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A Review of Prospective Memory in Individuals with Acquired Brain Injury

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Abstract

Objective: Prospective memory (PM) deficits have emerged as an important predictor of difficulty in daily life for individuals with acquired brain injury (BI). This review examines the variables that have been found to influence PM performance in this population. In addition, current methods of assessment are reviewed with a focus on clinical measures. Finally, cognitive rehabilitation therapies (CRT) are reviewed, including compensatory, restorative and metacognitive approaches.

Method: Preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Liberati, 2009) were used to identify studies. Studies were added that were identified from the reference lists of these.

Results: Research has begun to elucidate the contributing variables to PM deficits after BI, such as attention, executive function and retrospective memory components. Imaging studies have identified prefrontal deficits, especially in the region of BA10 as contributing to these deficits. There are now several clinical measures available with good psychometric properties. Rehabilitation techniques have mostly focused on compensatory strategies, but, in addition, some restorative and metacognitive approaches have shown preliminary promise.

Conclusions: PM deficits are a common and important deficit after BI. Clinical evaluation is recommended and further understanding of rehabilitation techniques are needed.

Keywords: Prospective Memory, Brain Injury, Episodic Memory, Memory for Intentions

Introduction

The ability to complete intended actions, prospective memory (PM), is critical for independent functioning. Successful performance is required for managing in vocational, home and community settings in healthy adults as well as those with neurological illnesses (e.g., Hannon, Adams, Harrington & Fries-Dias, 1995). Many activities of daily living (e.g., taking medications, attending appointments, purchasing food) depend upon intact PM (e.g., Raskin, Maye, Rogers, Correll, Zamroziewicz, & Kurtz, 2014). Survivors of acquired brain injury (BI) report failures relating to PM (e.g., I forget to take my medicine) as their most frequent memory problem (Kliegel, Jager, Altgassen, & Shum, 2008; Mateer, Sohlberg, & Crinean, 1987). In fact, they perceive PM deficits as more important to their daily lives than their significant others do (Huang, Fleming, Pomery, Chan, & Shum, 2014). Not surprisingly, then, there has been a large increase in interest in PM after BI in recent years, including advances in understanding the clinical manifestations, underlying neural processes, assessment and management (e.g., Knight, Harnett, & Titov, 2005; Raskin & Sohlberg, 2009).

In everyday life, successful PM performance depends on many factors, including the ability to pay attention, to maintain the intention in working memory, to call the intention to mind at the appropriate time and to recall the content of the intention (Groot, Wilson, Evans, & Watson, 2002). In addition, metacognitive abilities such as monitoring ongoing performance, evaluation of outcome, and awareness of PM limitations are required (Guynn, 2003). In any one individual, more than one of these underlying abilities may be affected. This is compounded by the heterogeneity of BI in terms of underlying damage and expressed symptoms. Thus, comprehensive assessment and rehabilitation efforts may need to be multifaceted, considering the different underlying reasons for failure at PM tasks in each individual, in what has been referred to as precision medicine (National Institutes of Health Consensus Development Panel on Rehabilitation of Persons with Traumatic Brain Injury,1998).

Definition of Prospective Memory

PM is defined as the ability to remember at a particular moment that one had previously decided to carry out a particular action at that moment (Kvavilashvili, 1992). PM may require self-cued remembering from a time-based cue, (e.g., remembering to return a phone call at 3:00 pm), or may follow an event-based cue (e.g., remembering to take a roast out of the oven in response to the oven timer) (Einstein & McDaniel, 1990; Kvavilashvili, 1992). Event-based tasks are typically easier to perform, most likely because time-based tasks rely on self-initiated monitoring and retrieval (Glisky, 1996).

PM has been conceptualized using three current theories, primarily derived from studies of healthy participants and then applied to those with conditions such as BI. The Multiprocess Theory of PM suggests that PM performance can be either spontaneous or rely on strategic monitoring, depending on the nature of the task. Differences can occur due to disparities in type of task, type of cue, the nature of the ongoing task, and the individual. Thus, as mentioned, tasks that must be remembered at a particular time may require more strategic monitoring than those that occur in response to an external cue (e.g., Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). More recently Scullin, McDaniel, & Shelton (2013) expanded this model to suggest there is a dynamic interplay between the spontaneous retrieval and the strategic monitoring, such that individuals will monitor in a context where cues are expected but then disengage from monitoring when cues are not expected. They refer to this as the Dynamic Mulitprocess Framework. The preparatory attentional and memory processes (PAM) theory, on the other hand, asserts that PM always requires attentional processes that are resource demanding due to explicit monitoring or the need to maintain the intention (Smith, 2003). This is assumed to be the PM aspect of the task whereas the recall of what one was supposed to do is based on retrospective memory (RM). The Attention to Delayed Intention (AtoDI) model uses imaging data to explain the brain regions responsible for intention maintenance and retrieval (Cona, Scarpazza, Sartori, Moscovitch, & Bisiacchi, 2015). The suggestion is that the dorsal frontoparietal network is involved in maintenance and allocation of top-down attention that is used both to monitor for the occurrence of the PM cue and to maintain the intention in mind. The ventral frontoparietal network, on the other hand, mediates the bottom-up attention automatically captured by the occurrence of the PM cues and used during retrieval. Given the prevalence of attention deficits in populations such as those with BI, and the importance of PM performance to everyday life, investigating whether some aspects of PM might be spared could lead to important directions in management post BI. This review will summarize the work that has been done to identify the types of PM deficits are prevalent in people with BI, assess whether these data are suggestive of a particular pattern of difficulty, and discuss cognitive treatment strategies that have been effective.

Identification of Articles for Inclusion

Preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Liberati, 2009) were used to identify studies. We reviewed PubMed/NCBI, and SCOPUS from 1990 to the year 2017. The following key words were used: prospective memory, memory for intentions, future thinking, and brain injury. To be included, an article must have used adult human participants who had experienced some form of acquired brain injury including trauma, stroke, tumor, infection, hypoxia and encephalopathy. Controlled trials, cohort and case studies were included. There also have been three previous review articles, which were not included in this review (Fish, Wilson, & Manly, 2010; Shum, Fleming, & Neulinger, 2002; Vakil, 2005). All identified articles were subject to title and abstract screening by two independent reviewers (SR, JW). Full-text screening was applied to all abstracts considered eligible by at least one reviewer. Discrepancies in selection status and reasons for exclusion were settled between the two reviewers by discussion and adjunction of a third reviewer (EA) if needed. This yielded 84 articles. There were no articles excluded due to methodological limitations or small sample size.

In terms of the samples studied, the majority of studies involved moderate to severe injury, with only two papers reporting on mild BI specifically. All studies were on adults (over the age of 18) and the majority (82) were on individuals under 65 years of age. There were five studies specific to individuals with stroke, one with individuals post-encephalitis, 36 studies identified the sample as entirely traumatic BI, and the rest (42) were of mixed etiology. See Figure 1.

Prospective Memory and Brain Injury

As would be expected, many of the early studies of PM after BI were largely descriptive in nature and focused on demonstrating that PM deficits exist in this group (Cockburn, 1996; Groot, Wilson, Evans & Watson, 2002; Kinsella, Murtagh, Landry, Homfray, Hammond, O'Beirne, Dwyer, Lamont, & Ponsford, 1996; Shum, Valentine, & Cutmore, 1999; Sohlberg, White, Evans, & Mateer, 1992). More recently there has been an increase in interest in this area of research with a greater focus on testing theoretical constructs (Kliegel, Eschen, & Thone-Otto, 2004; Mathias & Mansfield, 2005; Maujean, Shum, & McQueen, 2003; Raskin, 2009; Roche, Moody, Szabo, Fleming, & Shum, 2007; Schmitter-Edgecombe & Wright, 2004).

Relationship to brain substrates. Imaging studies have suggested that PM depends on rostral prefrontal cortex (rPFC) functioning, and, in particular, Brodmann area 10 (Benoit et al., 2011). rPFC has been shown to be engaged during the delay period that occurs between the intention formation and the execution of the intention (Burgess, Gonen-Yaacovi, & Volle, 2011). Brain activation during PM tasks has been distinguished from activation in areas associated with vigilance, dual task performance, and working memory (West, 2008). A number of studies have documented impairment in PM functioning following injuries in prefrontal regions (e.g., Burgess, Alderman, Volle, Benoit, & Gilbert, 2009; Neulinger, Oram, Tinson, O'Gorman, & Shum, 2016; Umeda, Kurosaki, Terasawa, Kato, & Miyahara, 2011), and PM impairments have been measured in neurological disorders that are presumed to include dysfunction of prefrontal structures (Raskin, Buckheit, & Waxman, 2012; Raskin et al., 2014; Raskin et al., 2011). Although it is acknowledged that individuals with BI have damage to large cortical regions, most demonstrate prefrontal cortical dysfunction (e.g., McAllister, 2011), and individuals with poor executive function performance (such as on the Stroop Color-Word Interference Test, Letter-Number Sequencing, Tower of London, and Controlled Oral Word Association Test) show greater PM impairment (Kliegel et al., 2004; Maujean et al., 2003; Raskin et al., 2017),

Retrospective memory contribution. A few studies of BI have tried to tease out the retrospective versus prospective components of performance. While people with BI frequently have retrospective memory deficits, these are not always comparable to the deficits in PM. On the one hand, Carlesimo, Casadio & Caltagirone (2004) reported that individuals with BI were less accurate in spontaneous initiation of the task but also significantly impaired compared to healthy participants at recalling the content of the information to-be-recalled. In contrast, Kliegel, Eschen & Thone-Otto (2004) reported that individuals with severe BI were impaired in intention formation, initiation and execution of the intention but not in retention of the intention. Henry et al. (2007) and Raskin et al. (2011) used a post-test recall to demonstrate that deficits were due to the prospective component of the task and that the participants with BI were able to successfully recall the content of the task to be performed. Finally, using a multinomial modeling approach, Pavawalla, Schmitter-Edgecombe, & Smith (2012) supported the finding that individuals with BI were significantly impaired in the prospective component of the task, and allocated fewer preparatory attentional resources to the PM task than healthy participants.

Even in studies that document retrospective memory deficits (Clune-Ryberg, Blanco-Campal, Carton, Pender, O'Brien, Phillips, Delargy, & Burke, 2011), these deficits generally do not explain the PM deficits (Mioni et al., 2013; Raskin, et al., 2017). Mioni et al. (2013) used Virtual Week and compared regular (daily) to irregular (occasional) tasks. They reported that the magnitude of the PM impairment was the same for both types of tasks in people with BI, suggesting that retrospective memory failures cannot explain PM deficits since it was assumed that daily tasks place less demands on retrospective memory. Overall, retrospective memory loss is a common sequelae of BI and is likely to be a contributing factor to PM failures in daily life. However, the evidence to date suggests that PM deficits are both independent of retrospective memory loss and have a greater impact on daily functioning (Raskin et al., 2011).

Time Delay. Although only a few studies have included varying time delays, individuals with BI have been shown to be able to successfully complete instructions for short time delays but not for longer ones (Raskin & Sohlberg, 1996; Raskin, 2009). The effect of time has not been investigated as a continuous variable, however, but only as a comparison of short time delays (e.g., 2 minutes) versus longer time delays (e.g., 15 minutes).

Time-based versus Event-based cues. The relationship between time-based and event-based cues was one of the first areas of interest in PM functioning after BI. Cockburn (1996) used a single time-based activity (described in Baddeley, 1981) and a single event-based activity. She found that healthy adults performed better than a group of people with BI on both. Mathias and Mansfield (2005) used event-based tasks from the Rivermead Behavioral Memory Test and time-based tasks adapted from Einstein et al. (1995). Individuals with BI in this study performed poorly compared to healthy adults on time-based tasks but also performed poorly when compared to healthy adults on event-based tasks judged to have low personal saliency.

Time –based tasks have consistently been found to be more difficult for this population than event-based tasks. Groot et al. (2002) used the Cambridge Behavioural Prospective Memory Test and reported that individuals with BI were superior at event-based tasks compared to time-based tasks. Using the Memory for Intentions Test (Raskin, Buckheit, & Sherrod, 2010), we also found individuals with BI showed superiority for event-based versus time-based cues (Raskin, 2009). Using a laboratory task that separated time-based, event-based, and activity-based items, once again time-based items were shown to be more difficult for a small study of 12 individuals with BI (Shum et al., 1999).

Interestingly, individuals with mild BI demonstrated deficits compared to healthy adults on the overall event-based score of the MIST but only on the longer delay (15 minutes) for the time-based items (Tay et al., 2010). These deficits were measured both acutely after the injury and three months later.

The majority of studies have thus suggested that individuals with BI show greater impairment with time-based tasks than with event-based tasks. This is consistent with the Multi-Process Theory which suggests that time-based tasks, that require greater cognitive control and self-initiated action, will be more likely to be impaired in those with executive function deficits. The interaction of this effect with factors such as length of time and personal saliency warrant further study.

Effect of ongoing task. There has also been interest in the effect of BI on controlled attentional processes required for successful PM. Maujean, Shum and McQueen (2003) directly measured the effect of the cognitive demand of the ongoing task. Participants with severe BI performed more poorly than participants in the healthy adult group in the condition of high cognitive demand but not in the condition of low demand. This suggests that PM performance is differentially affected by the cognitive demand of the ongoing task in individuals with BI. It is not known from this study whether this is due to reduced attentional capacity or reduced ability to allocate cognitive resources to the PM task. Further research on ongoing task response thresholds and capacity models are also needed in this population (see Heathcote, Loft, & Remington, 2015).

Effect of type of response. To our knowledge, this has only been studied in people with BI in one study (Raskin et al., 2011). If the enactment effect (e.g., Schult et al., 2016) is due to subcortical contributions, these functions may be intact in a BI population. It would be interesting to determine if individuals with BI show superiority for action intentions, as this might point to rehabilitation strategies. In the one study to look at the effect of enaction, individuals with BI did not exhibit any action superiority effect (Raskin et al., 2011), however, it is not clear from this study whether this is because the effect is eliminated, perhaps due to deficits in attention, or whether the task items were not sufficient to produce the effect (e.g., Steffens, Stulpnagel, & Schult, 2015).

Cue focality. It has been suggested that different PM tasks could very well challenge different cognitive systems depending on the task (McDaniel & Einstein, 2011). For example, tasks with focal cues may require little strategic monitoring and thus rely on the medial temporal structures while those with non-focal cues may require activity of the prefrontal cortex (e.g., McDaniel & Einstein, 2011). Focal cues are ones where the task to be completed is related to the ongoing task, whereas nonfocal cues are not related to the ongoing task. Schmitter-Edgecomb and Wright (2004) compared a high focal condition and a low focal condition in a group of individuals with severe BI. The ongoing task was to monitor words presented on a computer screen. If the word "recall" appeared they were to state the last three words presented. All words were surrounded by different backgrounds. In the high focal condition, participants were to press a key if a particular target word appeared. In the low focal condition, participants were to press a key if a particular background pattern appeared. There were no differences between the two conditions reported for either the people with BI or the healthy participants. Thus, it is not clear if individuals with BI are unaffected by varying cue focality or if this task failed to create that effect. ~~To our knowledge this has not been investigated in a BI population.~~

Effect of task complexity. Henry, Phillips, Crawford, Kliegel, Theodorou, & Summers (2007) looked at BI performance for a computerized PM task and varied the number of target events (in essence, the load on prospective remembering). Individuals with BI were impaired on both the one target task and the four-target task compared to controls. The authors concluded that increasing the number of targets does not, therefore, increase demands on controlled attentional processes.

Predictors of prospective memory performance. Fleming et al. (2008) demonstrated that length of time in post-traumatic amnesia (PTA) and verbal fluency predicted both time and event-based scores on the Cambridge Prospective Memory Test. Rule monitoring on executive function tasks was also found to predict PM performance, but only in individuals with TBI who also had retrospective memory deficits (Paxton & Chiaravalloti, 2014). It seems likely that other measures of severity of injury are also likely to lead to more severe PM deficits either due to medial temporal contributions to the recall of the item to be remembered or prefrontal contributions to prospective remembering itself. Given other studies that have demonstrated that PM performance is highly correlated with executive function tasks that require future planning, such as the Tower of Hanoi (Raskin & Sohlberg, 2009), we would imagine that this could be a fruitful line of future research. A measure of executive control, intraindividual variability, may also have predictive value (Stuss, Murphy, Binns, Alexander, 2003). In addition, time estimation may also be a worthwhile are to examine as a potential predictor of successful PM performance.

Severity of injury. Individuals with mild TBI have been shown to demonstrate deficits on the MIST (Tay et al., 2010) immediately after injury and three months later, and on the CAMPROMPT three months post injury (Kinsella, Olver, Ong, Gruen, & Hammersley, 2014). However, interestingly, these were no different from the deficits observed in a trauma control group when compared to a healthy population (Kinsella, Olver, Ong, Gruen, & Hammersley, 2014). We are not aware of a study that has compared a group with mild BI to a group with severe BI, although the finding that PTA predicted performance (Fleming, et al., 2008) suggests that there would likely be a difference.

In general, individuals with BI demonstrate poor performance in conditions when greater cognitive resources, especially those involving attention, working memory, and monitoring, are required. The one consistent finding over multiple studies is that time-based tasks are more difficult than event-based tasks (e.g., Raskin et al., 2012). This is likely explained by the greater cognitive resources required to monitor time, be aware that time has passed, and bring forward the intention. Similarly, the extra cognitive resources required to complete the ongoing task lead to greater impairments of PM as the difficulty of the ongoing task is increased (Maujean, Shum and McQueen, 2003). For the same reason, it would be predicted that non-focal cues would be more difficult than focal cues, but this is yet to be demonstrated. This was not found to be the case in one study measuring the effect of cognitive load (Henry et al., 2007) however this was a small sample size and the authors interpreted the finding to suggest that this aspect of PM performance was relying on automatic processes.

One area that has had a striking lack of research is whether or not individuals with BI show an action superiority effect. Given that subcortical motor structures are intact in these individuals and likely responsible for the effect, this warrants further investigation.

Similarly, there has been little research to date on issues such as severity of injury, location of lesion (e.g., medial temporal versus prefrontal), and primary cognitive deficits, all of which could help explain not only individual differences in PM in those with BI but might also provide important data on neural and cognitive substrates of PM.

Measurement of Prospective Memory

Measures of PM all have some common elements. These include the encoding and formation of an intention to be performed in the future, an ongoing task during the delay period, and a cue to signal it is time to perform the intention. Research on this topic has been performed using laboratory, self-report and clinical measures. It is thought that laboratory measures provide greater ability to manipulate specific variables to answer theoretical questions (e.g., Einstein & McDaniel, 2005). Self-report measures provide data on the subjective experience of PM (Roche et al., 2007) whereas clinical measures have been used in attempts to approximate more real-world applications of PM, such as calling the experimenter at a specified time (Rendell & Thomson, 1999). Each of these measures provides valuable data on PM performance, but clear and consistent relationships between them have yet to be defined (e.g., Raskin & Sohlberg, 2009; Rendell & Thompson, 1999; Uttl & Kibreab, 2011). Given the possibility that these measures are all capturing unique and not entirely overlapping aspects of PM, it may be important to compare the findings from each.

Laboratory Measures. Einstein and McDaniel (1990) introduced a dual-task laboratory paradigm that has been widely used in the literature. Like all PM tasks, there is a prospective remembering task embedded in an ongoing task, followed by a delay period. After this period, the ongoing task is reintroduced without a reminder of the PM task. The PM task, embedded in the ongoing task, is presented and the response of the participant is measured (Einstein & McDaniel, 2005). There are many different versions of this task, but, for example, the participant might be shown a series of noun-verb pairings and asked to remember them. Following this learning trial, the participant is shown a long series of nouns one at a time on the computer screen. The participant is required to press one key (e.g. "m") if the noun represents a manmade object and a different key (e.g., "n") if the noun represents a natural object. However, if the noun is one of the words from previous the noun-verb pairing task, the participant must instead press the "p" key. This laboratory paradigm has proven invaluable in testing specific theoretical questions about PM performance. However, these paradigms tend to involve only one type of PM response performed repeatedly, and, compared to other measures reviewed, the ecological validity is considered low (Delprado, Kinsella, Ong, Pike, Ames, Storey, Saling, Clare, Mullaly, & Rand, 2012). In addition, because different studies use slightly different task items, it has been shown that the sensitivity of these paradigms to neurological disorders can vary with the characteristics of the PM and ongoing tasks (e.g., Foster, McDaniel, Repovs, & Hershey, 2009). In a study done by Shum et al. (1999) using time-, event-, and activity-based PM tasks, the results revealed differences in all three types of tasks, with the individuals with TBI performing significantly worse on all tasks. In a recent study, individuals with BI performed more poorly than healthy participants in terms of false positives but not omission errors, suggesting a particular difficulty with impulsive responding and cue-detection (Raskin et al., 2017).

Self-Report Questionnaires. There are also several currently used self-report PM measures, including the Comprehensive Assessment of Prospective Memory (CAPM; Chau, Lee, Fleming, Roche, & Shum, 2007), the Prospective and Retrospective Memory Questionnaire (PRMQ, Crawford, Smith, Maylor, Della Sala, & Logie, 2003), and the Prospective Memory Questionnaire (Hannon, Adams, Harrington, Fries-Dias, & Gipson, 1995). Essentially, these self-report measures all quantify common PM tasks that are undertaken in daily life (such as remembering to take medications or remember to return library books), and as such may have a higher personal significance then laboratory measures, such as those requiring a key press at a certain time. Questionnaires have arguably high ecological validity and allow for a greater understanding of the experience of PM failures in daily life. They are generally brief, easy to use and understand, and time-efficient (Man et al., 2011). However, they have not been well-correlated with other measures of PM, perhaps due to limited insight or awareness in individuals with BI (Fleming et al., 2009; Roche et al., 2002).

The CAPM is one questionnaire that was designed to measure PM failures. It has been demonstrated to have good reliability (Chau, Lee, Fleming, Roche, & Shum, 2007). The internal consistency of the items within the IADL subscale was 0.92, the BADL subscale was 0.74, and the total CAPM was 0.94.

The full CAPM contains three sections, one that measures frequency of PM failure, one that measures the perceived importance of these failures and the third that measures the perceived reasons for forgetting (Roche, Moody, Szabo, Fleming, & Shum, 2007). It can be completed by an individual or by a family member. A principal components analysis of the first part, Section A, revealed that there were two components, one that related to basic activities of daily living (BADL), such as daily self-care (e.g., accidentally forgetting to brush your teeth), and one that related to instrumental activities of daily living (IADL), such as household management activities (e.g., forgetting an appointment with a doctor or therapist) (Chau et al., 2007). The CAPM has been used in previous studies with individuals who have BI and has demonstrated sensitivity to perceived failures in this population (Huang et al., 2014) and has been analyzed per Ellis's (1996) five phases of PM to demonstrate that those with TBI had difficulty with encoding and formation and initiation of prospective memories (Roche, Moody, Szabo, Fleming & Shum, 2007). More recently a short form has been developed, the Brief Assessment of Prospective Memory (Man, Fleming, Hohaus, & Shum, 2011). Using the BAPM, Man et al. (2016) demonstrated a relationship between self-report on this measure and functional measures of BADL and IADL.

The Prospective and Retrospective Questionnaire was created to provide a self-report measure of both prospective and retrospective memory slips in everyday life (Smith, Della Sala, logie, & Maylor, 2000). It consists of 16 items, eight about PM and eight about retrospective memory. It has been demonstrated to have good reliability (internal consistency). Cronbach's alpha was 0.89 for the Total, 0.84 for Prospective, and 0.80 for Retrospective scales (Crawford et al., 2003). The PRMQ has been used to measure treatment efficacy in rehabilitation studies of individuals with BI (e.g., Huckans, Pavawalla, Demadura, Kolessar, Seelye, Roost, Twamley, &

Storzbach, 2010; Jamieson, Cullen, McGee-Lennon, Brewster, & Evans, 2015). It has been translated into Spanish (Gonzalez-Ramirez, & Mendoza-Gonzalez, 2011) and several other languages including Chinese, Dutch, Finnish, French, Italian, Portuguese and Tamil.

The Prospective Memory Questionnaire has demonstrated good test-retest reliability and internal consistency as well as sensitivity to PM deficits after BI (Hannon, Adams, Harrington, Fries-Dias, & Gipson, 1995). It asks about the frequency of PM failures. There are four subscales: Long-Term Episodic (e.g., "I forgot to return books to the library by the due date"), Short-Term Habitual ("I forgot to lock my door when leaving my apartment or house"), Internally Cued ("I forgot what I was going to say in the middle of a sentence"), and Techniques to Remember, which measures the use of strategies. Reliability of the Prospective Memory Questionnaire was reported to be high, with coefficient alpha ranging from 0.78–0.90 for the subscales, and 0.92 for the total score, and test-retest reliability ranging from 0.64–0.88. In terms of validity, short-term prospective tasks significantly correlated with the questionnaire total score, but long-term tasks were not (Hannon et al., 1995).

Studies using questionnaires, however, have yielded mixed results. Hannon et al. (1995) found that individuals with BI reported difficulty with short-term habitual tasks but not with more long-term remembering. Roche, Fleming, and Shum (2002) reported that individuals with BI did not report more PM problems than healthy adults, although observers did report that the individuals with BI had more problems than healthy adults. On the Comprehensive Assessment of Prospective Memory (CAPM) Section A, responses by individuals with BI were correlated with psychosocial integration but not with clinical measures of PM, demonstrating low concurrent validity (Spearman's Rho correlations with total CAMPROMPT=-0.03 and with total MIST=-0.14) (Fleming, Kennedy, Fisher, & Gill, 2009). However, relative's reports on the

CAPM demonstrated better concurrent validity (Spearman's Rho correlation with total CAMPROMPT=-0.33 and with total MIST=-0.41). This suggests that self-report questionnaires are useful in understanding the person's own view of their prospective memory abilities, but that they may be effected by difficulties with insight and awareness that can be common in people with BI (e.g., Cockburn, 1996). Using section C of the CAPM, Roche, Moody, Szabo, Fleming and Shum (2007) reported that persons with BI encounter difficulty specifically with encoding, formation and initiation of prospective memories. A summary is presented in Table 1.

Clinical-Based Measures. To our knowledge, there are currently four standardized psychometric measures of PM and these are considered more naturalistic than laboratory measures. These are the Memory for Intentions Test (MIST) (Raskin, Buckheit, & Sherrod, 2010), the Cambridge Assessment of Prospective Memory Test (CAMPROMPT) (Wilson et al., 2005), Virtual Week (Rendell & Henry, 2009) and the Royal Prince Alfred Memory Test (Radford, Lah, Say, & Miller, 2011). These tests have all shown good psychometric properties and sensitivity to PM deficits, which will be reviewed below. However, only the MIST and the CAMPROMPT are published clinical measures with established normative data. The Virtual Week and Royal Prince Alfred Memory Test, on the other hand, can be described as laboratory measures that are naturalistic and clinically-relevant.

Published clinical tests. Some of the earliest studies to clinically assess PM used the two PM items from the Rivermead Behavioral Memory Test (Wilson, Cockburn, & Baddeley, 1985). This was then expanded to form the Cambridge Prospective Memory Test (CAMPROMPT) (Wilson et al., 2005). The CAMPROMPT has three time- and three event-based PM tasks and requires 30 minutes. The ongoing task is a series of items including a general knowledge quiz, word-finding puzzles, mazes, etc. The person being examined is permitted to write down notes to aid in recall. People with BI show impairments on the CAMPROMPT, with the impairment being greater for time-based tasks than for event-based tasks and deficits were related to both retrospective memory performance and executive function performance (Groot, Wilson, Evans, & Watson, 2002).

The MIST can separate out different aspects of performance, such as type of cue and time delay. The MIST includes both time-based and event-based cues that are either two minutes or fifteen minutes in duration between encoding and performance. The time-based cues allow for self-initiated retrieval ("In fifteen minutes, tell me that it is time to take a break") and, unlike most laboratory tasks, the event-based cues are related to the events that need to be performed (i.e. "When I hand you a red pen, sign your name on the paper"). The response of participants can either be an action or verbal response. The ongoing task is a word search puzzle. Due to the MIST's ability to measure different attributes of PM, it also allows for six types of errors to be analyzed if failure of a PM task were to occur (Raskin, 2009). There is a multiple choice retrospective memory questionnaire administered at the end of the test and an optional 24-hour delay item. The MIST has been demonstrated to be sensitive to PM deficits in individuals with BI (Raskin, 2009) and mild TBI (Tay et al., 2010) and has been shown to have good psychometric properties (Raskin, 2009; Woods, et al., 2008). The MIST was validated against the two items of the Rivermead Behavioral Memory Scale that deal with PM because at the time there was no other clinical measure of PM. The correlation of the MIST with the two items of the Rivermead in healthy individuals was 0.80. The test–retest reliability of the MIST was demonstrated in a group of 20 healthy participants who were given the MIST on two occasions two weeks apart. Inter-form reliability, comparing Form A and Form B in the same group of 20 participants, was found to be 0.89. Split half reliability was measured by Woods, Moran, Dawson et al. (2008) in a healthy sample of participants as 0.70 using the Spearman-Brown coefficient. While the inter-item reliability of the individual trials was reported to be poor (Cronbach's alpha = .48) the reliability of the six subscales was judged to be better (Cronbach's alpha = 0.89). Several studies have also reported finding that the MIST measures a cognitive construct that is separable from retrospective memory performance (e.g.,Woods, Moran, Carey et al., 2008). There are four alternate forms and it has been translated into several languages including Spanish, Portuguese, Italian and Chinese.

Clinically-oriented laboratory tasks. Virtual Week is a laboratory task with items similar to tasks required in everyday life. It was originally designed as a board game and is now computerized (Mioni, Rendell, Henry, Cantagallo, & Stablum, 2013). Individuals roll dice and move along on the board where they are required to perform real-world tasks some of which are based on events, "Buy a bus ticket when shopping," and some of which must be performed by the time indicated on the center of the board. The time on the board automatically moves forward as the person moves to a new space. Some items are regular (performed daily) and some are irregular (performed occasionally). As stated, at the center of the board game is a virtual clock which changes as the person moves around the board. The ongoing tasks are naturalistic items such as eating meals, going to the library, or having a visit from a neighbor. The reliability of Virtual Week was investigated by Rose, Rendell and McDaniel (2007) in a study involving healthy younger adults and older adults. Across the entire sample, reliability estimates ranged from .84 to .94 for the regular, irregular and time-check tasks. Test-retest reliability was measured in healthy adults by using an alternate form and no effect of test-retest was found (Mioni, Rendell, Stablum, Gamberini, & Bisiacchi, 2014). Individuals with BI were shown to have difficulties with both event-based ("Buy a bus ticket when shopping") and time-based

("Take your medication at 2:00 pm") compared to healthy participants, but with greater impairment on the time-based tasks.

The Royal Prince Alfred (RPA) Prospective Memory Test is also a laboratory task with real-life items that are very similar to the MIST. It contains time- and event-based tasks and both short and long time delay intervals (Radford, Lah, Say & Miller, 2011). The ongoing tasks are chosen by the examiner and can include questionnaires or other measures that themselves are part of a clinical battery. There are three alternate versions with good alternate-form reliability and it has been used in one study with a mixed group of neurological patients, including BI (*n*=2), stroke (n=7), tumor (*n*=2) epilepsy (*n*=5), arteriovenous malformation removal (*n*=2) systemic lupus erythematosus (*n*=1) and encephalitis (*n*=1). Items performed in the session are tasks such as "In 15 minutes time, I would like you to tell me it's time for a coffee break" and "When my mobile phone rings, tell me you would like a drink." The longer delay naturalistic items are returning a postcard and making a phone call. Interrater reliability was measured between two independent raters and found to be high for the control group, ICC (3, 1) .90, $p<.001$, and in the patient group, ICC (3, 1). .97, $p< .001$. Alternate form reliability was also satisfactory; Spearman correlation between Form 1 (M. 10.3, SD. 1.2) and Form 2 (M. 10.9, SD. 2.1) scores was significant in the control group, r. .71, $p<.05$, as was the correlation between Form 1 and Form 3 (M. 10.9, SD. 1.0) scores, $r=0.71$, $p<.01$. Patients demonstrated significantly poorer RPA PM performance in terms of total score. As a measure of validity the test was compared to the MIST and a questionnaire. Surprisingly, given that the items are very similar, RPA PM scores were not significantly correlated with MIST Summary scores, $r=0.18$. However, RPA PM scores were negatively correlated with subjective ratings on all three questionnaires: CAPM-Self, $r=0.67$, $p<.01$; EMQ, $r=0.62$, $p< .01$; and CAPM Other ratings,

$r=0.50$, $p<.05$. That is, better RPA PM performance was associated with fewer reported memory problems in everyday life. Information on these measures is presented in Table 2.

Naturalistic, Video and Virtual Reality Measures. Using naturalistic measures of activities of daily living, Fortin, Godbout & Braun (2002, 2003) reported that individuals with BI had difficulty due to trouble with organizing and planning intended activities, such as preparing a meal. These authors concluded that deficits in strategic planning and event-based PM are responsible for difficulties completing activities of daily living in these patients. Knight, Harnett & Titov (2005) created a novel videotape task of a person driving and walking through an unfamiliar city. Participants were given a list of tasks to be completed in the city and were required to recall them when the appropriate cue appeared on the videotape. In this study, the group with BI was impaired compared to healthy adults, but demonstrated low awareness. In a subsequent study they also demonstrated that individuals with TBI were more sensitive to distraction in this environment (Knight, Titov, & Crawford, 2006).

Several virtual reality tasks have also been created to assess PM in BI. The Virtual Reality Shopping Task (Canty, Fleming, Patterson, Green, Man, & Shum, 2014) was sensitive to BI and predicted performance on everyday activities such as independent living skills demonstrating good ecological validity. In the ongoing task, participants had to purchase 12 items in a pre-specified order from a selection of 20 shops in the virtual environment. For time-based PM tasks, text messages had to be sent at specified times. For the event-based PM task a key had to be pressed if an announcement came over the loudspeaker for a sale.

A study utilizing a virtual reality setting of working in a furniture store did not find good sensitivity of the task to BI, although overall people with BI scored significantly more poorly than a matched control group (Sweeney, Kersel, Morris, Manly, & Evans, 2010). Individuals who had had a stroke were impaired on event- and activity-based tasks and marginally on time-based tasks (Brooks, Rose, Potter, Jayawardens, & Morling, 2004).

In addition, there are several comprehensive measures that include PM items, including the Rivermead Behavioral Memory Test, the Brain Injury Cognitive Screen (Vaughan, Neal, Mulla, Edwards, & Coetzer, 2017) and TEM-PRO (Muhl, Augert, Wicky, Fedou, Devanthery, Jungo, Benaim, Leger, Vuadens, & Anne, 2016).

Relationship between Types of Measures. There have been some preliminary studies that have sought to compare the relationship between different types of measures (e.g., laboratory, clinical, self-report) (e.g., Raskin et al., 2017). Previous studies comparing questionnaires and clinical measures, for example, have yielded mixed results. Previous studies found no correlation between the CAPM and total score on the MIST, suggesting that either the two measures are measuring separate functions or that subjective experience and objective performance are not the same (Fleming et al., 2009; Raskin et al, 2017). Relatives' report on frequency of PM failure did correlate with the MIST total score as well as both the time-based cue and event-based cue scales, which suggest that the difference may be due to poor subjective awareness (Fleming et al., 2009). No data were provided on the relationship between the CAPM and the 24 hour delay item on the MIST. Another study used the PRMQ and found that while the MIST did not correlate with responses on the self-report questionnaire, the MIST did correlate with performance in daily life on 10 items over a week as reported by a significant other (Raskin & Sohlberg, 2009). Thus, this again suggests that the questionnaires are tapping into an aspect of the individual's perception of his/her performance that may not be related to the individual's actual performance.

In a study that compared the MIST to a laboratory measure, there was little relationship between these two forms of PM measurement for healthy participants but that there was a strong relationship for those with BI (Raskin, Shum, Ellis, Pereira, & Mills, 2017). For those with BI, the greatest relationship was with the event-based items on the clinical measure. This highlights the problem with using laboratory measures that include only event-based items if one is interested in a comprehensive picture of PM performance. The clinical measure was also related to false positive performance on the laboratory measure, in this case the number of PM errors. This may suggest that time-based remembering is related to self-monitoring more than event-based PM in this population.

These tasks may also require different levels of attentional resources. The laboratory measures tend to use only event-based cues; thus, they may be less attention demanding than the time-based tasks in the MIST. Furthermore, unlike the MIST, the event-based cue in the laboratory measure is usually embedded within the ongoing task, which may further serve to focus attention on the cue. On the other hand, in the laboratory paradigm the embedded PM task (i.e. press a key when you see a specific word) does not explicitly put the participant in a "retrieval mode" and instead requires participants to enter this mode on their own. In contrast, the event cues of the MIST put participants in a retrieval mode, (i.e. by handing the participants a form requesting medical records) in which they may be aware something should happen because of the high association between the intended action and the cue. On the other hand, the CAPM queries performance on both event-based (e.g., forgetting to lock the door when leaving home) and time-based (e.g., forgetting to take tablets at a prescribed time) everyday tasks. It can be argued that the CAPM is the only one that measures tasks in which the individual must form his/her own intention and create his/her own plan for execution (e.g., Dobbs & Reeves, 1996).

For the other tasks this is provided for the participants by the experimenter. However, because the CAPM relies on retrospective subjective report, it is not known if it is an accurate reflection of performance.

There are, arguably, three types of measures at this time: laboratory, psychometric and self-report. Each of these measures is useful in specific contexts. Laboratory measures are essential for their ability to control specific variables thus test hypotheses about the different aspects of cognition used in PM. Thus, laboratory measures are all constructed in a similar manner but with specific paradigms designed to answer specific questions. Because these have been primarily brought over from the cognitive psychology literature on healthy individuals, research is needed to determine the effects of these variables on people with BI and care must be taken to avoid floor effects.

Psychometric measures are useful clinically and to understand more naturalistic aspects of PM. Of these, the MIST, CAMPROMPT, and Virtual Week have the largest normative databases and psychometric properties. However, they are quite time-consuming to administer in a standard neuropsychological evaluation. Thus, a shorter measure, such as the RPA might be worth pursuing.

Self-report questionnaires are useful for understanding the individual's personal experience. It is important to note again, however, that it is likely these three types of measures are measuring aspects of PM that are overlapping but not completely overlapping. Thus, the information gleaned from one of these measures will be different from that gathered from a different measure. In particular, self-report measures do not typically correlate with standardized psychometric measures and thus, they cannot be used interchangeably. More research is needed to understand if this is due to poor insight into deficits or whether the types of PM problems queried on self-report measures are different from the types measured in psychometric tests.

In terms of clinical neuropsychological evaluations of PM performance in this population, to date only the CAMPROMPT and MIST are practical alternatives with adequate psychometric properties and well balanced normative data. A clinician could choose between the two based on a preference for a more behavioral real-world measure (CAMPROMPT) versus a measure that allows for a more fine-grained analysis of the source of any deficit (MIST). Both are time-consuming within a standard evaluation and short-forms would be useful. Of course, the limitation is that PM, by its very nature, requires a significant amount of time to pass. Thus any short form would need to embed other measures in the delay period (see Raskin & Race, 2018) rather than just have a shorter time delay for the PM items..

Rehabilitation

Cognitive rehabilitation approaches traditionally group cognitive rehabilitation therapy (CRT) into interventions that are considered compensatory and those that are considered restorative approaches (Sohlberg, 2006). It could be argued that metacognition or self-regulation interventions constitute a third category (Kennedy et al., 2007). An example of a metacognitive approach would be training people in the use of strategies or systems that facilitate self-monitoring during PM task completion (Levine et al., 1998). All three of these rehabilitation approaches have been evaluated for their potential to address deficits in PM functioning.

Compensatory Approaches to Rehabilitation. Compensatory approaches can be external (such as notebooks or pagers) or internal (such as visual imagery, first letter mnemonics, or elaborative encoding). One of the oldest rehabilitation techniques for PM deficits after BI is written diaries or memory notebooks (Sohlberg, 2005). Compared to more complex electronic systems, memory notebooks are more familiar to many people with BI and facilitate recall of a diverse range of functional tasks (Sohlberg & Mateer, 1989). There are two memory notebooks formats, the standard format, Sohlberg and Mateer (1989) and the modified format, Donaghy and Williams (1998). The standard memory journal follows the format of most standard personal organizers. The four section of this diary are as follows, weekly timetable, "to do" section, memory log, and transport notes. The modified diary has a timetable and a "to do" column for each day, with an adjacent page for the memory log. Additionally, it contains a full year calendar for appointments to be recorded.

McKerracher, Powell, and Oyebode (2005) conducted a single case experimental design comparing these two notebook formats for a man with memory problems caused by a mild traumatic BI. The patient was given five PM tasks per week. He used both the standard and modified journal for four weeks. McKerracher et al. found that the patient managed to carry out only one of 20 PM tasks while using the standard diary, but 15 of the tasks while using the modified journal (McKerracher et al., 2005). But it is difficult to reach broad conclusions based on a single case.

There is considerable evidence that giving a notebook alone without sufficient training is not effective (Raskin & Sohlberg, 2009). Moreover, self-instructional training, emphasizing self-awareness and self-regulation was found to be more effective than a diary alone in a group of 20 participants with acquired brain injury (Ownsworth & McFarland, 2009).

Thus, there are several difficulties with the use of notebooks. These include the need for extensive training in their use, the need to have a system to keep them from becoming misplaced, and the need to have a PM span of at least five minutes to use them effectively (Raskin & Sohlberg, 2009). For comprehensive discussions of the use of memory notebooks and the importance of training individuals to use them effectively, see Sohlberg and Mateer (2001) as well as McKerracher, Powell, and Oyebode (2005).

Electronic aids. Several electronic aids have also been evaluated to assist with PM deficits. The strongest evidence supporting the use of PM task prompting comes from a randomized, controlled trial evaluating the use of alphanumeric pagers to prompt certain simple routing behaviors (Wilson et al., 2001). When prompted with these pagers, individuals increased completion of daily tasks from approximately 47% to 75% follow through (Emslie, Wilson, Quirk, Evans, & Watson, 2007; Wilson, Emslie, Quirk & Evans, 2001; Wilson, Emslie, Quirk, Evans & Watson, 2001; Wilson, Scott, Evans, Emslie, 2003). Moreover, some patients could remember daily activities even after the pager was removed, suggesting an internalization of the external prompt.

Similar electronic systems have been employed to call individuals' mobile phones, such as Postie (Kirsch, et al., 2004) the Yahoo-Calendar System (O'Connell, Mateer, & Kerns, 2003) and Mobile Extensible Memory and Orientation System (MEMOS; Thone-Otto & Walther, 2003) and this prompting technology has shown its utility in improving PM functioning (Van den Broek, Downes, Johnson, Dayus, & Hilton, 2000; Wade & Troy, 2001; Yasuda, Misu, Beckman, Watanabe, Ozawa, & Nakamura, 2002). However, these studies have been single case studies with no experimental control, so it is difficult to generalize from the results.

Like SMS text messages, the use of a smartphone has been showed to hold promise for memory rehabilitation. Multiple studies have investigated how smartphone calendar reminders have been used as a compensatory memory strategy. Calendar reminders can be accessed via smartphone calendar function, email calendar, or google calendar (Baldwin & Powell, 2015; McDonald, Haslam, Yates, Gurr, Leeder, & Sayers, 2011). Ferguson (2015) conducted a study to determine if smartphone reminders help people complete pre-identified tasks and found a significant increase in task completion rates when smartphone prompts were present as compared with when they were absent. However, some drawbacks were the feeling of dependency and the additional stress for the participant receiving the reminders. For this reason, Evald (2015) conducted a study to investigate subjective satisfaction with and experiences of benefits and obstacles of using smartphones as a primary memory aid. Ten out of the thirteen participants (77%) stated that the reminder alarm sound and the visual pop-up messages helped them remember daily appointments and tasks (Evald, 2015). Having the capability to combine all personal communication and information into one assistive device, has shown to be effective in rehabilitation of PM. However, the risk of becoming dependent on the smartphone was reported by five participants (38%) (Evald, 2015). In addition to feelings of dependency, participants reported disadvantages such as risk of losing access to the information due to battery loss, or the loss of the device itself. Therefore, the advantages and disadvantages must be considered when smartphones are used by patients with BI as a compensatory memory strategy.

An alternative to carrying a handheld smartphone is receiving audiovisual reminders on the home television. Lemoncello et al. (2011) conducted a study that evaluated the Television Assisted Prompting (TAP) system as a novel assistive technology for cognition (ATC) device. The TAP system attaches to a person’s home television and allows for automated delivery of customized prompts such as reminders to complete daily activities. In this study, 23 participants experienced both the TAP condition and the typical practice (TYP) condition which instructs participants to carry out tasks using their typical methods, for two-week periods each. Lemoncello et al. (2011) found that the task completion was higher (72%) with TAP prompting than for TYP practice (43%). This suggests that when attention, memory, and executive function reminders are delivered through a familiar medium, the television, individuals with ABI will complete a greater number of tasks (Lemoncello et al., 2011).

The Voice Organizer, manufactured by Voice Powered Technology International, is a hand-held device that can be trained to recognize an individual's speech patterns, store messages, and replay messages dictated by its user. A study conducted by Van den Broek et al. (2000) examined the Voice Organizer's utility in the rehabilitation of PM impairment. Through a five-participant study, it was found that substantial improvements in PM functioning while using the Voice Organizer, as compared to the absence of any one. Additionally, it was found that the removal of the Voice Organizer resulted in a decline in performance for all subjects on both the Message-Passing task which required the subject to repeat four messages to their relatives after a 9-hour delay, and except for one subject for the Domestic task which required the subject to recall for tasks at prescribed times. Unfortunately, some limitations that the Voice Organizer obtains are that it cannot be used by those with significant expressive speech impairments, poor manual dexterity, or visual deficits (Van den Broek et al., 2000).

Current research demonstrates the promise of assistive technologies to help people with PM impairments (Baldwin & Powell, 2015; Gillette & DePompei, 2008; Kim, Burke, Dowds, Boone, & Park, 2000; Kirsch et al., 2004; Tam et al., 2003; Wong, Sinclair, Seabrook, McKay & Ponsford, 2016). However, high tech devices are still not widely used by many people with brain injuries who demonstrate deficits in PM (Evald, 2015; Evans, Wilson, Needham, & Brentnall, 2003). Identified barriers for long term use include problems with a range of device characteristics, such as being overly complex or having inaccessible interfaces (LoPresti, Mihailidis, & Kirsch, 2004; Stock, Davies & Gillespie, 2013), lack of training in their use (Wong, Sinclair, Seabrook, McKay & Ponsford, 2016) and especially cost, and fears of losing the device (Evald, 2015). This digital divide between those with access to mobile devices and those without (Gonzales, 2016) is seen in the BI community (e.g., Bryan, Carey, & Friedman, 2007; Newman, Browne-Yung, Raghavendra, Wood, & Grace, 2016). For a discussion of why technologies are used or not used see Scherer and Federici (2015). Thus, non-technological approaches are still needed.

Cognitive Symptom Management and Rehabilitation Therapy (CogSMART), developed by Twamley et al. (2014), is a 12-week compensatory cognitive training intervention that was shown to improve post-concussive symptoms, including sleep disturbance, fatigue, headaches, and tension. CogSMART includes modules with compensatory techniques for PM, attention, learning and memory, and executive functioning. The PM training included the use of to-do lists, a daily calendar, and learning to link "can't miss reminders" to tasks to be performed. Twamley et al. (2014) evaluated the CogSMART intervention through a study consisting of fifty veterans with mild to moderate TBI. Not only did the veterans who received CogSMART rated it highly with regard to helpfulness for post-concussive symptoms and PM strategies but researchers also found that there were significant reductions in self-reported post-concussive symptoms and improvements in real-world PM tasks (Twamley et al., 2014). In addition, the gains made in PM performance on CogSMART were maintained through the one-year follow-up (Twamley, Thomas, Gregory, Jak, Bondi, Delis, & Lohr, 2015).

Stringer developed the Ecological-oriented Neurorehabilitation of Memory (EON-Mem) which uses a treatment manual approach, standardized across patients and therapists, to train patients to compensate for memory impairment (Stringer, 2007). The EON-Mem program consists of a 4-step compensatory method, "Word, Organize, Picture, and Rehearse" (Stringer et al., 2011). Various modules were used to teach patients to apply this compensatory method to specific memory content. Stringer et al. (2011) designed a study to investigate the differential responses to EON-Mem from patients with all levels of memory impairment severity and diagnosis. It was found that the EON-Mem produced statistically significant improvements in everyday memory content regardless of the impairment severity (Stringer et al., 2011).

The most commonly used internal compensation technique for prospective memory deficits in people with acquired brain injury is visual imagery. Studies using visual imagery to improve PM have been designed not to learn to create images, per se, but to use image generation to increase awareness of when a cue arrives and a response is required. Kaschel et al. (2002) trained nine patients to use visual imagery to imagine themselves fulfilling the PM task at the correct time or to the correct cue. Individuals who received 20 sessions of the imagery training showed higher rates of keeping appointments than the control group of memory impaired patients who received standard memory rehabilitation strategies. Similarly, Potvin et al. (2011) used a five-stage training program to train individuals with BI to visualize cues in a PM task. They also reported that individuals with BI demonstrated improvements in PM in daily life. On a self-report measure of PM failures, a significant reduction in failures was reported following three months for the treatment group but not for the control group. Both Grilli and McFarland (2011) and Grilli and Glisky (2010) used a technique previously found to be effective in retrospective episodic memory recall to train individuals with neurological impairment in visual imagery techniques. They reported that self-imaging resulted in better PM performance and postulated that this is due to a superiority based on mnemonic mechanisms specifically related to the self. Mioni, Bertucci, Rosato, Terrett, Rendell, Zamuner, & Stablum (2017) used a technique they named future event simulation that appears to be similar to these visual imagery studies (i.e., using as many sensorial details as possible to imagine the sequence of events required to complete the PM task). This future event simulation strategy was demonstrated to improve PM in individuals with BI. Raskin et al. (2017) used a similar technique in a cross-over controlled design and demonstrated improvement in PM in individuals with BI using visual imagery. Moreover, treatment gains generalized to daily life and were maintained for one year after treatment was concluded.

The modified Story Memory Technique (mSMT) teaches the participants to utilize imagery by reading stories for which they are to remember target words and form mental imagery. Furthermore, participants are instructed to apply the mSMT to real-life memory tasks (Chiaravalloti, Dobryakova, Wylie, & DeLuca, 2015; Chiaravalloti, Sandry, Moore, DeLuca, 2016). Individuals in the treatment group demonstrated significant improvement on the memory task, objective measures of PM, and family report of disinhibition in daily life relative to the control group. These studies show that visual imagery has excellent promise. However, the studies have been of brief duration (only 10 sessions over 5 weeks), despite evidence from cortical plasticity that repetition over time is necessary for successful long-term change in brain organization (e.g., Kolb, Cioe, & Williams, 2011), and have not measured generalization to daily life.

Restorative Approaches. A restorative approach has the potential of improving functions in all aspects of a person's life, not just those directly trained. The theoretical basis of restorative approaches derives from studies of repetitive activity, which appear to facilitate neuroplasticity. That is, repeated use of a particular cognitive process should strengthen connections in the underlying neural circuitry and lead to an increase in the ability to perform that task (Kolb, Cioe, & Williams, 2011).

Sohlberg, White, Evans, & Mateer (1992a&b) reported on a case study of PM restoration with a person with BI. Using a within-participant repeated measures design they implemented repetitive practice, carrying out target tasks at increasingly longer time intervals. Measurement using probes to evaluate generalization revealed a steady increase in the person's PM span. However, the training and generalization data were somewhat ambiguous, as improvement occurred in both the experimental and control conditions. In a study by Raskin and Sohlberg (1996), participants with traumatic BI were required to execute actions at future designated times. This prospective memory training (PMT) involves giving a participant tasks to perform at specified times in the future, in which the length of time between task administration and task execution is systematically lengthened (Sohlberg & Raskin, 1996). Once the participant successfully completes five consecutive tasks in a row, the time interval is increased by one minute. Results supported the ability to increase participants' PM span. Participants improved on both naturalistic probes (e.g. laboratory tasks that simulated real-world tasks, such as "When this session is over, please remind me to call your physician") and performance in daily life by use of a diary study.

Metacognitive Strategies. Metacognitive strategies are designed to improve self-awareness or self-regulation. In a comprehensive review of the literature on executive function treatment, Kennedy et al. (2007) found substantial evidence from 11 intervention studies that training individuals with BI to use metacognitive regulation strategies improved problem solving, planning, and organization necessary for carrying out goal directed activity. An example of a metacognitive intervention pertinent to managing PM impairment is to provide individuals with reminders to self -regulate that can later be faded. Manly et al. (2001) presented participants with BI audible tones to cue them *to do the next task* in a series of 6 "hotel" tasks that were multifaceted and complex. A study conducted by Gracey et al. (2016) examined the efficacy of brief goal-directed rehabilitation paired with periodic SMS text messages to enhance executive monitoring of everyday intentions. While completing the Goal Management Training (Levine, et al., 2011) program, each participant received SMS text messages containing the acronym "STOP," indicating one to check the status of their intentions (Gracey et al., 2016). The authors suggested that the random occurrence of cues, SMS texts, prompted mental review of intentions that contribute to improved performance on tasks requiring attentive control of goal-directed behavior. In a similar study, Fish et al. (2007) and Fish et al. (2015) also performed a study evaluating an alerting strategy. The retrospective component of learning the task to be performed that was encoded under conditions of errorless learning with vanishing cues. Training in the PM task used a modified brief version of Goal Management Training (Levine et al., 2011). Twenty individuals with BI were sent a text message of "stop" at varying points during the day. The message carried no content information and was not sent at the time that the activity (calling a voicemail service) needed to be performed. Nevertheless, the authors reported improvement in PM performance on the days that the message was sent, with a medium to large effect size. This suggests that nonspecific cuing can lead to enhanced goal monitoring in these individuals.

Forming implementation intentions is described as a self-regulatory strategy (Gollwitzer & Brandstatter, 1997). Unfortunately, this strategy was not shown to improve PM performance in individuals with BI (Mioni, Rendell, Terrett, & Stablum, 2015). In this study, the outcome measure was the Virtual Week task. For the implementation intentions condition, participants were instructed to form an implementation intentions statement relating to the PM task presented. This involved reforming intention into the format of, when I (cue) I will (action) (e.g.,"when I eat lunch, I will take my medication") and were required to repeat the statement 3 times aloud.

Computerized approaches. Virtual reality computerized formats have also been utilized in studies of CRT. Matthews et al. (2016) and Mitrovic et al. (2016) used a combination of visualization and a virtual reality program with small numbers of participants who had had stroke over 10 sessions. They reported that individuals showed improvement on PM skills measured on the CAMPROMPT. Two studies used virtual reality training in individuals with stroke and measured performance in real-life settings. A 12-session virtual reality-based PM program was developed using a non-immersive form of virtual reality (VR), in which a virtual environment was generated and displayed through computers and LCD monitors (Yip et al., 2013). People with BI demonstrated improvements in behavioral assessments of performance in both the virtual environment and a real-life setting (Yip et al., 2013). In a similar study 20 participants with stroke were given 10 training sessions in how to use the local Mass Transit Railway stations. Participants were able to learn the transit system and showed transfer of training and increased scores on a measure of self-efficacy (Lam et al., 2006).

Combination approaches. Clinically, practitioners often combine the use of external compensatory aids and metacognitive strategies to address PM deficits in patients. Fleming, Shum, Strong, and Lightbody (2005) evaluated a multi-component intervention in three individuals with BI. These interventions included self-awareness training, teaching organizational strategies, and selection of a compensatory device (e.g., notebook, electronic diary). The authors reported an improvement in PM performance based on objective memory assessments. In a follow-up randomized controlled trial, with four groups of participants, the groups with compensatory PM training demonstrated greater improvement than those given self-awareness training alone (Shum, Fleming, Gill, Gullio, & Strong, 2011).

Rehabilitation strategies that have received the most attention are compensatory strategies, especially external explicit ones such as datebooks, calendars, and reminders. It seems appropriate to include these within any treatment regimen. There is some preliminary evidence that external, implicit strategies may also be effective, such as making tasks habitual or pairing intentions like taking medication to routine tasks such as meals. Of the internal strategies, visual imagery and rote rehearsal have shown the most promise and are each likely to be an effective tool with this population. Rote rehearsal has shown the greatest gains, although it also requires the longest treatment duration. Implementation intentions, which has shown promise in other populations, was not shown to be effective, perhaps because it requires intact executive monitoring.

Thus, a recommended treatment plan might include several sessions in identifying an appropriate compensation tool and training in its use. Then the inclusion of visual imagery with rote repetition could serve to increase overall PM performance. The final sessions would then focus on generalization of treatment to daily life using something like a diary study and perhaps some training in episodic future thinking.

The literature is difficult to interpret because many of the studies reviewed are single case studies or very small sample sizes. Only three could be considered randomized controlled trials. On the other hand, there is evidence that BI is so heterogeneous that randomized controlled trials may not be the best study design and that carefully controlled multiple case study designs might be more appropriate (Wilson, 1987). Future studies would be important that attempt, at least, to create individualized treatment programs based on the underlying nature of the PM deficit (i.e., a deficit in attention versus a deficit in time monitoring). Further, many studies reviewed used only a short duration of treatment or a low intensity of training (e.g., one hour per week). Research in cortical plasticity suggests that high intensity over a longer period is essential if restorative effects are to be achieved (Kolb et al., 2011).

Conclusions

PM is an important area of research in individuals with BI (e.g., Kliegel et al., 2008). PM has been shown to be related to activities of daily living, such as taking medications, attending appointments, and performing daily household duties (e.g., Raskin & Sohlberg, 2009), in addition to being needed in virtually all places of employment (e.g., Mateer, Sohlberg, & Crinean, 1987). Considerable research to date has helped to clarify the nature of PM deficits (e.g., Knight, Harnett, & Titov, 2005), the underlying neural substrates (e.g., Neulinger et al., 2015), and the component cognitive processes that predict PM performance (e.g., Kliegel et al., 2004). Attention, retrospective memory and executive functioning have been shown to be important components, although they do not necessarily predict accuracy (Pavawalla, et al., 2012). More research is needed to understand their individual contributions.

Individuals with BI have been consistently demonstrated to have superior event-based performance as compared to time-based performance (e.g., Raskin et al., 2011). However, more research is needed to better understand the relationship of variables such as time sense, future thinking and PM.

For example, although it has been documented that individuals with BI have dysfunction in time estimation (e.g., Schmitter-Edgecombe & Rueda, 2008), time sense in people with BI has not been systematically investigated for its role in successful PM performance to our knowledge, although preliminary data suggest that it plays a role (Raskin, 2003).

Similarly, episodic and semantic future thinking have not been systematically examined in individuals with BI (however see Rasmussen & Bernsten, 2012) and the relationship between future thinking and PM in this population could lead to interesting approaches to rehabilitation. For example, findings suggesting a relationship between them could suggest visual imagery techniques based on episodic future thinking.

It is also possible that the relationship between the cue and the intention to be performed will have a differential effect on PM performance in people with BI, given findings of an effect with aging and mild cognitive impairment (e.g., Pereira, Ellis, & Freeman, 2012a, Pereira, Ellis, & Freeman, 2012b; Pereira, de Mondonca, A., Silva, D., Guerreiro, M., Freeman, J., & Ellis, J., 2015). For example, on the MIST all items are intentionally highly related (e.g., when I hand you an envelope, please self-address it). This contrasts with items that are not related (e.g., when I show you a picture of an elephant, please touch your nose). Thus Cue-Intention Relation is another area of research that could lead to a greater understanding of the attentional processes underlying PM deficits in people with BI as well as rehabilitation strategies.

There are currently several available measures of PM. Between them most clinicians should be able to find a measure that is appropriate for their individual setting. Findings of deficits in individuals with BI and the relationship to activities of daily living and quality of life suggest that this is an area that should be assessed more consistently in clinical neuropsychological evaluations.

CRT that focuses on compensatory devices have been found to be effective and the format can be easily tailored to an individual's needs, abilities and resources. Various electronic pagers and smartphones are becoming increasingly available. More research would be helpful in elucidating the best ways to train individuals in their use, similar to techniques designed for training the use of notebooks.

More careful research is needed on restorative techniques that show promise both in improving PM in the laboratory but also in daily life. Computerized programs, like Virtual Week, may show promise for individuals with BI, as it has been shown to be helpful as a training technique in people with in older adults (Rose, Rendell, Hering, Kliegel, Bidelman, & Craik, 2015). Other computerized approaches could be created that would allow participants to augment treatment sessions with at home sessions and can be programmed to be responsive to systematically increase difficulty as the participant improves. Computer programs can also take advantage of virtual reality environments to approximate everyday scenarios.

It will be important to evaluate subgroups of people with BI to determine if certain treatments are more effective depending on level of severity or on the constellation of symptoms (e.g., attention deficits versus executive function deficits). For example, for those with attention deficits, Attention Process Training (Raskin & Palmese, 2000; Sohlberg, et al., 2000) might be the first treatment applied. For those with primary executive function deficits Goal Management Training (Levine, et al., 2011) might be more effective. Some potential approaches that have not been investigated include time estimation training, training using systematically reduced cue-intention pairing, training using systematically reduced cue focality, use of enactment, or systematically increasing the cognitive load or items to be held in memory (Raskin, Race & Aiken, 2017). The optimum duration and intensity of treatment also needs to be determined.

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*indicates article obtained through systematic screening

Table 1. Self-Report Measures

Name of Measure	Number of Items	Scales	Languages Available	Publication with ABI
Prospective Memory Questionnaire	52	Long-term episodic Short-term habitual Internally cued Techniques to assist memory scale	English	Hannon et al., 1995 Raskin et al., 2011
Prospective and Retrospective Memory Questionnaire	16	Prospective Memory Retrospective Memory	English, Chinese, Dutch, Finnish, French, German, Greek, Hindi, Italian, Japanese, Korean, Malay, Portuguese, Romanian, Spanish, Swedish, Tamil, Turkish	Huckans et al., 2010 Jamieson et al., 2015
Comprehensive Assessment of Prospective Memory	54	Frequency of Forgetting Perceived Importance of Lapses Perceived Reasons for Forgetting	English, Chinese	Raskin, et al. 2017 Roche, Fleming & Shum, 2002 Roche et al., 2007 Fleming, et al., 2008 Huang et al., 2014

ABI-acquired brain injury

Table 2. Clinical Measures of Prospective Memory

Measure	Type of Cues	Time Delay	Time to Administer	Alternate Forms	Languages Available	Psychometric properties	Publications with ABI
CAMPROMPT	Time and Event	7, 13, and 20 minutes	30 min	1	English, Chinese	Wilson et al., 2005	Groot, et al., 2002 Fish et al., 2007 Man et al., 2015 Fleming et al., 2008
MIST	Time and Event; Action and Verbal	2 and 15 minutes; 24 hour	30 min	4	English, Spanish, Chinese, Czech, Italian	Woods et al. 2008 Raskin, 2009	Raskin et al., 2017 Raskin et al., 2012 Tay et al., 2010
Virtual Week	Time and Event; Regular and Irregular	Varies but includes 2 minutes 30 seconds and 4 minutes 15 seconds	20 min	2	English, Italian, Farsi	Rendell & Craik, 2000 Rendell & Henry, 2009	Mioni et al., 2013 Mioni et al., 2015 Mioni et al., 2017
Royal Prince Alfred Prospective Memory Test	Time and Event	15 minutes and 1 week	10 min	3	English	Radford et al., 2011	Radford et al., 2011

ABI-acquired brain injury

Figure 1. PRISMA flow diagram of literature search for prospective memory and brain injury. The PRISMA flow diagram depicts the flow of information throughout the different phases of this systematic review. It includes the number of records identified, included and excluded and the reasons for exclusions