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Prospective Memory Following Traumatic Brain Injury: A Meta-Analysis

by

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Prospective Memory Following Traumatic Brain Injury: A Meta-Analysis

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Abstract

Individuals with traumatic brain injury (TBI) report frequent and significant prospective memory deficits (Shum et al., 2011). This study presents a review and meta-analyses on prospective memory and TBI; focusing on clarifying the true effect of prospective memory deficits, the influence of task demands on performance, and the relationship between prospective memory and other cognitive functions. The results revealed that the difference in prospective memory performance between TBI and control groups was large (d = 0.987, SE = 0.087), indicating that TBI patients have significantly lower prospective memory performance than matched controls. Subgroup analyses revealed that prospective memory was poorer when tasks were more demanding. In addition, prospective memory was significantly correlated with attention, retrospective memory and executive functions. Prospective memory should be regularly assessed in individual with TBI, and task-related demands should be considered when deciding appropriate assessment measures and compensatory strategies.

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CHAPTER I

REVIEW OF LITERATURE

Traumatic Brain Injury

Traumatic brain injury (TBI) refers to brain damage that disrupts normal brain functioning resulting from blows or jolts to the head. Leading causes of TBI are falls, unintentional blunt trauma (being hit by an object), motor vehicle accidents, and assaults (Lezak, Howieson, Bigler, & Tranel, 2012; Schoenberg & Scott, 2011). According to Lezak and colleagues (2012), the majority of traumatic brain injuries are closed head injuries, in which the outer membrane of the brain remains intact and the brain is not exposed. In contrast, in open head injuries the skull and dura mater are penetrated by an object, such as in gunshot wounds.

In closed head injuries, direct blows and abrupt movements of the head result in cerebral focal contusions and hemorrhages (Lezak et al., 2012; Schoenberg & Scott, 2011). These initial effects are referred to as primary brain damage. The frontal and temporal lobes are particularly vulnerable to focal contusions due to their location within the skull. White matter damage also occurs when the brain jolts inside the skull due to acceleration and deceleration forces associated with an impact. A series of secondary effects can further exacerbate brain damage, these include ongoing hemorrhages, increased intracranial pressure, hypoxia, ischemia, and changes in the brain metabolic physiology (Lezak et al., 2012; Schoenberg & Scott, 2011).

TBI is a major cause of death and disability worldwide (Belanger, Curtis, Demery, Lebowitz, & Vanderploeg, 2005; Dikmen et al., 2009). When TBI does not lead to death, it can result in neurological (balance/motor disorder), psychiatric (depression/anxiety/psychosis), cognitive (memory), and functional/behavioral problems (managing day-to-day/personality changes) that result in temporary, prolonged or permanent disability (Dikmen et al., 2009; Finnanger et al., 2013; Lezak et al., 2012; Schoenberg & Scott, 2011). Severity is a good predictor of recovery and outcome. TBI is classified as mild, moderate, or severe based on the state of altered consciousness that follows the injury. The Glascow Coma Scale (GSC) is a widely used instrument that evaluates severity based on the length and depth of loss of consciousness (Lezak et al., 2012). Post-traumatic amnesia is another indicator of TBI severity. Most individuals with mild TBI do not have long-term impairment and make a good recovery. However, individuals who sustain a severe TBI often have long-term disability, and are less likely to live independently and resume occupational activities (Dikmen et al., 2009; Lezak et al., 2012; Schoenberg & Scott, 2011).

Cognitive impairments relating to attention, executive functions (e.g., planning, inhibition, monitoring), working and episodic memory, and processing speed are frequent and debilitating outcomes of moderate to severe TBI (Belanger et al., 2005; Dikmen et al., 2009; Finnanger et al., 2013; Lezak et al., 2012; Schoenberg & Scott, 2011). When these neurocognitive deficits persist they can impair long-term functioning, and become an impediment to resuming employment, leisure, and independent living activities (Dikmen et al., 2009; Finnanger et al., 2013; Schoenberg & Scott, 2011). Specifically, executive and memory functions have been found to be important indicators of global functioning and predict recovery in this population (Finnanger et al., 2013).

Past research on memory functions and TBI concentrated primarily on deficits in retrospective memory, which is the ability to remember past events and previously learned information (Henry et al., 2007; Shum, Valentine, & Cutmore, 1999). However, there is an increasing interest in investigating prospective memory in individuals with TBI. Prospective memory is the ability to remember to do something in the future at the right time and place to formulate future plans, retain them, recollect them, and act on them appropriately (Graf, 2012; Uttl, Graf, Miller, & Tuokko, 2001; Henry et al., 2007; Uttl, 2008).

Prospective Memory

Increased interest in prospective memory reflects its important role in completing daily activities (Graf, 2011; Shum, Levin, & Chan, 2011; Uttl et al., 2001). Prospective memory allows us to formulate and execute plans necessary for independent living, such as personal care and homemaking. For example, when we maintain our appointments, remember to get groceries, and pay our bills on time we are successfully relying on our prospective memory (Graf, 2012; Uttl, 2008). Patients with TBI report significant and frequent prospective memory failures that limit their ability to return to pre-injury levels of functioning (Henry et al., 2007; Mioni, Rendell, Henry, Cantagalo, & Stablum, 2013; Raskin, Buckheit, & Waxman, 2012; Shum et al., 2011).

Prospective memory is a complex ability involving multiple processes (Kliegel, Eschen, & Thone-Otto, 2004; McDaniel & Einstein, 2000; Mioni et al., 2013). It involves a planning component, a retrospective memory component in which there is retrieval of previously formed intentions from long-term memory, and it also involves monitoring the environment for cues, switching between activities, and action initiation (Kliegel et al., 2004; Uttl et al, 2001). For instance, to get groceries at the end of the day; we begin by planning to get groceries in our way home from work. After formulating our plan, we continue working on unrelated tasks, but while driving home, we must retrieve our previously formed plan and execute it at the appropriate place.

Kliegel and colleagues (2004) proposed a stage-model of prospective memory that includes intention formation (e.g., intending to get groceries), intention retention (e.g., holding the intention to get groceries while we work), and intention initiation and execution (e.g., driving to the grocery store to buy groceries). Intention initiation and execution are triggered by prospective memory cues; for example, a coffee cup at work can serve as a cue that triggers the previously formed plan to buy groceries (McDaniel & Einstein, 2000; Uttl et al., 2001).

Prospective memory is divided into three subtypes that represent slightly different abilities; episodic, habitual, and vigilance/monitoring prospective memory (Graf, 2011; Uttl et al., 2001). Episodic prospective memory allows us to bring back to awareness a previously formed intention at the right time and/or place, typically in response to a cue (Graf, 2012; Uttl, 2008). It refers to one time future plans, and it is characterized by a retention interval between formulation and execution of plans (Graf, 2012). The retention interval is typically filled with other activities; thus successfully executing an episodic prospective memory plan requires interruption of an ongoing activity as in the previous scenario of getting groceries while driving home (Graf, 2012; Uttl et al., 2001). Habitual prospective memory refers to future plans that need to be brought back to consciousness repeatedly, such as adhering to a medication schedule (Graf, 2012; Uttl, 2008).

Vigilance/monitoring is similar to episodic prospective memory but the intention is rehearsed and/or maintained in conscious awareness until it can be executed (Graf, 2011; Uttl, 2008). For example, remembering what to say while waiting for your turn to answer a question (Graf, 2011). Another difference is that the retention interval between formulation and execution of the future intention is shorter for vigilance/monitoring than for episodic prospective memory (Graf, 2011; Uttl, 2008). In addition to the distinctions in the above types of prospective memory there is also a distinction between event-based and time-based prospective memory. Time-based prospective memory allows us to perform an intended action in response to a time cue, such as remembering to make a phone call at an exact time; whereas event-based prospective memory is cued by an event, such as when we remember to stop by the post office after seeing a mailing envelope (Schmitter-Edgecombe & Wright, 2004).

Measures of Prospective Memory

Several measures have been used to assess episodic prospective memory in patients with TBI (Mioni et al., 2014; Shum et al., 2011). In a typical experimental design, participants are asked to encode a prospective memory intention to be executed at a later instance in response to a prospective memory cue (e.g., pressing a keyboard key upon seeing the word “DOG” on the screen; Shum et al., 1999). Following encoding, participants complete a 5 to 10 minute filler task (e.g., puzzles) so that the prospective memory intention (e.g., pressing the key) leaves consciousness; making the task a measure of episodic prospective memory as opposed to vigilance/monitoring (Henry et al., 2007). After, participants are given instructions for an ongoing task (e.g., lexical decision) during which the prospective memory cue (“DOG”) appears, and the participant must recognize the cue, inhibit performance of the ongoing task, and execute the prospective memory intention (e.g., pressing the key).

The previous example describes a measure of event-based prospective memory (Henry et al., 2007). In contrast, in time-based tasks, the cue could be a specific time or time interval (e.g., pressing the key every 5 minutes). The number of cues varies between studies (Shum et al., 2011). Some studies have used a single cue and applied a binary success/failure measure as an index of prospective memory performance (Hannon, Adams, Harrington, Fries-Dias, & Gipson, 1995; Kondo et al., 2010; Mathias & Mansfield, 2005; Umeda, Kurosaki, Terasawa, Kato, & Miyahara, 2011). However, a binary index often leads to ceiling/floor effects, limiting the validity and reliability of the measure (Mioni et al., 2014; Uttl, 2008). In order to avoid this methodological limitation, most studies use multiple cues to obtain an index of prospective memory performance (Fleming et al., 2008; Groot, Wilson, Evans, & Watson, 2002; Henry et al., 2007; Kliegel et al., 2004; Mioni et al., 2013; Raskin et al., 2012; Schmitter-Edgecombe & Wright, 2004; Shum et al., 1999; Pavawalla, Schmitter-Edgecombe , & Smith, 2012; Tay, Ang, Lau, Meyyappan, & Collinson, 2010). For example, the prospective memory cue could be presented 6 times during the course of the task, and the index of prospective memory performance is calculated as the average number of correct prospective memory executions. Past research indicates that prospective memory is best characterized by such a continuous measure (Mioni et al., 2014; Uttl, 2008; Uttl & Kibreab, 2011).

In addition, several prospective memory tasks have been developed and standardized to investigate prospective memory functioning in clinical populations. The most commonly used tests are the Memory for Intentions Test (MIST; Raskin, 2009), and the Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2005). The designs of these tests were motivated by theoretical definitions and results of experimental studies to assess prospective memory in clinical settings (Raskin, 2009). Thus, these tests have the main characteristics of experimental prospective memory tasks; including encoding of prospective memory intentions, retention interval, multiple prospective memory cues, and ongoing task (Raskin, 2009).

One criticism of prospective memory research has been that experimental tasks lack ecological validity, and performance on such tasks does not directly translate to prospective memory in naturalistic settings (Banville & Nolin, 2012; Banville et al., 2010; Mioni et al., 2013). While most studies have demonstrated experimental tasks of prospective memory do provide important data regarding real-world performance, there is an effort to improve ecological validity, and recent studies have designed virtual reality tasks where the prospective memory intentions, cues, and ongoing tasks resemble daily living activities (Banville & Nolin, 2012; Canty et al., 2014; Kinsella, Ong, & Tucker, 2009; Mioni et al., 2012; Mioni et al., 2013).

Self-report questionnaires are also used to document prospective memory failures (Hannon et al., 1995; Raskin et al., 2012; Roche, Moody, Szabo, Fleming, & Shum, 2007; Shum et al., 2011; Smith, Della Sala, Logie, & Maylor, 2000). The most commonly used are the Prospective Memory Questionnaire (PMQ; Hannon et al., 1995), the Prospective and Retrospective Memory Questionnaire (PMRQ; Smith et al., 2000), and the Comprehensive Assessment of Prospective Memory (CAPM; Roche et al., 2007). Self-report questionnaires are easy and quick to administer; therefore, clinicians may prefer them to assess prospective memory in clinical settings. However, research findings regarding the validity of such measures have been mixed. Several studies report that self-reported functioning does not correlate with performance on prospective memory experimental tasks of normal and clinical populations, lacking convergent validity (Mateer, Sohlberg, & Crinean, 1987; Raskin et al., 2012; Uttl & Kibreab, 2011). Thus, self-report questionnaires may not accurately document prospective memory functioning, and should not be the sole measure of prospective memory failures in clinical settings (Raskin et al., 2012; Roche et al., 2007).

A review of the literature indicates that patients with TBI experience prospective memory impairment (Henry et al., 2007; Lezak et al., 2012; Mioni et al., 2014; Shum et al., 2011). The frontal and temporal lobes, frequently damaged as a result of TBI, are associated with processes essential for prospective remembering; such as initiation, encoding, and execution of actions (Lezak et al., 2012; Mioni et al., 2014). Initial studies were mostly descriptive and established that prospective memory failures in TBI are frequent and significant (Groot et al., 2002; Kliegel et al., 2004; Knight et al., 2005; Schmitter-Edgecombe & Wright, 2004). These deficits limit patients’ ability to live independently and resume occupational activities. To better elucidate prospective memory functioning in TBI, recent studies have explored variables that may influence prospective memory, these include prospective memory tasks characteristics and other cognitive functions (Canty et al., 2014; Henry et al., 2007; Mioni et al., 2014; Raskin et al., 2012). Understanding how these variables impact performance is essential for post-TBI assessments, and development of compensatory strategies to assist independent living.

Prospective Memory Task Characteristics

Successful prospective memory performance requires individuals to plan and encode intentions, monitor for prospective memory cues, perform an ongoing task, inhibit certain responses, and appropriately execute prospective memory intentions (Kliegel et al., 2004; Mioni et al., 2013). Complex and demanding prospective memory tasks, those with increased attentional and effortful processing demands, are thought to decrease prospective memory accuracy (Henry et al., 2007; McDaniel & Einstein, 2000; Mioni et al., 2013). Several task characteristics influence the overall demands of prospective memory tasks. These include the complexity of the ongoing task, the number of associations between prospective memory cues and intentions, the distinctiveness or saliency of the cues, and the length of the retention interval (Graf, 2012; Kliegel et al., 2008; McDaniel & Einstein, 2000; Mioni et al., 2013; Raskin et al., 2012).

Healthy individuals with no neurological impairment have decreased accuracy when attentional and/or working memory demands of the task are increased, with rapid stimuli presentation, and when the ongoing task is unfamiliar and requires multiple responses (McDaniel & Einstein, 2000; Penningroth, 2005; Rendell, McDaniel, Forbes, & Einstein, 2007). Older adults perform significantly worse than young adults in complex prospective memory tasks that impose greater attentional and effortful processing demands (Kliegel, Jager, & Phillips, 2008; McDaniel & Einstein, 2000; Rendell et al., 2007; Uttl, 2008). With advanced age, individuals begin to experience deficits in attention, processing speed, and executive functions, especially on tasks that involve controlled and effortful processing (Kliegel et al., 2008; Lezak et al., 2012; Uttl, 2008). TBI patients also have impairments relating to attention, processing speed, working memory, memory, and executive functions. Accordingly, prospective memory tasks with greater attentional and effortful processing demands are thought to have a more pronounced impact on TBI patients' performance (Mioni et al., 2013; Raskin et al., 2012).

However, increasing task demands by manipulating a single task characteristic have not always led to poorer prospective memory performance in individuals with and without neurological impairment (Chi et al., 2014; Henry et al., 2007; McDaniel & Einstein, 2000; Penningroth, 2005). For instance, Chi et al. (2004) used different types of prospective memory cues to manipulate effortful processing, and found no difference in performance between conditions in individuals with mild cognitive impairment. In contrast, Blanco-Campal, Ceon, Lawlor, Walsh, and Burke (2009) found that making the task more difficult by presenting non-salient cues and giving non-specific instructions decreased performance in a similar sample. Similarly, in a sample of individuals with no neurological impairment, prospective memory tasks with increased attentional and working memory load and unfamiliar cues resulted in decreased accuracy (Penningroth, 2005). It is possible that such variability in findings is due to between study heterogeneity relating to samples and task designs (Chi et al., 2014; Costa, Caltagirone, & Carlesimo, 2011). Also, it could be that specific task characteristic do not have the same impact on prospective memory (Shum et al., 2011).

The complexity of the ongoing task is thought to influence performance. After initial encoding of the prospective memory intention, prospective memory tasks involve monitoring and detection of cues, retrieval of the previously formed intention, inhibition, and execution of the previously formed plan while simultaneously completing an ongoing task. Cognitive resources must be allocated to the ongoing task, and to retrieval and execution of prospective memory intentions. Thus, cognitive resources are easily depleted when the ongoing task is complex and demanding (Henry et al., 2007; Maujean et al., 2003; Raskin et al., 2012). With limited cognitive resources, prospective memory performance suffers (Mioni et al., 2013; Shum et al., 2011). This effect should be particularly significant in TBI due to executive dysfunction and difficulties in adequately distributing cognitive resources, such as attention, across multiple tasks (Henry et al., 2007; Maujean at el., 2003; Raskin et al., 2012).

Accordingly, some studies have found that complex ongoing tasks with increased cognitive demands result in decreased prospective memory performance of TBI groups (Carlesimo, Casadio, & Caltagirone, 2004; Maujean et al., 2003). However, Raskin et al. (2012) manipulated ongoing task demands and found that although matched controls performed better in the non-demanding condition, patients with TBI did not show such an advantage, and their performance was similarly impaired in both conditions. One limitation was that their conditions were very similar, and their demanding ongoing task may not have been sufficiently demanding (Raskin et al., 2012). Similarly, another study failed to find prospective memory deficits in a TBI sample using a simple ongoing task with minimal cognitive demands (Banville & Nolin, 2012). Ongoing tasks with minimal demands can lead to high accuracy and near ceiling performance, impeding the ability to observe differences in performance (McDaniel & Einstein, 2000; Uttl et al., 2001).

Another prospective memory task characteristic, the number of cue-intention associations to be encoded and executed, also influences performance (Carlesimo et al., 2004; Henry et al., 2007; Raskin et al., 2012). Prospective memory tasks with a single cue-intention association are less demanding than tasks with multiple associations (Henry et al., 2007; Smith & Bayen, 2004). For example, a task may require participants to execute a prospective memory intention each time they encounter the word “DOG”. In this case, participants need to encode, monitor, and identify a single cue. On the other hand, a task may require participants to execute a prospective memory intention each time they encounter multiple prospective memory cues, the words “DOG” and “PARK”. The latter task has increased attentional and retrospective memory demands compared to the first one because participants have to encode, monitor, and identify multiple cues as opposed to one (Henry et al., 2007; Raskin et al., 2012).

The type of cue is another factor influencing the execution of previously formed intentions in prospective memory tasks (McDaniel & Einstein, 2000; Uttl et al., 2001). For example, cues that are salient and distinctive, such as words printed in colored ink during a reading ongoing task, easily capture attention and tend to facilitate prospective memory performance over non-colored cues (Chi et al., 2014; McDaniel & Einstein, 2000). Prospective memory cues that are considered typical or familiar, such as frequent words or common objects, also lead to increased prospective memory accuracy (Blanco-Campal et al., 2009; Penningroth, 2005).

Related to saliency is whether cues are defined as focal or non-focal. Similar to salient cues, focal cues are thought to require less attention and monitoring to be detected. Focal cues are those that can be directly processed as part of the ongoing task (Chi et al., 2014; McDaniel & Einstein, 2000). For example, a word cue in a word categorization task is said to be focal because words have to be processed as units. In contrast, if the cue is a syllable, additional attention and monitoring efforts are needed for detection because each individual syllable is not processed as a unit in this task (Loft & Humphreys, 2012; McDaniel & Einstein, 2000). Additionally, when salient prospective memory cues are presented in the context of a less demanding ongoing task, prospective memory is further facilitated, suggesting that these task characteristics interact (Penningroth, 2005).

Execution of prospective memory intentions cued by event-based cues is thought to also require less effortful monitoring than those cued by time-based cues. With time-based cues, participants have to independently monitor time, whereas event-based cues are external and facilitate intention retrieval (Carlesimo et al., 2004; Henry et al., 2007; Mioni et al., 2013; Raskin et al., 2012; Schmitter-Edgecombe & Wright, 2004). Accordingly, it is expected that patients with TBI have greater deficits in time-based as opposed to event-based prospective memory tasks (Mioni et al., 2013; Raskin, 2009; Raskin et al., 2012; Schmitter-Edgecombe & Wright, 2004). Despite this assumption, the findings regarding performance on time- versus event-based prospective memory tasks have been mixed (Mioni et al., 2012; Shum et al., 2011). In some cases, TBI groups have showed greater impairment on time-based as opposed to event-based prospective memory tasks, but not in others (Groot et al., 2002; Shum et al., 1999, Shum et al., 2011). However, studies measuring time-based prospective memory performance have used less cognitively demanding ongoing tasks, which could explain failure to observe differences (Hannon et al., 1995; Kinsella et al., 2009; Mathias & Mansfield, 2005; Shum et al., 1999; Shum et al., 2011).

These findings suggest the need for an interactionist approach to understanding the influence of task demands on prospective memory (Blanco-Campal et al., 2009; McDaniel & Einstein, 2000; Penningroth, 2005; Raskin et al., 2012; Shum et al., 2011).

Inconsistent findings could be the result of between-study heterogeneity in regards to tasks and sample characteristics. One objective of the current study is to explore the influence of task characteristics on prospective memory in TBI.

Associated Cognitive Functions

Other cognitive abilities have been found to be associated with prospective memory (Clune-Ryberg et al., 2011; Graf, 2012; Raskin, 2009; Schmitter-Edgecombe & Wright, 2004; Shum et al., 2011). Although associations between prospective memory and attention, processing speed, retrospective memory, and executive functions have been reported, there are disagreements as to which functions are most important (Henry et al., 2007; Kliegel et al., 2004; Mioni et al., 2013). Some studies suggest that prospective memory performance heavily relies on both retrospective memory and executive functions (Carlesimo et al., 2004; Clune-Ryberg et al., 2011; Kliegel et al., 2004).

In a study of 16 patients with TBI, Clune-Ryberg and colleagues (2011) explored the association between prospective and retrospective memory. They reported that TBI patients were impaired in both prospective and retrospective memory, as measured by delayed cued-recall of previously encoded intentions (Clune-Ryberg et al., 2011). This measure also correlated with performance on formal neuropsychological tests of episodic retrospective memory. However, they reported that deficits in retrospective memory were not the main factor underlying prospective memory failures, and that the ability to monitor the environment plays an essential role. Another study by Mioni et al. (2013) found that among a sample of 18 patients with TBI that underwent a virtual reality prospective memory task, individuals with impaired executive functions had poorer prospective memory regardless of retrospective memory performance.

Patients with TBI perform poorly on measures sensitive to executive dysfunction (e.g., semantic fluency) that impose demands on self-initiated retrieval processes similar to prospective memory tasks (Mathias & Mansfield, 2005; Mioni et al., 2013). Damage to the frontal lobes is common in TBI, and is associated with impaired executive functions, such as initiation and self-monitoring (Dikmen et al., 2009; Lezak et al., 2012; Mioni et al., 2013). These executive processes play a fundamental role in prospective memory; therefore, such deficits could be a potential mechanism underlying prospective memory failures (Kliegel et al., 2004; Mathias & Mansfield, 2005; Mioni et al., 2012; Mioni et al., 2013). Another objective of the current study is to integrate previous findings on the association between prospective memory and other cognitive functions.

Summary

A review of the literature reveals that patients with TBI have significant and frequent prospective memory failures that hinder their daily functioning (Henry et al., 2007; Mioni et al., 2013; Mioni et al., 2014; Schmitter-Edgecombe & Wright, 2004; Shum et al., 2011). Individual studies report that TBI is associated with poorer performance as measured by experimental prospective memory tasks, standardized tests, and self-report questionnaires (Hannon et al., 1995; Henry et al., 2007; Mioni et al., 2013; Raskin, 2009; Shum et al., 2011). Additionally, most studies indicate that prospective memory task characteristics and other cognitive functions influence prospective memory in TBI (Carlesimo et al., 2004; Mioni et al., 2013; Raskin et al., 2012; Schmitter-Edgecombe & Wright, 2004; Shum et al., 2011).

However, differences in study designs has led to variability across findings from individual studies. For instance, most studies have designed different prospective memory tasks to be used with TBI samples, and some studies investigated prospective memory task characteristics individually (e.g., manipulating type of prospective memory cue but disregarding ongoing task complexity; Carlesimo et al., 2004; Groot et al., 2002; Henry et al., 2007; Shum et al., 2011). This variability has made it difficult to develop a clear understanding of the influence of task demands on performance (Henry et al., 2007; Mioni et al., 2013; Shum et al., 2011). TBI is associated with multiple cognitive deficits; thus, subtle differences in task characteristics can impact accuracy (Dikmen et al., 2009; Lezak et al., 2012; Shum et al., 2011).

Objectives

The current study reports a review and meta-analyses of the growing literature on prospective memory in TBI. Meta-analysis is a statistical technique that quantitatively integrates findings from multiple individual studies (Hunter & Schmidt, 2004; Liberati et al., 2009). The first objective of this study is to clarify the true effect size of prospective memory deficits in the population of adults with moderate and severe TBI. Another objective is to investigate task-related influences, namely ongoing task complexity, number of cue-intention associations, and type of prospective memory cues, on performance. In addition, this study investigates the association between prospective memory and attention, retrospective memory, and executive functions.

My long-term research goal is to develop a neuropsychological model that can be used to adequately capture the range of prospective memory deficits in patients with TBI. A first step in doing that will be to uncover patterns of performance across the range of studies of TBI that have looked at prospective memory through a meta-analytic review. The findings will primarily describe the true nature of prospective memory deficits in TBI by clarifying the influence of task demands and association with other cognitive functions. Given that prospective memory is essential for independent living and employment, a better understanding of post-TBI prospective memory impairments is crucial for outcome assessment and rehabilitation planning.

CHAPTER II

DESIGN AND METHODOLOGY

Search

A comprehensive search identified relevant articles using the databases PsycINFO and MEDLINE. The following keywords were used in the search: S1 - “prospective memory” OR “memory for intentions”, and S2 - “brain injury” OR “head injury”. Then, S1 and S2 were combined with AND. The reference lists of articles retrieved from the database search were reviewed, and an additional search in Google Scholar (search terms: “prospective memory” and “brain injury”) was completed to identify any additional sources. The last search was conducted on December 2014.

Inclusion Criteria

To be included in the meta-analyses studies had to meet the following inclusion criteria: 1) include a sample of adult patients with TBI, 2) include a control group matched on age and years of education, 3) include a continuous behavioral measure of prospective memory (prospective memory performance indices based on binary success/failure measures were excluded due to poor validity), 4) prospective memory tasks had to include an ongoing task, encoding of prospective memory intentions, prospective memory cues and prospective memory execution, 5) and studies had to report sufficient data to allow for calculation of effect sizes. In order to explore the relationship between prospective memory and other cognitive functions, studies that to meet the same inclusion criteria except criteria 2 (inclusion of control group). For this part of the analysis the correlations were extracted from TBI groups only.

Variables Extracted

The following TBI and control groups' data were extracted from individual studies meeting the inclusion criteria: sample size, mean age, mean years of education, the period of time between brain injury and assessment (time since injury), severity of brain injury, and prospective memory performance scores (*M* and *SD*).

Additionally, the following prospective memory task characteristics were extracted: type of ongoing task, type and number of cues, whether reminders were used, type and number of prospective memory intentions, and number of prospective memory cue-intention associations to be executed. These task characteristics are reported to influence the overall demands of the task (Chi et al., 2014; McDaniel & Einstein, 2001; Penningroth, 2005; Raskin et al., 2012). To determine whether prospective memory task characteristics influence performance, each task characteristic was classified as high- or low-demand, and then each prospective memory task was also classified as high- or low-demand based on criteria listed in the Appendix (*p*. 61).

First, for each task, the total number of prospective memory cue-intention associations was extracted, prospective memory cues were classified as salient versus non-salient, and the ongoing task was classified as complex or simple (Appendix, *p*. 61). Tasks with salient prospective memory cues, a single prospective memory cue-intention association, and simple ongoing tasks require less attentional resources and minimal effortful processing, making the overall task less cognitively demanding (Chi et al., 2014; McDaniel & Einstein, 2000). For descriptive purposes, these characteristics were labelled as “low demand task characteristics”.

On the other hand, tasks with non-salient cues, multiple cue-intention associations, and complex ongoing tasks are more cognitively demanding (McDaniel & Einstein, 2000). These characteristics were labelled as “high demand task characteristics”. Some studies have found that a combination of two of these characteristics impact prospective memory performance (Blanco-Campal et al., 2009; Rendell et al., 2007; Penningroth, 2005). Therefore, for the purposes of this study, prospective memory tasks with two or more of the “high-demand” characteristics were classified as high-demand tasks. In contrast, prospective memory tasks with none or only one of the “high-demand” characteristics were classified as low-demand tasks.

Furthermore, for individual studies that included measures of attention, retrospective memory, and executive functions, the name of the tests, performance scores, and correlations with prospective memory performance for each cognitive domain were extracted.

Statistical Procedures

For each individual study effect sizes were calculated as the standardized mean difference (Cohen’s *d*) in prospective memory performance between TBI and control groups. Accurate calculation of effect sizes depends on available data, including sample sizes, means (*M*), and standard deviations (*SD*). Therefore, when *M* and *SD* were not reported in individual studies, effects sizes were calculated from reported *t* statistic and sample size (Maujean et al., 2003). One study did not report *SD* or *t* values; thus the reported *d* value was used in the analyses (Carlesimo et al., 2004).

Individual studies’ effect sizes were pooled to obtain a weighted (by sample size) effect size of prospective memory performance using a random effects model. A random effects model was chosen because the set of studies included vary in regards to methodology and sample characteristics. A random effects model assumes that effect sizes differ between studies, and allows to estimate this variance (Hunter & Smith, 2004; Viechtbauer, 2010). The specific random effects model used to estimate the between-study variance and combined effect size was the Restricted Maximum Likelihood Model, which estimates the variance (τ^2) component conditionally after estimating the mean effect size, and is considered unbiased and efficient (Hedges & Vevea, 1998; Viechtbauer, 2010).

Subgroup analysis can answer particular questions about differences between studies (Borenstein & Higgins, 2013). In this study task classification (high- versus low-demand), a categorical variable, was used to divide the set of studies into subgroups. Then, a subgroup analysis was performed to determine whether prospective memory performance is influenced by task demands. Pearson's moment correlation coefficients were pooled to obtain the combined effects describing the relationship between prospective memory and attention, retrospective memory, and executive functions.

Effect size heterogeneity was evaluated with the Cochran Q test and I^2 statistics. The Q test statistic is a significance test that indicates the presence or absence of heterogeneity in a set of studies (Hunter & Smith, 2004). The I^2 statistic is the percentage of total variation due to true heterogeneity between individual studies (Liberati et al., 2009). For example, a result of $I^2 = 0$ in a meta-analysis means that all the variability in effect size estimates is due to sampling error within studies, and not due to true heterogeneity between studies. Some level of heterogeneity is expected due to chance, but high heterogeneity indicates substantial differences between individual studies

(Hunter & Smith, 2004; Liberati et al., 2009). Standard normal distribution *Z* scores were used to determine whether effect sizes were significantly larger than zero.

A publication bias exists when only certain studies, such as those with significant or positive effect sizes, are published (Hunter & Smith, 2004). In the presence of publication bias, the results of a meta-analysis would be misleading since it is based on a biased subsets of studies. In this study, publication bias was assessed by plotting effect sizes by their standard error in funnel plots (Hunter & Smith, 2004; Liberati et al., 2009). An asymmetrical funnel shape indicates potential publication bias. Additionally, the file drawer technique, which allows to estimate the number of potential unidentified studies with null findings ($d = 0$) that would have to exist to make the current *d* value non-significant was conducted (Hunter & Smith, 2004). A small number of studies suggests that the results are likely based on a biased sample of studies (Hunter & Smith, 2004).

Although these methods are useful in determining the presence of a potential publication bias, they do not correct for it (Hunter & Smith, 2004). Another recently developed method, the trim and fill method, estimates the number of studies missing from a funnel plot, and uses that estimate to increase the precision of the combined effect size (Duval & Tweedie, 2010). This method was applied because given the small number of studies included in the meta-analyses, interpretation of the funnel plots was difficult. R statistical software (metafor package) was used to conduct all statistical analyses (Viechtbauer, 2010).

CHAPTER III

ANALYSIS OF RESULTS

Search Results

The search yielded 105 unique articles. Fifty two studies discussed prospective memory and TBI, but only 15 studies met the inclusion criteria. These 15 studies included a sample of adult patients with moderate or severe TBI, a control group matched in age and years of education, measured prospective memory using a continuous measure, used prospective memory tasks that included an ongoing task, encoding of prospective memory intentions, retention interval, prospective memory cues, and prospective memory execution, and reported sufficient data to calculate effect sizes. These 15 studies used a quasi-experimental design using intact groups of brain-injured individuals. Out of the 52 studies, 37 were not included because 1) they used a pediatric sample, 2) did not include a control group matched on age and years of education, 3) prospective memory performance was based on a binary measure or the task was not based on a dual-task paradigm, 4) used the same sample as another study, or 5) were review articles. A study conducted by Tay et al. (2010) was not included because the sample only included individuals with mild TBI, and research indicates that the profile of neuropsychological functioning is different between mild and more severe types of TBI; as most individuals with mild TBI return to premorbid levels of cognitive functioning (Lezak et al., 2012; Schoenberg & Scott, 2011).

Out of these 15 studies, 10 included measures of attention, retrospective memory, and executive functioning. There were another three studies that did not include a control group, but included measures of these cognitive functions. Thus, a total of 13 studies were included in the analyses of the relationship between prospective memory and these cognitive functions.

Sample Characteristics

Sample sizes ranged from 12 to 38 for TBI and control groups. In TBI groups, the mean age was 34.81 (*SD* = 6.97), and mean years of education was 12.42 (*SD* = 1.27). The indicators of TBI severity were scores on the Glasgow Coma Scale, duration of coma, and duration of post-traumatic amnesia obtained from hospital records. Three studies did not report the period of time between brain injury and assessment (time since injury). When time since injury was reported, it ranged from a minimum of 3 months to a mean of 3.78 years.

In control groups the mean age was 34.31 (*SD* = 6.90), and mean years of education was 13.13 (*SD* = 1.37). There were no significant differences between TBI and control groups in terms of age and years of education. Table 1 lists the main characteristics of the 15 studies included. Table 2 summarizes information about prospective memory tasks characteristics for each study. Table 3 lists the neuropsychological tests used to measure attention, retrospective memory, and executive functions.

Table 1
Individual studies' characteristics

Author. Year	**TBI**					**Control**		
	N	Age	Edu	Severity	Time injury (mo)	*N*	Age	Edu
Shum et al. 1999	12	23.5	11.42	Severe	24.58	12	22.25	12.5
Maujean et al. 2003	14	32.86	11.57	Severe	9.71	14	30.21	12.14
Carlesimo et al. 2004	16	27.4	11.4	Severe	6 mo*	16	matched	matched
Schmitter et al. 2004	24	34.42	14.08	Severe	nr	24	35.36	14.17
Knight et al. 2005	25	39.04	12.4	Severe	113.76	20	38.42	13.79
Knight et al. 2006	20	44.95	12.53	Severe	13.35	20	43.35	12.4
Henry et al. 2007	16	44.4	12.2	Moderate to severe	nr	15	48.4	12.4
Kinsella et al. 2009	16	42.31	11.88	Severe	3 mo*	16	40.12	12.31
Carlesimo et al. 2010	18	28.1	11.5	Severe	6 mo*	18	27.4	12.5
Clune-Ryberg et al. 2011	32	30.16	13.41	Moderate to severe	nr	16	30.69	14.5
Pavawalla et al. 2012	17	34.41	15.76	Moderate to severe	12 mo*	17	33.47	15.76
Banville et al. 2012	31	27.0	12.0	Moderate to severe	3.78 yr	31	27.0	12.0
Raskin et al. 2012	18	44.47	13.8	Severe	12 mo*	15	37.27	16.0
Mioni et al. 2013	18	31.72	12.22	Severe	66.94	18	32.0	12.0
Canty et al. 2014	30	31.68	11.71	Severe	138 days	24	29.72	12.52

Note. Time since injury listed as months. *minimum number of months since injury for subjects included in each study, Edu = years of education, matched = control group matched in age and education but no means reported, nr = not reported.

Table 2

Prospective memory task characteristics

First Author. Year	**Prospective memory task characteristics**		
	Cue – intention	*Number of associations*	*Ongoing task*
Shum et al. 1999	Words – pressing key	4	Timed knowledge test
Maujean et al. 2003	Words categories– pressing key	8	Lexical decision + distractor task
Carlesimo et al. 2004	Letter/time – actions	3	Cancellation task
Schmitter et al. 2004	Words – pressing key*	1	Word reading and recall
Knight et al. 2005	Object – message to tester related to object*	20	Monitor objects in video
Knight et al. 2006	Object – action related to object	3	Monitor video objects/actions
Henry et al. 2007	Word category – pressing key	4	Working memory task
Kinsella et al. 2009	Object – naming	8	Monitoring objects in video
Carlesimo et al. 2010	Time – actions	3	Cancellation task
Clune-Ryberg et al., 2011	Objects – action related to object	6	Monitor video objects and actions
Pavawalla et al. 2012	Colored word – pressing key	6	Word-color matching task
Banville et al. 2012	Object – naming object	3	Watching video
Raskin et al. 2012	Pictures/words – actions	5	Letter cancellation/sentence alphabetization
Mioni et al. 2013	Objects – actions related to objects	6	Monitor actions in video
Canty et al. 2014	Objects – actions related to objects	8	Monitor actions in video
Canty et al. 2014	Word category – pressing key	8	Lexical decision

Note. * Reminders were given.

Table 3

Neuropsychological tests of attention, retrospective memory, and executive functions

Author. Year	**Cognitive Domain**		
	Attention	***Retrospective memory***	***Executive function***
Magdalinski. 2002	Digit Span Letter Number Sequencing	WMS LM I and II WMS VPA I and II RAVLT	WCST
Schmitter et al. 2004	Digit Span Symbol Digit Trial Making A Alphabet Span	WMS LM and VS	COWAT Stroop Test Trial Making B WCST
Knight et al. 2005	NI	WMS LM	WCST Semantic/design fluency COWAT Trial Making Test
Knight et al. 2006	Selective Attention Test	WMS LM	NI
Patry. 2007	Digit Span	RAVLT	NI
Fleming et al. 2008	NI	NI	Trial Making Test COWAT
Kinsella et al. 2009	Digit Span	Hopkins verbal learning test	Trial Making Test
Carlesimo et al. 2010	NI	List learning Story recall	Word fluency WCST

Note. NI = domain not included, WMS = Wechsler Memory Scale, LM = Logical Memory, VPA = Verbal Paired Associates, VS = Visual Reproduction, RAVLT = Rey Auditory Verbal Learning Trial, COWAT = Controlled Oral Word Association Test, WCST = Wisconsin Card Sorting Test, DKEFS = Delis-Kaplan Executive Functioning System, RBANS = Repeatable Battery for the Assessment of Neuropsychological Status, SART = Sustained Attention to Response Test.

Table 3 *(cont.)*

Neuropsychological tests of attention, retrospective memory, and executive functions

Author. Year	**Cognitive Domain**		
	Attention	***Retrospective memory***	***Executive function***
Clune-Ryberg et al. 2010	Digit Span SART Stroop Test	WMS LM RAVLT Doors test	DKEFS Stroop Test DKEFS Verbal Fluency Trial Making Test
Pavawalla et al. 2012	RBANS Attention Index	RBANS Immediate and delayed memory indices	DKEFS Design fluency Trial Making Test
Mioni et al. 2013	NI	NI	Phonemic Fluency Semantic Fluency Trial Making Test WCST
Raskin et al. 2012	The Revised Attention Process Test	RANDT: story recall and picture recognition	COWAT Animal Naming task Trial Making Test Tower Test
Canty et al. 2014	Letter Number Sequencing	Hopkins verbal learning test	COWAT Hayling Test Trial Making Test

Note. NI = domain not included, WMS = Wechsler Memory Scale, LM = Logical Memory, VPA = Verbal Paired Associates, VS = Visual Reproduction, RAVLT = Rey Auditory Verbal Learning Trial, COWAT = Controlled Oral Word Association Test, WCST = Wisconsin Card Sorting Test, DKEFS = Delis-Kaplan Executive Functioning System, RBANS = Repeatable Battery for the Assessment of Neuropsychological Status, SART = Sustained Attention to Response Test.

Meta-Analyses Results

For each study, effect sizes (Cohen's *d*) were calculated to reflect the difference in prospective memory performance between TBI and control groups. Effect sizes were calculated using means, the pooled standard deviation, and sample size. In one study, means and standard deviations were not reported, thus the effect size was calculated using the *t* statistic and sample size (Maujean et al., 2013). Effect sizes for each study are listed in Table 4.

Random effects meta-analyses (REML) were conducted to integrate effect sizes across the 15 studies weighted by sample size. The combined effect size estimate was 0.987 ($SE = 0.087$, 95% CI = 0.82-1.16). This combined effect size is significantly larger than 0 ($Z = 11.30$, $p < .001$), and considered large according to Cohen's criterion (Cohen, 1992). The test for heterogeneity was not significant ($Q = 16.14$, $p = .372$). The I^2 statistic indicates a small percentage of true heterogeneity between studies ($I^2 = 2.38\%$).

Based on its characteristics, prospective memory tasks were classified as low- or high- demand (see Table 4). Task demands (low-demand vs. high-demand), a categorical variable, was used to separate the set of studies into subgroups to conduct subgroup analyses. Random effects meta-analyses were conducted to integrate weighted effect sizes across each subgroup of studies, those with low- and high-demand tasks. The results are summarized in Table 5, and displayed in Figures 1 and 2. Heterogeneity estimates were not statistically significant. The combined effect size of high-demand prospective memory tasks was 1.22 (95% CI = 0.89-1.54; $k = 8$). The estimate for low-demand tasks was 0.85 (95% CI = 0.63-1.06; $k = 8$). Both estimates were significantly larger than 0 ($p < .001$; see Table 5).

Table 4

Classification of prospective memory tasks and calculated effect sizes

First Author. Year	**Task characteristics**	**Task demands**	**Cohen's *d***
Shum et al. 1999	Non-salient cue Multiple cue-intention associations Complex ongoing task	High demand	1.25
Maujean et al. 2003	Non-salient cue Multiple cue-intention associations Complex ongoing task	High demand	1.01
Carlesimo et al. 2004	Non-salient cue Multiple cue-intention associations Complex ongoing task	High demand	1.56
Schmitter et al. 2004	Salient cue One cue-intention association Complex task (short)	Low demand	0.68
Knight et al. 2005	Salient cue Multiple cue-intention associations Simple ongoing task	Low demand	1.08
Knight et al. 2006	Salient cues Multiple cue-intention associations Simple ongoing task	Low demand	1.05
Henry et al. 2007	Non-salient cue Multiple cue-intention association Complex ongoing task	High demand	0.97
Kinsella et al. 2009	Salient cue Multiple cue-intention associations Simple ongoing task	Low demand	0.96
Carlesimo et al. 2010	Non-salient cue Multiple cue-intention associations Complex ongoing task	High demand	1.32

Table 4 *(cont.)*
Classification of prospective memory tasks and calculated effect sizes

First Author. Year	**Task characteristics**	**Task demands**	**Cohen's *d***
Clune-Ryberg et al. 2011	Salient cues Multiple cue-intention associations Simple ongoing tasks Reminders were given	Low demand	0.75
Pavawalla et al. 2012	Non-salient cue Multiple cue-intention association Complex ongoing task	High demand	0.51
Banville et al. 2012	Salient cue Multiple cue-intention association Simple ongoing task	Low demand	0.59
Raskin et al. 2012	Non-salient cues Multiple cue-intention associations Complex ongoing task	High demand	2.08
Mioni et al. 2013	Salient cues Multiple cue-intention associations Simple ongoing task	Low demand	0.82
Canty et al. 2014	Salient cues Multiple cue-intention associations Simple ongoing task	Low demand	0.96
Canty et al. 2014	Non-salient cues Multiple cue-intention associations Complex ongoing task	High demand	1.37

Table 5

Meta-analyses of high-demand and low-demand prospective memory tasks

Subgroup	**N**	***d (SE)***	**z**	***p***	**95% CI**	**Heterogeneity**		
						Q	***I^2***	***p***
High-demand *k* = 8	100	1.22 (0.16)	7.35	<.001	0.89-1.54	9.44	26.76%	.22
Low-demand *k* = 8	196	0.85 (0.11)	7.70	<.001	0.63-1.06	2.57	0%	.92

Note. *SE* = standard error.

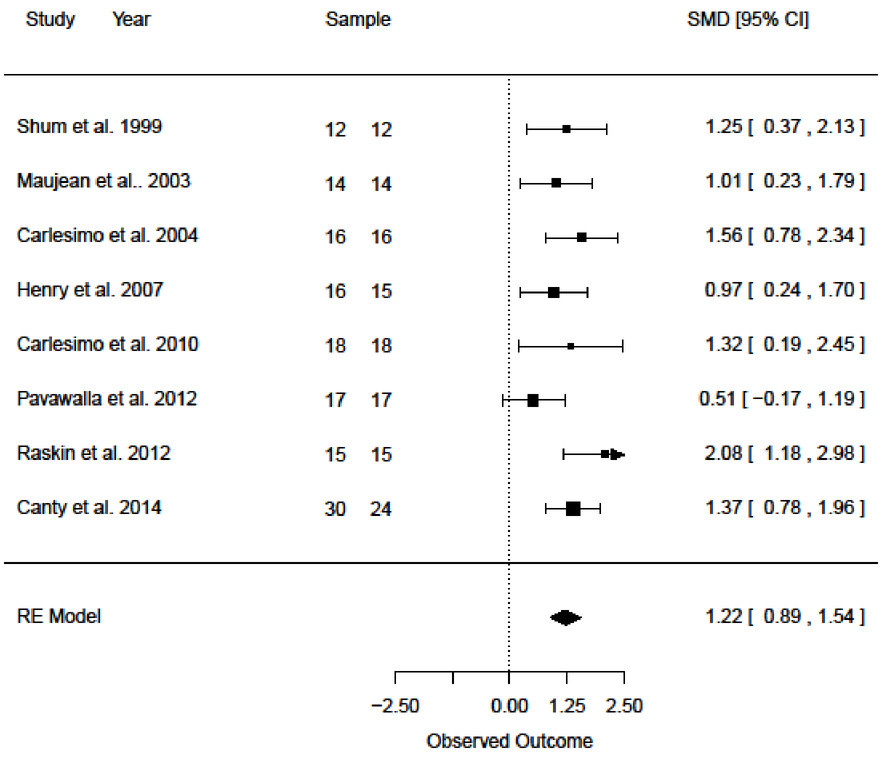

Figure 1. Meta-analysis across high-demand prospective memory tasks.

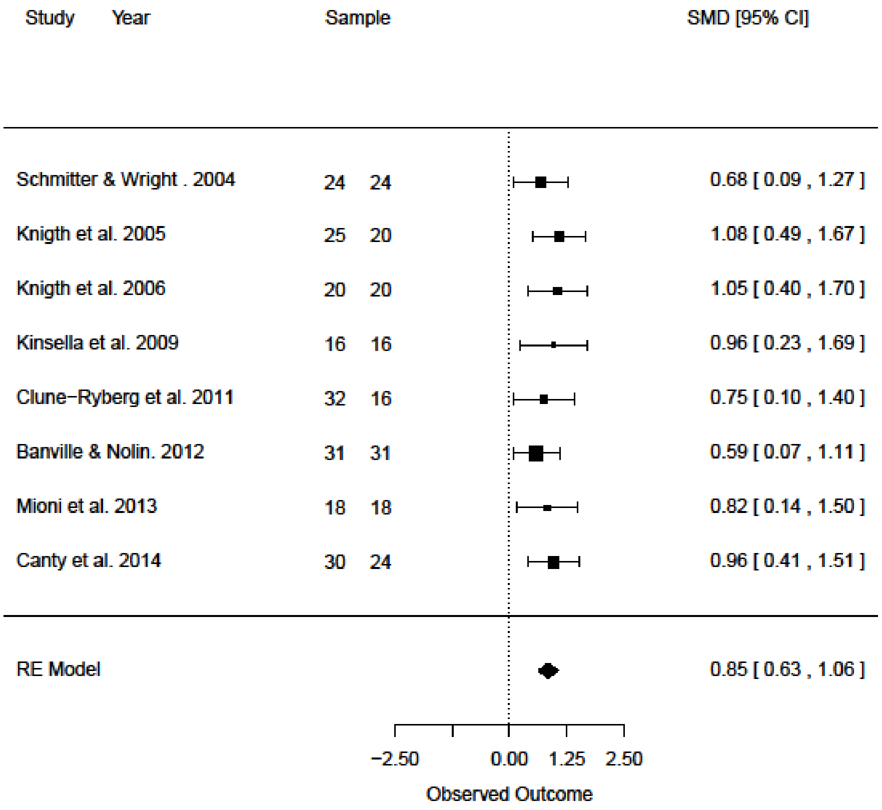

Figure 2. Meta-analysis across low-demand prospective memory tasks.

Publication Bias

Publication bias was assessed visually using funnel plots presented in Figures 3, 4, and 5. The graph plotting the 15 studies does not show marked asymmetry. However, given the small number of studies, assessing publication bias using this method is difficult. The funnel plot displaying the subgroup of high-demand tasks appears more asymmetric, with more effect sizes located above the mean effect size. Using the file-drawer technique, the file-safe *N* was equal to 785, indicating that 785 individual studies with null findings would have exist to bring the combined effect size to non-significance.

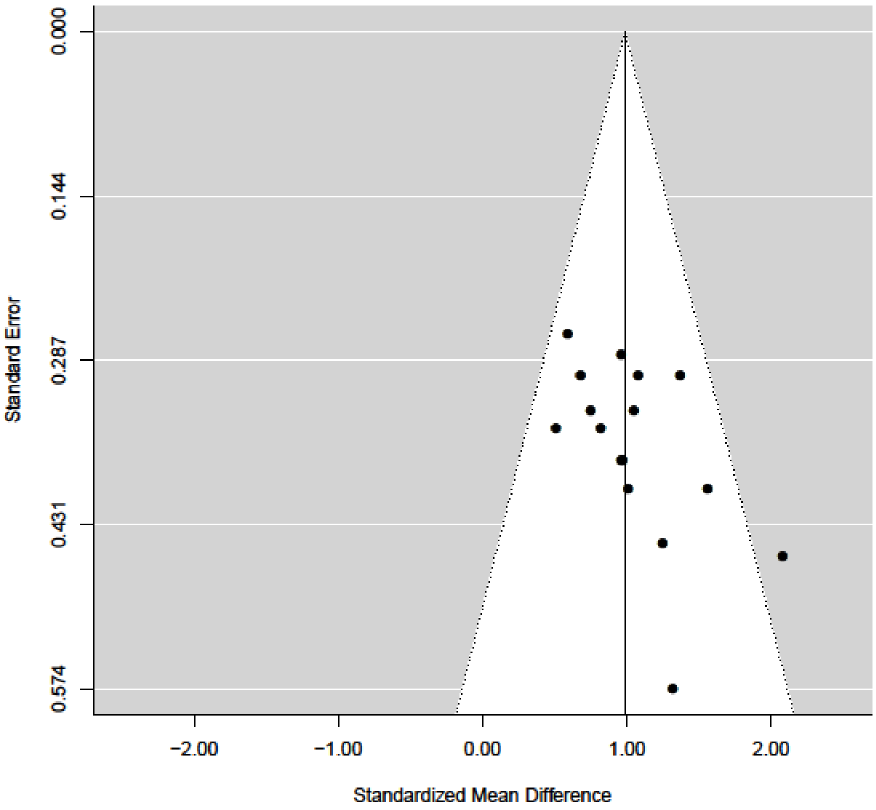

Figure 3. Funnel plot of the 15 studies included.

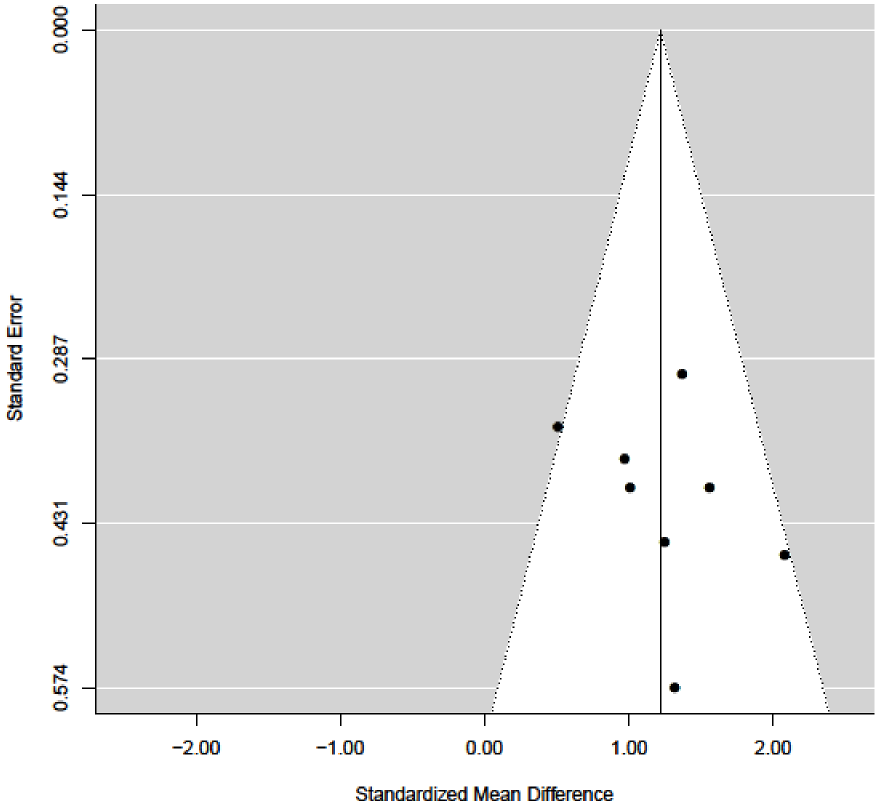

Figure 4. Funnel plot of studies with high-demand tasks.

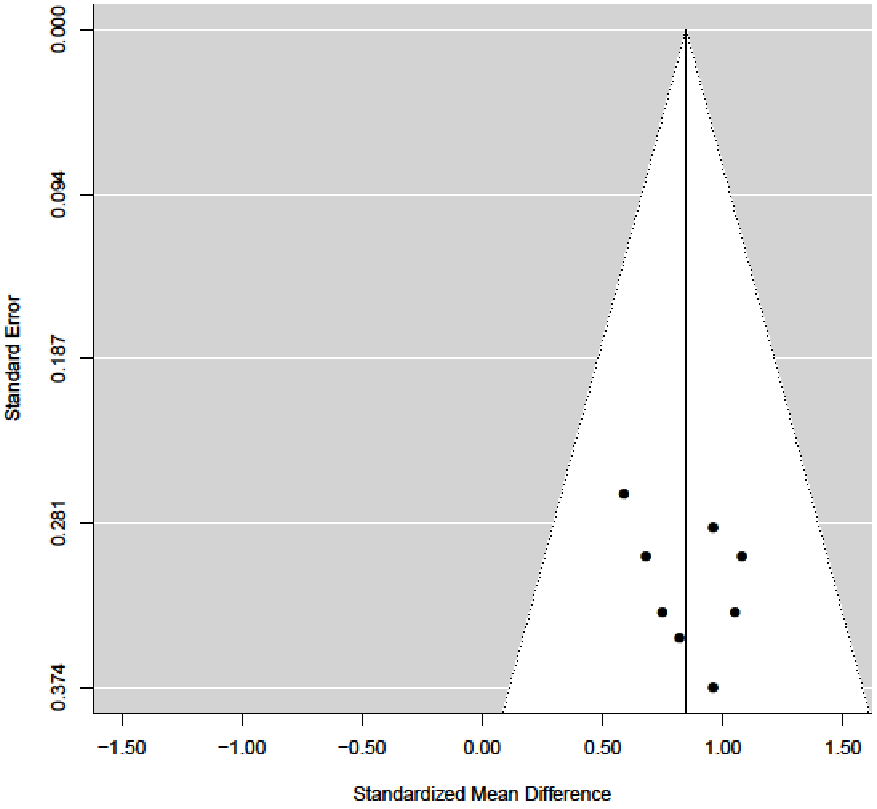

Figure 5. Funnel plot of studies with low-demand tasks.

The trim and fill method estimates the number of studies missing from a meta-analysis (Duval & Tweedie, 2010). It then uses that estimate to construct a more symmetric funnel plot, and makes a more precise estimation of the combined effect size (Duval & Tweedie, 2010). According to this method, two studies with effect sizes lower than the mean effect size were missing among the studies with high-demand tasks. According to this method, the re-calculated estimate for this subgroup was 1.05 (*SE* = 0.17, 95% CI = 0.70-1.40). Two studies with effect sizes lower than the mean were estimated to be missing among studies with low-demand tasks, and the re-calculated estimate was 0.77 (*SE* = 0.09, 95% CI = 0.58-0.96). The combined effect sizes using this method were lower; however, the difference in performance between TBI and control groups remained larger among studies with high-demand tasks.

Taken together, these results indicate that compared to healthy individuals matched on age and years of education, individuals who have sustained a moderate to severe TBI have impaired prospective memory performance. In addition, such impairments are more pronounced when prospective memory tasks are increasingly demanding.

The second objective of the study was to explore the association between prospective memory and attention, retrospective memory, and executive functions. Thirteen studies included a variety of neuropsychological tests of attention, retrospective memory, and executive functions (see Table 2). The results of meta-analyses on the correlations between prospective memory performance and measures of attention, retrospective memory, and executive function are summarized in Table 6. All the correlations were significantly larger than 0. The correlation values were higher between prospective memory and retrospective memory (*r* = .45), and executive functions (*r* = .41).

Table 6

Meta-analyses of the correlations between prospective memory and attention, retrospective memory, and executive functions in TBI

Cognitive domain	***k***	***N***	***r***	**z**	***p***	**95% CI**
Attention	7	153	.318	2.789	.005	.09-.54
Retrospective memory	10	212	.454	4.051	<.001	.23-.67
Executive functions	10	234	.416	3.949	<.001	.21-.62

CHAPTER IV

CONCLUSIONS

General Discussion

The current study reported on the growing literature on prospective memory in TBI through meta-analyses. Although the majority of studies have consistently reported impaired prospective memory after TBI, differences in study designs and prospective memory task characteristics has led to variability in findings across individual studies. Therefore, one of the main objective of this study was to clarify the true effect size of prospective memory deficits in the population of adults with moderate and severe TBI. A comprehensive search identified articles on prospective memory and TBI, and those that used a continuous behavioral measure in a sample of adult individuals who had sustained a moderate to severe TBI, and a control group matched on age and years of education were included in the meta-analyses.

Fifteen individual studies meeting the inclusion criteria were identified. Across all studies, a random effects meta-analysis indicated that the difference in performance is significantly large (d = 0.987; SE = 0.09; 95% CI = 0.82 -1.16). The results indicate that individuals with moderate to severe TBI have impaired prospective memory when compared to healthy individuals. On average, individuals with TBI will perform approximately one standard deviation below healthy individuals in prospective memory tasks. Considering that the size of this effect is large, prospective memory should be properly assessed and targeted following a TBI.

Furthermore, this study investigated whether prospective memory task demands influence prospective memory. Task characteristics reported to affect attentional and effortful processing demands were used to classify each prospective memory task as high- or low-demand. Random effects meta-analyses indicated that individuals with moderate to severe TBI have poorer prospective memory performance compared to matched control groups on both low- and high-demand prospective memory tasks. Notably, this difference is larger when tasks are more demanding and require increased attentional resources and effortful processing. These results suggest that prospective memory abilities of individuals with TBI are more negatively affected by demanding task characteristics.

These results are consistent with the predominant theoretical view describing prospective memory. Prospective memory is described as a complex ability requiring individuals to plan and encode future intentions, monitor the environment, inhibit ongoing task responses, and execute planned intentions at the appropriate time and/or place (Kliegel et al., 2008; McDaniel & Einstein, 2000; Uttl et al., 2001). A central component of prospective memory is becoming aware of prospective memory cues and bringing back previously formed plans into conscious awareness (Uttl et al., 2001). Thus, while performing ongoing tasks, attentional resources are needed to monitor our environment and detect prospective memory cues. Attentional focus has to be switched and redirected between cue monitoring and demands of the ongoing task. When prospective memory tasks become more complex and cognitively demanding, our attentional resources are depleted more easily, and our capacity to process information decreases, lowering our accuracy in executing prospective memory intentions.

With increased attentional and effortful processing demands, the ability to successfully execute prospective memory intentions of individuals with moderate to severe TBI is increasingly impaired. Healthy individuals also display decreased accuracy with increasing demands, but the impairment displayed by individuals with TBI is larger. The greater prospective memory impairment observed in individuals with TBI is likely associated with deficits in basic cognitive functions essential for prospective memory, such as speed of information processing, the ability to sustain and switch attention, and the ability to encode and retrieve information from memory (Finnanger et al., 2013; Kliegel et al., 2008; Lezak et al., 2012; Schoenberg & Scott, 2011; Smith & Bayen, 2004).

The frontal and temporal lobes of the brain are very vulnerable to TBI, being a frequent site of structural damage (Lezak et al., 2012; Schoenberg & Scott, 2011). These areas of the brain are associated with processes important for prospective remembering (Henry et al., 2007; Mioni et al., 2013; Mioni et al., 2014). Frontal neural structures are associated with critical processes of prospective memory, such as planning, monitoring, switching activities, and initiating, sustaining and switching attentional focus (Lezak et al., 2012; Mioni et al., 2013; Schoenberg & Scott, 2011). Moreover, the temporal lobes are critically involved in encoding, consolidating, and retrieving information from memory (Lezak et al., 2012; Schoenberg & Scott, 2011).

A few studies have investigated the neuroanatomical correlates of prospective memory. For example, Okuda and colleagues (1998) used Positron Emission Tomography in a sample of healthy adults, and found increased activation in the dorsolateral prefrontal region, ventromedial prefrontal region, and left frontal pole while performing a prospective memory task. These regions of the frontal lobe are respectively associated with working memory, performing dual cognitive operations, active processing of information, and control of attentional resources (Okuda et al., 1998; Schoenberg & Scott, 2011). The authors concluded that engagement of these regions is needed because prospective memory tasks require individuals to divide their attention and process information related to prospective memory cues and demands of the ongoing task (Okuda et al., 1998). The left parahippocampal region was also activated, which is associated with detecting and monitoring novel targets, and encoding and retrieval functions (Okuda et al., 1998). Similarly, computed tomography and magnetic resonance imaging of damaged brain areas revealed that the dorsolateral, dorsomedial, and ventromedial prefrontal regions of the brain are associated with prospective memory performance in a TBI sample (Umeda et al., 2011).

In addition to structural damage, another complication of TBI is damage to the white matter connections or axons of the brain (Lezak et al., 2012; Schoenberg & Scott, 2011). White matter damage disrupts information processing between different cortical regions, within cortical regions, and between cortical and subcortical regions, and such damage is associated with deficits in attention, concentration, and memory functions (Lezak et al., 2102). Using diffusion tensor imaging, a magnetic resonance imaging technique that enables evaluation of diffuse axonal injuries, Kondo and colleagues (2010) identified three clusters of axonal damage in individuals with TBI. These clusters were located in the left parahippocampal area, which is associated with encoding, retrieving, and recognition memory; the left anterior cingulate, which is a bundle of white matter connections anatomically close to the ventromedial and dorsomedial prefrontal regions; and the left inferior parietal lobe, which is associated with working memory. Damage to these bundles of axons was correlated with prospective memory performance, and these findings are consistent with cortical damage findings (Kondo et al., 2010; Okuda et al., 1998; Umeda et al., 2011).

The abilities to sustain and switch attention; and to actively process, encode, and retrieve information are associated with functioning of prefrontal regions and associated white matter connections (Kondo et al., 2010; Okuda et al., 1998; Schoenberg & Scott, 2011; Umeda et al., 2011). Increased attentional and effortful processing demands in prospective memory tasks can overload the limited functional capacity of these damaged regions, resulting in increasingly impaired prospective memory in TBI.

Another objective of this study was to explore the association between prospective memory and attention, retrospective memory, and executive functions. The results of meta-analyses indicated that prospective memory is positively correlated with attention, retrospective memory, and executive functions. All of these correlations were significantly larger than 0. Not surprisingly, the strongest correlation coefficient was between performance on prospective memory and retrospective memory tasks. Prospective memory has a retrospective memory component because plans of future intentions have to be encoded in long-term memory, and successfully retrieved at the appropriate time and place (Henry et al., 2007; Kliegel et al., 2004). The second strongest correlation was between prospective memory and executive functions. Executive functions is a broad cognitive domain encompassing processes such as initiation, monitoring and execution of actions; performing multiple operations; inhibition of behavior, among others (Lezak et al., 2012; Schoenberg & Scott, 2011).

One limitation is that neuropsychological tests of attention, retrospective memory, and executive functions are not pure measures of these domains. For example, tests of memory require attention, language, and visuoperceptual abilities (Drozdick et al., 2011; Lezak et al., 2012). In addition, within specific domains, tests emphasize different aspects of cognitive functions. For example, neuropsychological tests can emphasize different aspects of attention, such as sustained attention, ability to switch attentional control, auditory attention, and others may have a working memory component (Drozdick et al., 2011; Lezak et al., 2012). The current results cannot identify the unique components of attention and executive functions that contribute most to prospective memory.

Implications

The findings of this review indicate that prospective memory is significantly impaired in individuals with TBI. The severity of the injury and associated cognitive impairments are linked to functional outcome (Balanger et al., 2005; Dikmen et al., 2009; Lezak et al., 2012). One important consideration is whether individuals can live independently and return to employment after a TBI. We rely on prospective memory for independent living; and with frequent prospective memory failures, individuals have to rely on others for frequent reminders to follow through with their plans. Therefore, prospective memory should be evaluated after a TBI, and deficits should be targeted during the recovery period.

Understanding how task characteristics influence prospective memory is useful when deciding how to assess prospective memory in individuals with TBI. Decreased attentional and effortful processing demands facilitate prospective remembering. Therefore, when assessing prospective memory post-TBI, it should be noted that simple tasks will facilitate accuracy. If one uses a very simple prospective memory task, deficits may not be observable as a result of decreased task demands. This is important because prospective memory plans in our every-day life are seldom simple. To complete activities of daily living, including occupational activities, we must plan and execute multiple intentions, and we usually encounter multiple distractions, which places high demands on our prospective memory abilities.

Assessing cognitive functioning at different points in time after TBI is useful to measure recovery and progress after participation in rehabilitation programs. Prospective memory deficits continue to be present 6 months post-injury, the period when most functional recovery occurs (Finnanger et al., 2013; Mioni et al., 2014; Shum et al., 2011). During this period, application of strategies that target prospective memory deficits will be crucial.

Rehabilitation techniques for prospective memory deficits have focused on two main strategies: remedial and compensatory (Fleming et al., 2005; Mioni et al, 2014; Potvin et al., 2011; Shum et al., 2011). A remedial approach attempts to restore prospective memory functioning, but such training programs are expensive and time-consuming. They have been reported to be efficacious in instances of mild brain injury, but its efficacy for cases of moderate and severe TBI remains unclear (Fleming et al, 2005; Potvin et al., 2011; Shum et al., 2011). A compensatory approach introduces external aids, such as detailed instructions and external prompts, to prevent prospective memory failures (Fleming et al, 2005; Mioni et al., 2014; Shum et al., 2011).

Given the current findings, compensatory strategies targeting prospective memory failures should attempt to reduce attentional and effortful processing demands. In one study, Potvin and colleagues (2011) proposed using visual imagery as a prospective memory aid. They argued that associating the prospective memory cues with planned intentions using visual imagery increases familiarity of the cues, which reduces the amount of attention and monitoring required for detection. Most importantly, this technique can be applied to every-day prospective memory tasks (Potvin et al., 2001). Compensatory strategies, such as external reminders, have also been found to improve prospective memory in TBI (Fleming et al., 2005).

Every-day prospective memory tasks can be very complex and demanding. For instance, hosting a family dinner requires us to plan and execute multiple prospective memory tasks. More research is needed to explore how every-day prospective memory tasks can be adapted by decreasing attentional and effortful processing demands. Some strategies could be to break down large tasks into smaller ones, use salient cues that are strongly associated with planned intentions, and use external reminders to refocus attention. For those individuals with prospective memory deficits, these techniques can help them be more independent and improve overall quality of life.

Limitations

There are some limitations to this study. The number of studies that met the inclusion criteria was relatively small. Also, the accuracy of the effect sizes depends on the quality of individual studies and how raw data was collected, which was not evaluated in this review. Another limitation is that neuropsychological tests of cognitive functions are not pure measures. Thus, this review could not determine whether prospective memory relies on unique aspects of attention, retrospective memory or executive functions.

One question that remains unanswered is whether individuals with TBI have pronounced impairment in specific stages of prospective memory. Kliegel and colleagues

(2004) have argued that prospective memory is a multi-stage process comprised of intention formation, intention retention, intention re-instantiation and execution. In one study they found that individuals with TBI and older adults with no neurological impairment had deficits in all the stages of a prospective memory task, but they noted that these stages may not be completely independent. However, if brain damage results in stage-specific impairments, compensatory strategies could be planned to target those specific failures.

The current review and meta-analyses demonstrated that individuals with moderate and severe TBI suffer from significant prospective memory deficits, as measured by a variety of prospective memory tasks. The results revealed that prospective memory task characteristics that increase attentional and effortful processing demands decrease prospective remembering. Therefore, when assessing post-TBI cognitive functioning, the type of task used to measure prospective memory should be considered. Moreover, remedial or compensatory strategies targeting prospective memory failures should attempt to decrease those demands, in order to facilitate prospective remembering. Our results revealed that prospective memory performance in TBI is positively correlated with performance on neuropsychological tests of attention, retrospective memory, and executive functions. These findings advance the current understanding of neuropsychological function patterns observed in moderate and severe TBI.

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APPENDIX

Criteria used to classify prospective memory tasks as low-demand or high-demand tasks

Task characteristics	**High-demand**	**Low-demand**
Type of cue	Non-salient (non-focal)	Salient (focal)
Number of cue-intention associations	More than one association	One association
Ongoing task	Complex: Require sustained attention Require continuous responses Working memory component	Simple: Do not require sustained attention Do not require continuous responses No working memory component

Note. Tasks with salient prospective memory cues, one cue-intention association, and simple ongoing tasks impose less attentional and effortful processing demands. Tasks with non-salient cues, more than one cue-intention association, and more complex ongoing tasks are more demanding. Based on these criteria, tasks were classified as high- or low-demand tasks. Tasks with two or more of the high-demand characteristics were classified as high-demand tasks. Tasks with none or only one of the high-demand characteristics were classified as low-demand tasks.

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