data for the ongoing color-matching task[2]. The analysis revealed a significant main effect of Block, $F(1,28) = 4.88$, $p < .05$, $\eta^2 = .15$, that was modified by a significant Block X Trial Type interaction, $F\ (1,28) = 15.68$, $p < .01$, $\eta^2 = .36$. Break down of the interaction revealed that the groups showed a reduction in accuracy for match trials from the baseline to the experimental block, $t(29) = -2.43$, $p < .05$, but not for non-match trials, $t(29) = 1.24$, *NS*. There was also a significant three-way interaction, $F(1,28) = 5.67$, $p < .05$, $\eta^2 = .17$. As seen in Figure 1, breakdown of the interaction revealed a non-significant and smaller difference in accuracy between the TBI and control groups for the baseline match trials (TBI: $M = .92$, $SD = .07$;

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[2] The assumption of homogeneity of variance was violated for accuracy on non-match trials. We further evaluated the data by examining the multivariate statistics. The results of both analytical techniques revealed an identical pattern of findings. Therefore, we have chosen to present the data using the more conventional univariate statistic.

control: *M* = .93, *SD* = .07) as compared to the baseline non-match trials (TBI: *M* = ..85, *SD* = .19; control: *M* = .95, *SD* = .07) and the experimental match (TBI: *M* = .81, *SD* = .11; control: *M* = .89, *SD* = .10) and non-match trials (TBI: *M* = .88, *SD* = .14; control: *M* = .94, *SD* = .08). According to the PAM theory (Smith & Bayen, 2006), a reduction in accuracy from the baseline to the experimental block signifies a cost to performance with the addition of the PM task. Thus, our findings for match trials suggest that our PM task usurps cognitive resources, even on non-target trials.

Reaction Times (RT). Individual response times at or above 2.5 standard deviations were considered outliers and removed from RT analyses. This resulted in the removal of less than 0.05% of the RT data. A Group (TBI vs. control) X Block (baseline vs. experimental) X Trial Type (match vs. non-match) mixed-model ANOVA was conducted on the RT data. Similar to findings obtained by Smith and Bayen (2006), participants were significantly faster in the baseline block with no PM task (*M* = 1222.44, *SE* = 73.69) as compared to the experimental block in which the PM task was embedded (*M* = 1786.78, *SE* = 103.87), $F(1,28) = 39.28$, $p < .00$, $\eta^2 = .58$, suggesting a significant cost to ongoing task performance with the addition of the PM task. A significant main effect was also found for Trial Type, $F(1,28) = 4.82$, $p < .05$, $\eta^2 = .15$, indicating that participants took longer to respond to non-match trials (*M* = 1546.34, *SE* = 86.84) than to match trials (*M* = 1462.88, *SE* = 73.12). Although the difference in RT between control participants (*M* = 1384.22, *SE* = 110.30) and TBI participants (*M* = 1625.00, *SE* = 110.30) did not reach statistical significance, $F(1,28) = 2.38$, $p = .13$, $\eta^2 = .08$, the data revealed a group difference of approximately 250 ms ($d = .29$), suggesting a trend in the expected direction (see Figure 2). None of the interactions were significant, *F*'s < 2.00.

Analyses were also conducted on RT difference scores, which were computed for each participant. Given the influence of trial type on RT, difference scores were computed separately for each trial type. More specifically, the mean RT for match trials on the baseline block (Block 1) was subtracted from the mean RT for match trials on the experimental block (Block 2) with the embedded PM task, and this process was conducted for non-match trials as well. Difference scores in RT data for control participants were significantly greater than zero for both the match trials, $t(14) = 5.66$, $p < .00$, and non-match trials, $t(14) = 4.98$, $p < .00$. Similarly, difference scores for TBI participants on both the match trials, $t(14) = 4.42$, $p < .01$, and non-match trials, $t(14) = 3.01$, $p < .01$, were above zero. These findings suggest a cost to ongoing task performance for both groups when the PM task was embedded (see Figure 2).

When examining for group differences, we found that RT difference scores for the match trials did not reach statistical significance between the TBI ($M = 561.06$, $SD = 470.81$) and control participants ($M = 542.86$, $SD = 360.56$), $t(28) = 0.12$, *NS*. The RT differences scores for non-match trials also did not differ significantly between the TBI ($M = 498.90$, $SD = 716.88$) and control participants ($M = 654.53$, $SD = 476.69$), $t(28) = -0.70$, *NS*. According to the PAM theory (Smith & Bayen, 2006), if the control participants are allocating greater attentional processes to the PM task than the TBI participants, then the RT difference score of the control participants should be greater than the RT difference score for the TBI participants, which was not observed in our data. However, as discussed in Smith and Bayen (2006), RT analyses have limitations for interpretation due to unequal baselines between groups. As such, conclusions regarding preparatory attentional processes based on RT data can be misleading. The use of the MPT modeling approach can allow for understanding the allocation of preparatory attentional processes without the limitations brought on by unequal baseline response times (Smith & Bayen, 2006).

Multinomial Process Tree Modeling

The MPT model used in the current study was originally developed and validated by Smith and Bayen (2004) and was also utilized by those authors to assess adult age differences in prospective remembering (Smith & Bayen, 2006). The model and a diagram of the processing tree from Smith and Bayen (2006) are detailed in Figure 3. As Smith and Bayen (2004, 2006) describe, the model is set to estimate four free parameters: (1) parameter P represents the prospective component, or the likelihood of engaging in preparatory attentional processes; (2) parameter M represents the recognition memory aspect of the retrospective component, or the likelihood of accurately discerning between the target and non-target words; (3) parameter C_1 represents the likelihood of correctly detecting a match on the color-matching task; (4) parameter C_2 represents the likelihood of accurately detecting a non-match trial on the color-matching task. The experiment consisted of four different trial types (PM targets on match trials, PM targets on non-match trials, non-PM targets on match trials, and non-PM targets on non-match trials) and three response options for each trial (Yes, No, or PM Target). The raw response frequencies obtained for each trial type are listed for the TBI and control groups in Table 2.

For the MPT analyses we utilized the HMMTree program, which was designed to compute parameter estimates, confidence intervals, and goodness-of-fit statistics for MPT models (Stahl & Klauer, 2007). Using the goodness-of-fit test statistic G^2 for the four free parameters within the individual model, we found the model to be a good fit to the data for both the TBI group, $G^2(4) = 0.93$, and the control group, $G^2(4) = 0.94$, as both values were below the critical value of 9.49 for $df = 4$. To examine potential group differences in the likelihood of engaging in preparatory attentional processes, we then set *P* equal across both groups. This yielded a value of $G^2(1) = 2.85$, which is smaller than the critical value of 3.84 for $df = 1$ at an α-level of .05. However, the value exceeds the critical value of 2.70 for $df = 1$ at an α-level of .10, suggesting a trend in the expected direction, with control participants demonstrating greater likelihood of engaging in preparatory attentional processes (*P*). An examination of the effect of group on recognition memory for the PM target events as measured by parameter *M* yielded a value of $G^2(1) = 4.75$, which exceeded the critical value of 3.84. As depicted in Figure 4, control participants were more likely to correctly discriminate between PM targets and non-targets as compared to TBI participants, despite the fact that our groups did not differ in their post-test recall of the PM task and the target words. Following the same procedure for the ongoing task parameters, group was found to significantly affect both the probability of detecting a color match (C_1), $G^2(1) = 8.13$ and the probability of detecting that a color does not match (C_2), $G^2(1) = 8.71$, with control participants exhibiting greater probability of detecting both as compared to TBI participants.

Correlational Analyses

Exploratory correlational analyses were conducted to examine potential relationships between the proportion of PM responses and RT difference scores (match and nonmatch) for the experimental PM task and characteristics of age, neuropsychological tests of retrospective memory (select subtests of the RBANS) and executive functioning (select subtests of the D-KEFS and RBANS, and Trail Making Test Part B), as well as prospective and retrospective memory questionnaire findings (PRMQ), and executive functioning questionnaire findings (DEX). Data were initially examined separately for each group, and then collapsed across both groups to increase power. Because a large number of variables were examined, a more conservative *p*-value of .01 was used to interpret statistical significance in order to decrease the likelihood of Type I errors.

Table 3 shows that for the control participants, the proportion of correct PM responses made on the experimental PM task was found to significantly correlate with RT differences scores for the non-match trials (*r* = .69). The proportion of PM responses was also significantly correlated with RT difference scores for both match and non-match trials for the TBI group (match: *r* = .81; non-match: *r* = .76) and when both groups were collapsed together (match: *r* = .66; non-match: *r* = .72). The proportion of PM responses was also found to significantly correlate with flexible thinking and planning (D-KEFS Design Fluency subtest) for the TBI group (*r* = .75) and for both groups combined (*r* = .52). Finally, with both groups combined, the proportion of PM responses significantly correlated with list-learning ability (RBANS List Learning subtest; *r* = .51). The PM task variables were not found to be significantly correlated with any questionnaire data or TBI injury characteristics. Overall, more PM responses made in the experimental task was related to a greater increase in RT from the baseline to the experimental blocks, suggesting that participants may have put more effort in monitoring for PM cues. In addition, more PM responses were found to be related to greater rote verbal learning abilities, and greater flexibility in thinking and planning.

CHAPTER FOUR

DISCUSSION

The goal of this study was to utilize a formal multinomial processing tree (MPT) model of event-based PM (Smith & Bayen, 2004) to disentangle the influence of prospective processes (i.e., remembering *that* an action needs to be taken) and retrospective recognition processes (i.e., remembering *when* the action needs to be executed) that might contribute to impairments in prospective remembering following moderate to severe TBI. Using a computerized event-based PM task that was analyzed by both traditional methods of analysis and the MPT modeling approach, we expected to find that TBI participants would demonstrate fewer PM responses, slower response times, and significantly reduced likelihood of engaging in preparatory attentional processes compared to healthy controls. Furthermore, an important goal of this study was to assess for differences in retrospective processes as they occur *during* the PM task as well as at post-test recall.

Using traditional methods of data analysis for the experimental computer task, we found that while the control group made more PM responses than the TBI group, the difference did not reach statistical significance. However, we found a large effect size for group differences in PM performance on the computer task, which strongly suggests that our ability to detect a statistically significant difference may have been hampered by our small sample size. The trend in the data from our experimental computer task seemed consistent with previous research demonstrating that individuals with a TBI are significantly more impaired than controls on various PM tasks (e.g., Carlesimo, Casadio, & Caltagirone, 2004; Cockburn, 1996; Fortin, Godbout, & Braun, 2003; Groot et al., 2002; Henry et al., 2007; Kliegal, Eschen, & Thone-Otto, 2004; Kinsella et al., 1996; Knight, Harnett, & Titov, 2005; Knight, Titov, & Crawford, 2006; Mathias & Mansfield, 2005; Roche, Fleming, & Shum, 2002; Roche, Moody, Szabo, Fleming, & Shum, 2007; Schmitter-Edgecombe & Wright, 2004; Shum, Valentine, & Cutmore, 1999).

Traditional methods of analysis on the accuracy data for the ongoing experimental task in which the PM task was embedded revealed a significant reduction in accuracy from the baseline to experimental blocks for the match trials. We also found that, in general, TBI participants were notably less accurate than controls for all trials types and blocks, with the exception of commensurate accuracy for match trials in the baseline block. Results of the MPT analyses were also able to uncover significant group differences on both match (C_1) and non-match (C_2) trial parameters, suggesting that our groups differed in their ability to accurately detect whether an item was or was not a match. The parameter findings are similar to the findings obtained by Smith and Bayen (2006), who found that older adults were less accurate than younger adults on both ongoing task parameters.

Traditional methods of analysis of the RT data from the experimental computer task revealed that both groups were significantly slower on the experimental block than the baseline block in which no PM task was embedded. We also found that participants were significantly faster at identifying that a color matches than at identifying that a color does not match. Although the finding did not reach statistical significance, control participants tended to exhibit faster overall RTs than TBI participants. Similar to findings obtained by Smith and Bayen (2006), we found that the RT difference scores for both groups were significantly greater than zero. Together, these findings indicate a cost to ongoing task performance with the inclusion of the PM task, which supports the PAM theory contention that this PM task required resources.

While the use of traditional analyses on RT difference scores can be used to examine the prospective component of preparatory attentional processes, the presence of unequal baselines between our groups presented an important limitation to interpretation. The MPT modeling approach allowed for further examination of the allocation of preparatory attentional processes without the limitations brought on by unequal baseline response times (Smith & Bayen, 2006). The use of the MPT model also allowed us to tease out and separately examine the retrospective recognition component of PM, or the ability to discriminate between targets and nontargets (i.e., the *when* component) from the prospective component.

Given that the PAM theory speculates that preparatory attentional processes are resource-demanding, we expected that our control participants would allocate preparatory attentional processes at a significantly greater rate than our TBI participants. This prediction was based upon findings indicating that individuals with a TBI experience deficits in resource-demanding, strategic cognitive processes (e.g., Schmitter-Edgecombe & Beglinger, 2001; Schmitter-Edgecombe, Marks, & Fahy, 1993; Schmitter-Edgecombe & Rogers, 1997; Vakil, Blachstein, & Hoofien, 1991). This prediction would also be in line with the fact that deficits in PM following TBI have generally been attributed to impairments in the prospective component (e.g., Cockburn, 1996; Fish et al., 2006; Fortin et al., 2003; Groot et al., 2002; Kinsella et al., 1996; Knight et al., 2005; Knight et al., 2006; Mathias & Mansfield, 2005; Shum et al., 1999). Using the MPT approach to analyze the data, the trends in our findings indicated that TBI participants may be experiencing greater difficulty with allocating preparatory attentional processes.

Recent findings by Bisiacchi and colleagues (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009) indicate that the nature of PM task instructions can impact the level of attentional and cognitive control processes needed to complete the PM task. They examined the electrophysiological underpinnings of an event-based PM task embedded within either a task-switch or dual-task condition. Task-switch instructions require participants to stop the ongoing task performance upon encountering the cue and execute the PM task instead of the ongoing task. In contrast, dual-task instructions require participants to make a PM response after they execute a response for the ongoing task. Bisiacchi and colleagues (2009) argued that task-switching entails two rules (i.e., stop ongoing task, complete PM task) in which one response has to be suppressed, while dual tasks rely on parallel processing, or one rule (i.e., complete task) for both the ongoing and PM tasks. By manipulating task instructions, the authors found that task-switch and dual-task instructions were supported by separate neural mechanisms, with task-switch instructions requiring greater cognitive control and attentional resources.

We did not specify task-switch or dual-task instructions in the current study because, as suggested by Smith and Bayen (2004), specifying a task-switch or dual-task response may fail to adequately replicate the nature of interrupting an ongoing task in a real-life situation. Given that our sample may consist of both approaches since participants were free to determine which way to execute the task, Bisiacchi and colleagues' (2009) findings would suggest that our results may represent two different neural processes, which may be a confound in our study. However, findings obtained by Smith and Bayen (2004) provide evidence of the same degree of preparatory attentional processes regardless of the type of procedure (i.e., task-switch or dual-task), which would contradict the above argument. It will be helpful for future research to further explore this discrepancy in findings by Smith and Bayen (2004) and Bisiacchi and colleagues (2009) regarding the impact of task-switch versus dual-task instructions on cognitive resources.

One important result of the MPT modeling approach was the finding that participants in our TBI group were significantly more impaired than controls in the retrospective recognition parameter (i.e., the *when* aspect of the retrospective component). This finding is of particular interest because it suggests that despite having intact retrospective memory for the PM task and target words (i.e., *what* component), participants in the TBI group had significant difficulty with discriminating between targets and non-targets as they were engaged in the task. This finding is consistent with previous cognitive research indicating that recognition failure can occur for items that are successfully recalled at a later time (Tulving & Thomson, 1973). This is an important finding given that most studies fail to differentiate retrospective memory for the PM task and targets (i.e., the *what* component) from recognition processes (i.e., the *when* component) as they are engaged during task execution.

In addition to greater impairment in our TBI group in the ability to discriminate between targets and non-targets, the MPT model analyses also indicated that our TBI participants had greater impairment in the ability to discriminate between match and non-match trials. Thus, one important question that arises from our findings is whether our results are related to a broader problem with item discriminability for the TBI participants, rather than a process specifically related to memory functioning. Future research will need to examine this possibility more thoroughly, as a general impairment in discriminability would have starkly different implications for rehabilitation and remediation than those implicated for impairments specific to prospective remembering.

There are several important limitations to this study. One of these limitations is a lack of power to detect statistically significant differences. Many of our results trended in the expected direction and yielded medium-to-large effect sizes, but still failed to reach statistical significance. This strongly suggests that the issue of power was paramount in our findings. Given that six participants with a TBI had to be excluded from final analyses due to various cognitive difficulties (e.g., inability to encode PM target words, etc.), future research will benefit from starting with a larger sample size. Another possible limitation is the nature of our moderate to severe TBI sample. Given a lack of significant group differences on neuropsychological measures, our sample may consist of a more heterogeneous TBI sample than anticipated. However, group comparisons of neuropsychological data yielded medium-to-large effect sizes in many cognitive domains, further suggesting an issue of low power due to a small sample size. Finally, because our participants were self-selected and self-referred rather than having been recruited through a medical setting, selection bias may be a potential confound. The possibility of selection bias also limits the generalizability of our findings. Future research will need to address these concerns in order to provide a more thorough picture of how prospective and retrospective components contribute to PM impairment following moderate to severe TBI.

The findings obtained in this study are important for several reasons. To the knowledge of this author, no other study has attempted to use a statistical model to understand the impact of prospective and retrospective processes underlying PM impairment in a TBI population. In general, despite the limitations from our lack of power, our data showed trends indicative of better PM performance by control participants. While this finding seemed to be largely driven by significantly reduced retrospective recognition processes in TBI participants during task execution, a trend for greater allocation of preparatory attentional processes by control participants also appeared to be a contributing factor. Given that many studies examining PM following TBI tend to assume that observed deficits are due to impairments in the prospective component of prospective remembering (e.g., Cockburn, 1996; Fish et al., 2006; Fortin et al., 2003; Groot et al., 2002; Kinsella et al., 1996; Knight et al., 2005; Knight et al., 2006; Mathias &

Mansfield, 2005; Shum et al., 1999), it will be important to further examine and replicate this finding in a larger study with greater power.

Taken together with findings from traditional methods of data analyses, our results seem to provide further support for the PAM theory in that prospective remembering within this event-based PM task requires capacity-demanding resources. Future research will need to further examine whether these findings are consistent across other types of PM tasks. Because impairments in PM can be detrimental to successful rehabilitation following TBI due to the need to remember important activities such as medical appointments, it is important for researchers and clinicians to gain a thorough understanding of the processes and components involved in this unique construct. Gaining a better understanding of PM can allow for clinicians to more effectively address PM impairments in response to TBI, as well as to understand the extent to which survivors of TBI experience residual deficits in PM functioning.

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APPENDIX

Table 1. Demographic data, performance-based neuropsychological variables, and self-reported questionnaire data for TBI (*n* = 15) and control groups (*n* = 15).

	TBIs		**Controls**		
Variables or test	***M***	***SD***	***M***	***SD***	**d**
Age (years)	36.00	11.17	34.93	10.35	---
Education (years)	15.73	1.83	15.73	1.53	---
RBANS[a]					
List Learning	29.33	4.47	31.47	3.38	.54
List Recall	6.13	2.85	7.67	1.17	.71
Story Memory	16.73	4.50	19.20	3.00	.65
Story Recall	9.00	3.18	10.13	1.60	.45
Digit Span	10.47	2.67	11.33	2.61	.33
Coding	47.33	12.45	60.27**	6.93	1.28
D-KEFS Design Fluency[b]	10.92	3.43	13.40*	2.69	.80
Trail Making Test – Part A[c]	27.87	10.47	25.00	11.06	.27
Trail Making Test – Part B[c]	64.73	49.17	58.20	35.94	.15
PRMQ Prospective Scale[a]	26.67	7.84	16.67**	5.58	1.47
PRMQ Retrospective Scale[a]	21.07	6.79	14.13**	5.57	1.12
DEX Total[a]	29.67	10.30	13.33**	9.76	1.63

Notes. TBI = Traumatic brain injury; RBANS = Repeatable Battery for the Assessment of Neuropsychological Status; D-KEFS = Delis-Kaplan Executive Functions System; PRMQ = Prospective-Retrospective Memory Questionnaire; DEX = Dysexecutive Questionnaire; PM = prospective memory.

[a] Raw scores.

[b] Composite scaled score.

[c] Time in seconds.

*p < .05

***p* < .01.

Figure 1. Mean accuracy data plotted as a function of Group (TBI vs. control) by Trial Type (match vs. non-match) for baseline and experimental blocks.

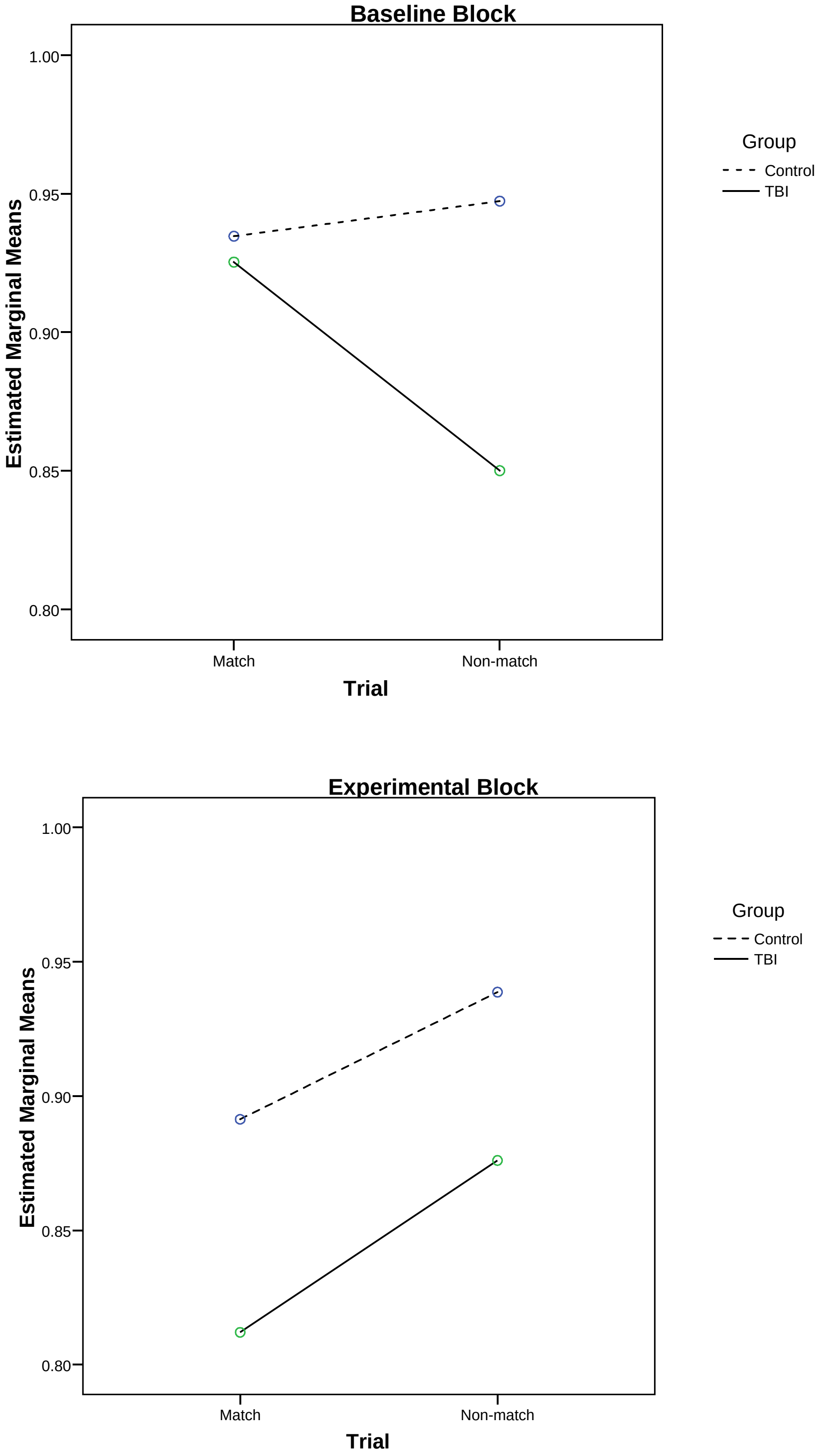

Figure 2. Mean reaction times (ms) for ongoing color-matching task in Block 1 (baseline) and Block 2 (experimental) by trial type (match and non-match). Also shown is the mean change in reaction time from Block 1 to Block 2. Bars represent standard errors. RT = reaction time. NM = non-match.

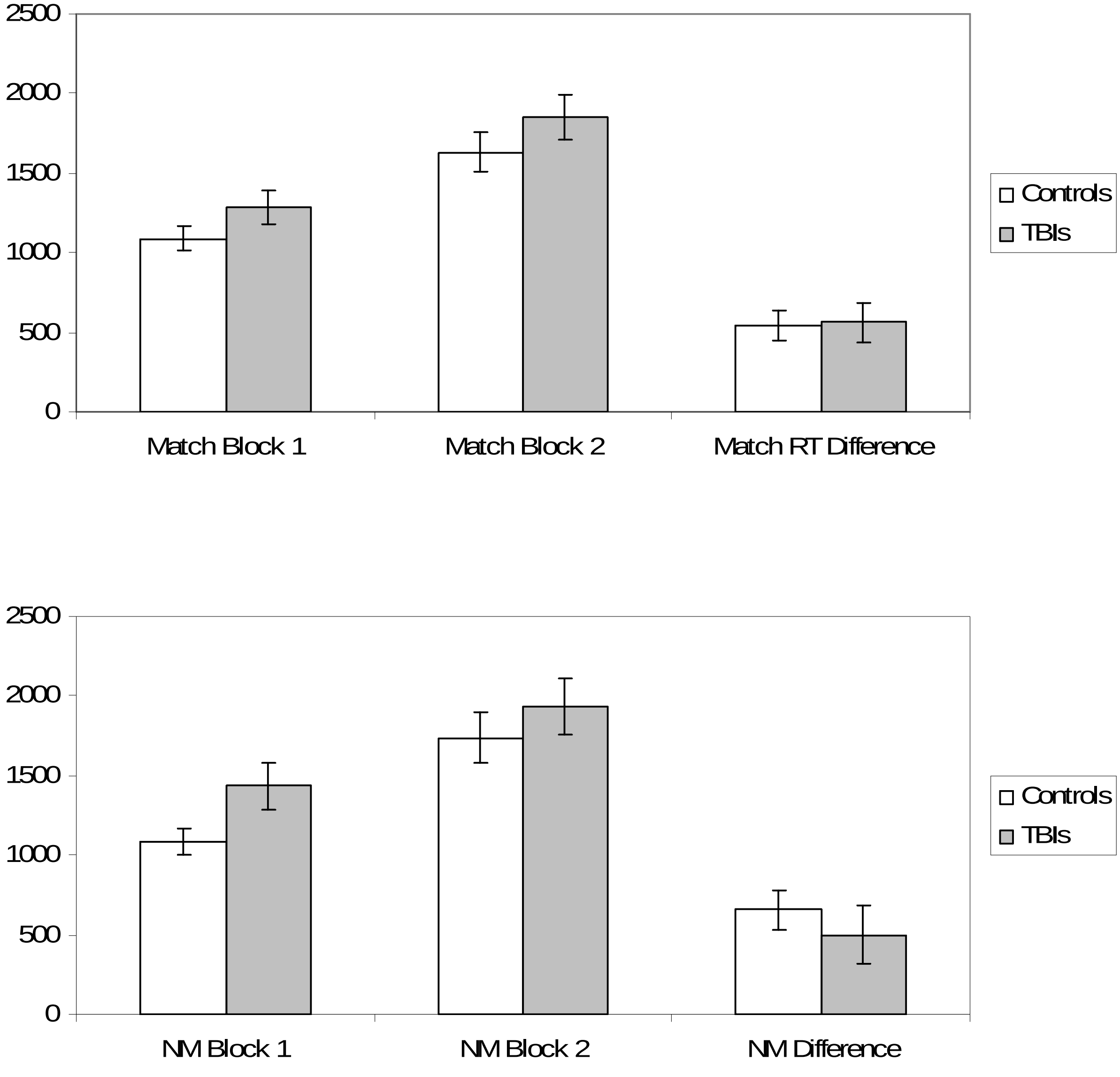

Figure 3. Multinomial model of event-based prospective memory. Taken from "The source of adult age differences in event-based prospective memory: A multinomial modeling approach" by R. E. Smith and U. J. Bayen, 2006, *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(3), p. 634. PM = prospective memory; *P* = probability of engaging in preparatory attentional processes; *M* = probability to discriminating between targets and non-targets; *g* = probability of guessing that a word is a target; *c* = probability of guessing that a color matches; C_1 = probability of detecting a color match; C_2 = probability of detecting that a color does not match.

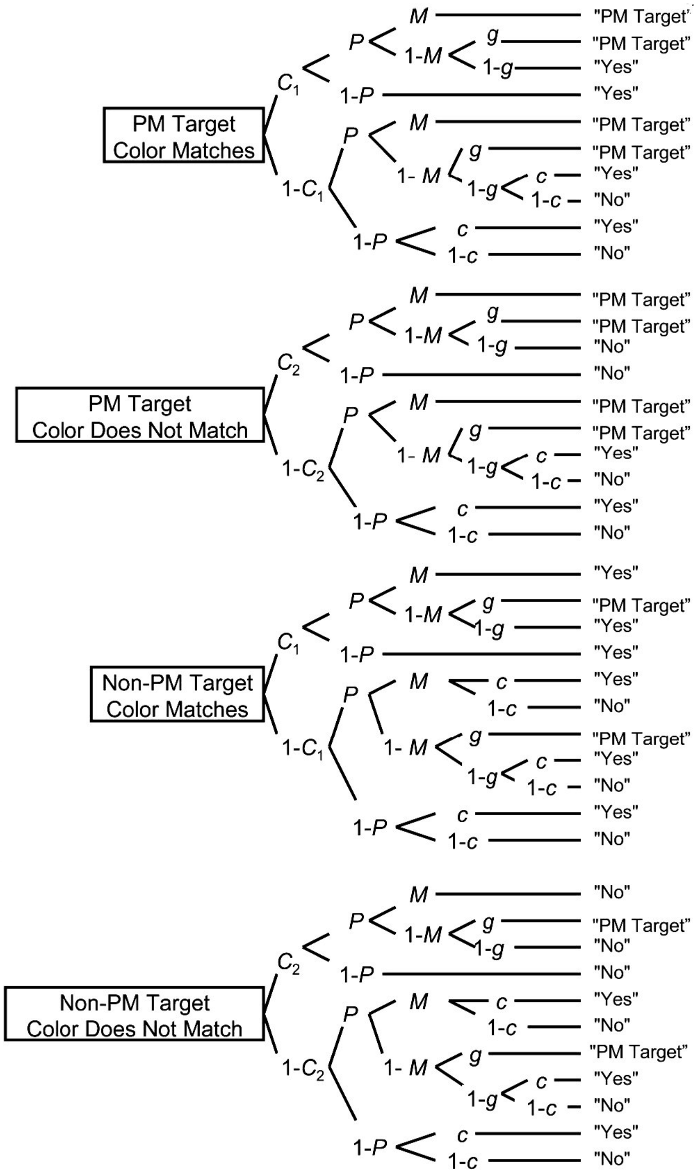

Figure 4. Multinomial parameter estimates. *P* = probability of engaging in preparatory attentional processes; *M* = probability to discriminating between targets and non-targets; *g* = probability of guessing that at color matches; C_1 = probability of detecting a color match; C_2 = probability of detecting that a color does not match. Error bars represent 95% confidence intervals.

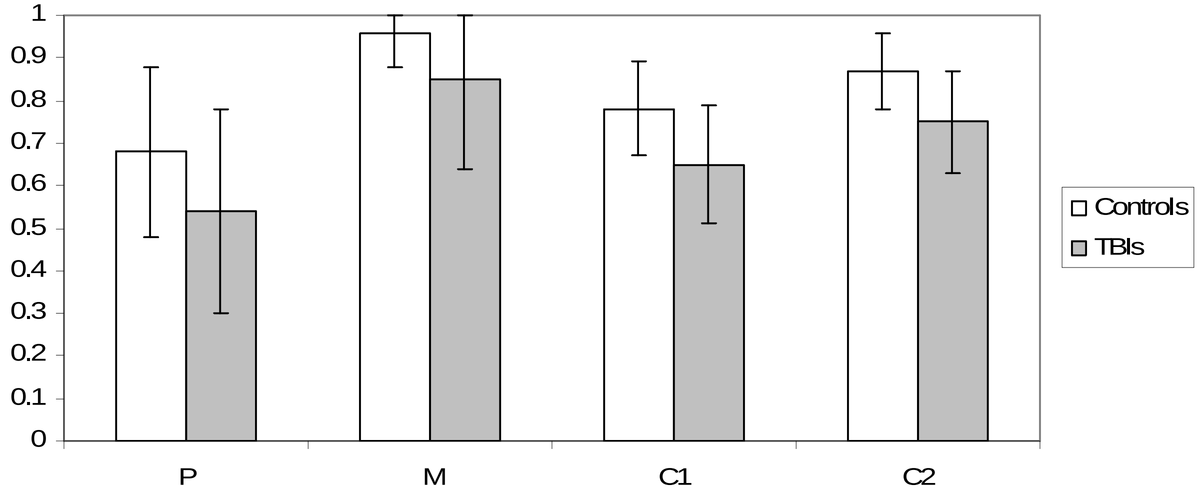

Table 2. Response frequencies for the prospective memory (PM) task for TBI and control groups.

	Response Type		
Item Type	**Yes**	**No**	**PM Target**
TBI group			
Target, match	19	3	20
Target, nonmatch	3	17	22
Nontarget, match	314	74	4
Nontarget, nonmatch	52	337	3
Control group			
Target, match	14	3	27
Target, nonmatch	0	18	24
Nontarget, match	348	44	0
Nontarget, nonmatch	26	365	1

Table 3. Correlations (*r*) for experimental task variables and neuropsychological characteristics for TBI and control participants.

Variable		PM response proportion	Match RT Difference Score	Non-match RT Difference Score
PM response proportion	Control:	X	X	X
	TBI:			
	Combined:			
Match RT Difference Score	Control:	.530	X	X
	TBI:	.808**		
	Combined:	.661**		
Non-match RT Difference Score	Control:	.689**	.860**	X
	TBI:	.755**	.826**	
	Combined:	.724**	.825**	
Age	Control:	-.111	.134	-.138
	TBI:	-.203	-.171	-.402
	Combined:	-.167	-.043	-.301
Design Fluency Composite Scaled Score	Control:	.122	-.186	-.141
	TBI:	.745**	.672	.550
	Combined:	.517**	.298	.324
RBANS List Learning	Control:	.367	.152	-.066
	TBI:	.561	.513	.450
	Combined:	.512**	.360	.300
RBANS Story Memory	Control:	-.171	.037	.054
	TBI:	.317	.340	.349
	Combined:	.195	.217	.284
RBANS Digit Span	Control:	.385	.023	.193
	TBI:	-.075	.014	.046
	Combined:	.180	.014	.122
RBANS List Recall	Control:	.483	.219	.115
	TBI:	.428	.407	.284
	Combined:	.462	.321	.272
RBANS Story Recall	Control:	.042	-.011	.004
	TBI:	.408	.285	.185
	Combined:	.319	.189	.164
Trails B	Control:	-.128	.462	.365
	TBI:	-.269	-.239	-.085
	Combined:	-.223	.014	.051

** $= p < .01$.

Table 3 (continued)

Variable		PM response proportion	Match RT Difference Score	Non-match RT Difference Score
PRMQ Prospective	Control:	.283	-.080	.071
	TBI:	-.073	-.117	-.209
	Combined:	-.097	-.069	-.173
PRMQ Retrospective	Control:	.337	-.019	.089
	TBI:	-.261	-.129	-.242
	Combined:	-.125	-.063	-.173
DEX	Control:	.161	-.147	-.067
	TBI:	-.076	.056	.190
	Combined:	-.133	-.008	-.017
Years Since Injury	Control:	X	X	X
	TBI:	-.068	-.149	-.035
	Combined:	X	X	X
Coma Duration (hours)	Control:	X	X	X
	TBI:	.204	.214	.274
	Combined:	X	X	X
PTA Estimate	Control:	X	X	X
	TBI:	-.450	-.407	-.515
	Combined:	X	X	X

** = $p < .01$.