Older Adults with Mild Traumatic Brain Injury: Naturalistic Approaches, including Augmented Reality, for Assessment of Prospective Memory Outcome

Submitted by

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Summary of Current Publication Status of each Article in this Thesis

The alternative thesis format is used in this Doctor of Psychology thesis and adheres to the requirements outlined by La Trobe University (**Appendix A**). The thesis is centred around two published and one submitted journal article (currently under review). This format was chosen as it allows for the publication of work conducted during candidature and facilitates the dissemination of results with the wider research community. The first three chapters provide an overview of the relevant literature. This is followed by an outline of the current research aims and research questions. The empirical work is presented across three chapters and consists of manuscripts that have been published or are currently under review. The methodology is contained within each study. An additional methodological chapter is provided for the augmented reality task developed as part of this thesis (Chapter 6).

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List of Abbreviations

ACRM	American Congress of Rehabilitation Medicine
AR	Augmented reality
CAMPROMPT	Cambridge prospective memory test
cmTBI	Complicated mild traumatic brain injury
CT	Computed tomography
DTI	Diffusion tensor imaging
GOS	Glasgow Outcome Scale
GOSE	Glasgow Outcome Scale-Extended
HOA	Healthy older adults
LIST	LaTrobe Itemised Shopping Task
LOC	Loss of consciousness
MRI	Magnetic resonance imaging
mTBI	Mild traumatic brain injury
OC	Orthopaedic controls
OI	Orthopaedic injury
PM	Prospective memory
PRMQ	Prospective and retrospective memory questionnaire
PTA	posttraumatic amnesia
TBI	Traumatic brain injury
VR	Virtual reality
WHO	World Health Organisation
XR	Extended reality

Abstract

Mild traumatic brain injury (mTBI) in older adults is a growing public health concern, yet there is limited research assessing cognitive outcomes in this population. Prospective memory has been identified as an index of everyday cognition for older adults and a potentially useful tool for identifying patients at risk of impairment after mTBI. However, traditional prospective memory tasks have limited ecological validity and naturalistic style tasks, such as augmented reality (AR), may provide a viable alternative. As such, the aim of this research is to investigate prospective memory in older adults after mTBI using naturalistic approaches of assessment. Study 1 explored the relationship between subjective and objective prospective memory measures in healthy older adults (*n* = 43), with medium sized associations found between self-report and performance on a naturalistic task. Study 2 assessed prospective memory performance in older adults three months following mTBI (*n* =39) and orthopaedic injury (*n* = 63), together with community controls who had not sustained an injury (*n* = 46). The mTBI group performed significantly lower than controls on an augmented reality (AR) prospective memory task, the LaTrobe Itemised Shopping Task (LIST). Retrospective memory and executive function were also found to moderate the relationship between severity of brain injury and prospective memory. Study 3 examined the validity of the LIST with healthy older adults (*n* = 46) and a mixed trauma group (*n* = 102). The findings provide preliminary evidence of validity and demonstrates the usefulness of AR assessments. Overall, this research indicates that older adults may experience cognitive challenges three months after mTBI and naturalistic approaches, such as AR tasks, may be a superior method in which to detect these difficulties.

Statement of Authorship

This thesis includes work by the author that has been published or submitted for publication as described in the text. Except where reference is made in the text of the thesis, this thesis contains no other material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

The articles reported in this thesis (Chapters 5, 7 & 8) involve the work of joint authorships and collaboration. In all instances, I am the primary author and have made the most substantial contribution to the work presented. Additional authors have also contributed to the presented work. Professor Glynda J. Kinsella and Dr Bradley Wright provided research supervision and contributed to the design of each study, selection of materials, choice of statistical methodology, and reviewed drafts of the articles. Professor Biswadev Mitra contributed to the design of the larger mild traumatic brain injury project (Chapters 7 and 8) and reviewed drafts of the articles. Camilla Hume assisted with participant screening, data collection, and file management for Studies 1, 2 and 3. The estimated collective contribution of all other authors to the articles presented is less than 30%.

The research procedures used in Study 1, 2 and 3 were approved by the Alfred Hospital (**Appendix B**) and La Trobe University ethics committees (**Appendix C**) (project ID 382/15). This work was supported by an Australian Commonwealth Research Training Scheme fees offset scholarship and La Trobe University Postgraduate Research Scholarship. No conflicts of interest are reported.

Signed:

Lei Gryffydd

Dated: 9 July 2021

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I wish to thank my associate supervisor, Professor Biswadev Mitra for his assistance in undertaking this research and acknowledge the vital role Professor Mitra, together with The Alfred Hospital and National Trauma Research Institute, played in the recruitment of the trauma participants in this research. I am also appreciative of Professor Mitra's help exploring additional recruitment pathways. I thank Dr Stephen Lee for his contribution in the early stages of the development of the LaTrobe Itemised Shopping Task.

I would like to extend my gratitude to all the participants who volunteered their time and energy to this project. The assistance of Camilla Hume with recruitment and data collection is also acknowledged with immense gratitude. Lastly, thank you to my family and friends for their support and encouragement.

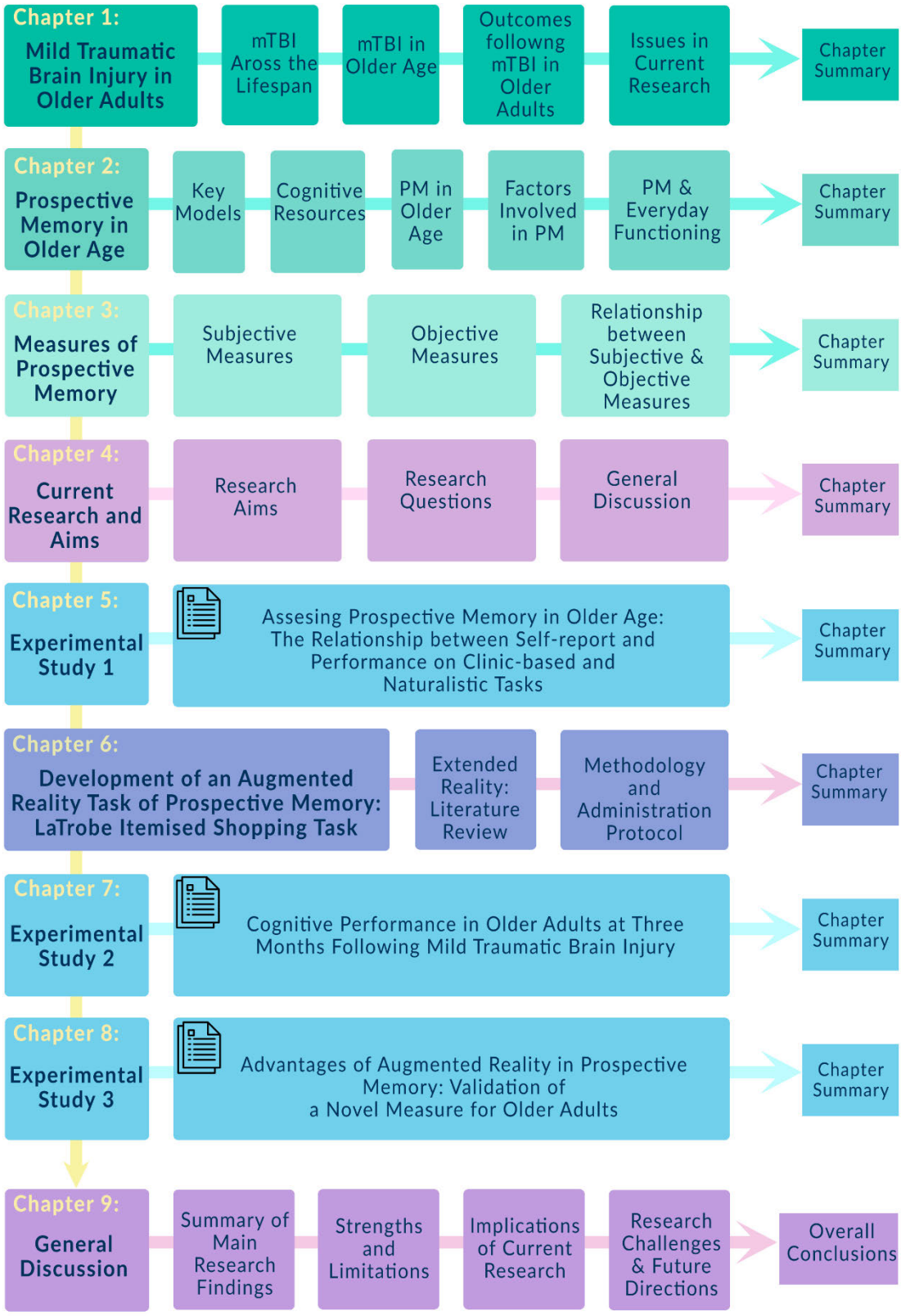
Thesis Outline

This thesis consists of nine chapters, three of which contain publications. Due to journal publication requirements, there may be overlap or repetition regarding the research background and primary themes. The reference lists are placed at the end of each chapter and only contain references relating to that chapter or published article.

The first chapter of this thesis reviews the literature regarding mild traumatic brain injury (mTBI), with a focus on older adults. In Chapter 2, an overview of prospective memory (PM) is provided before PM measures are discussed in Chapter 3. In Chapter 4, the research aims and questions for the present research are outlined. The results from the first experimental study are presented in Chapter 5, which examined the relationship between subjective and objective PM in healthy older adults. Chapter 6 outlines the development of an augmented reality task of PM, the LaTrobe Itemised Shopping Task (LIST). This is followed by experimental Study 2 (Chapter 7), an investigation of PM performance in older adults following mTBI. Chapter 8 contains experimental Study 3, an evaluation of the validity of the LIST for use with older adults. Lastly, the findings of the three studies are discussed in Chapter 9, the general discussion, together with implications and suggestions for future research. Overall, the current work suggests older adults may experience cognitive difficulties three months following mTBI and naturalistic style measures of PM, particularly augmented reality, may be a useful tool for assessing older adults.

The flow chart below depicts a visual representation of the thesis outline.

Thesis Outline



Note. PM = Prospective Memory; mTBI = Mild Traumatic Brain Injury

Chapter 1 Mild Traumatic Brain Injury in Older Adults

1.1 Chapter Overview

This chapter presents an overview of mild traumatic brain injury (mTBI) in older age by first discussing mTBI across the lifespan, before focusing on older age in detail. After outlining the current literature in this area, methodological factors and considerations for future research will be presented.

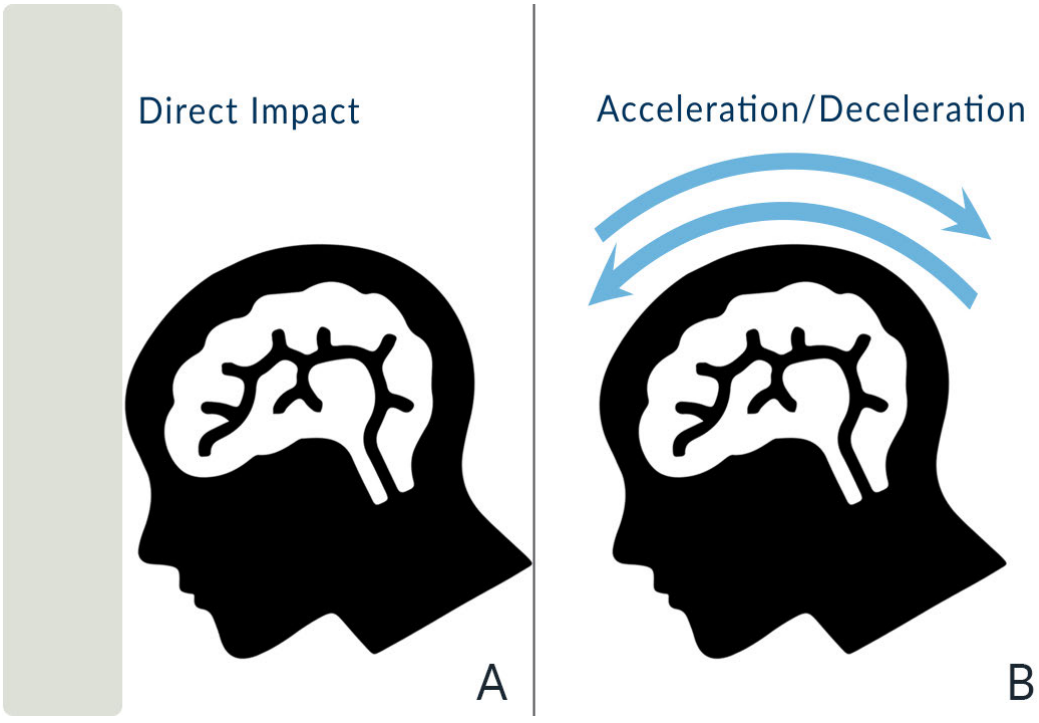
1.2 Mild Traumatic Brain Injury Across the Lifespan

1.2.1 *Definition of Mild Traumatic Brain Injury*

Traumatic brain injury (TBI) is defined as an acute injury resulting from mechanical force to the head (Kristman et al., 2014), as illustrated in Figure 1.1. Such trauma can vary in severity and guidelines have been published to define the categories of injury, i.e., very severe, severe, moderate, and mild (Menon et al., 2010; Savitsky et al., 2016).

Figure 1.1

Illustration of Mild Traumatic Brain Injury



Note. Image A shows direct impact injuries which typically occur from falls. Image B depicts acceleration/deceleration injuries which are often caused by motor vehicle accidents.

Mild TBI (mTBI) accounts for approximately 70 to 90% of trauma cases presenting to hospital emergency departments (Cassidy et al., 2004) and yet has been the most contentious in terms of definition and outcome (Carroll et al., 2004b; Lefevre-Dognin et al., 2021; Levin & Diaz-Arrastia, 2015; Mayer et al., 2017). After inconsistency in the reporting and operationalisation of mTBI in the past, an International World Health Organisation (WHO) Working Group (Carroll et al., 2004b) proposed guidelines for classifying mTBI, which have been subsequently revised by the International Collaboration on Mild Traumatic Brain Injury Prognosis (Kristman et al., 2014), including three main indices of criteria: Glasgow Coma Scale (GCS), duration of loss of consciousness (LOC) and posttraumatic amnesia (PTA). The specific criteria are provided in Table 1.1.

Table 1.1

International Collaboration on mTBI Prognosis Operational Criteria for mTBI

Definition and Criteria for mTBI
(1) One or more of the following symptoms: (i) confusion or disorientation (ii) loss of consciousness (LOC) ≤ 30 minutes (iii) posttraumatic amnesia (PTA) for < 24 hours (iv) other transient neurological abnormalities (e.g., focal signs, seizure, and intracranial lesion not requiring surgery)
2) Glasgow Coma Scale (GCS) score of 13 to 15 by 30 minutes post-injury or later upon presentation for health care
3) Symptoms are not due to drugs, alcohol, medications, caused by other injuries or treatment for other injuries (e.g., intubation), caused by other problems (e.g., psychological trauma, language barrier, co-existing medication condition), or caused by penetrating craniocerebral injury

Note. Definition and specific criteria for mTBI proposed by the International Collaboration on mTBI Prognosis (Kristman et al., 2014).

These are useful guidelines, but they can be difficult to follow. Furthermore, Levin and Diaz-Arrastia (2015) raise valid concerns regarding the reliance on recall of the event and subjective reporting of LOC, PTA, and other symptoms in unwitnessed

injuries; and Gasquoine (2020) contends that duration of loss of consciousness be removed from definitions of mTBI due to the potential for confusion and reliance on the observation of others. However, it has also been suggested that diagnostic criteria should capture individuals with mTBI who may initially present with only subjective symptoms (Silverberg et al., 2021). Reviews of the literature indicate the diagnostic criteria for mTBI remains fragmented (Lefevre-Dognin et al., 2021; Mayer et al., 2017). Given the impact this has on research and clinical practice, the American Congress of Rehabilitation Medicine (ACRM) definition for mTBI (an additional international set of guidelines) is currently being updated (Silverberg et al., 2021).

One of the challenges within this field is the wide range of severity within the mTBI diagnostic framework and inconsistent use of neuroimaging (Lefevre-Dognin et al., 2021). Although the guidelines proposed by Kristman et al. (2014) include patients with intracranial trauma on neuroimaging not requiring neurosurgery, the inclusion of these patients (often referred to as complicated mTBI; or cmTBI) is a contentious issue. Levin and Diaz-Arrastia (2015) argue that patients with cmTBI should be considered "moderate" TBI and Servadei et al. (2001) propose excluding patients with GCS of 13 as the risk of intracranial lesion is similar to those with moderate TBI. More recently, the ACRM mTBI Task Force found experts strongly endorse evidence on computed tomography (CT) or magnetic resonance imaging (MRI) scans as indicative of mTBI diagnosis (Silverberg et al., 2021), implying that this criterion will remain in the updated definition of mTBI. At a local level, the International Collaboration on mTBI Prognosis guidelines (Kristman et al., 2014) has been found to be robust in identifying acute mTBI cases presenting to an emergency department in Australia (Pozzato et al., 2020) and at present, provide an appropriate operational definition of mTBI for ongoing research.

1.2.2 *Pathophysiology*

There is debate over whether pathophysiology is generally observed following mTBI. Historically, negative neuroimaging findings were considered characteristic of mTBI (Alexander, 1995). Athletes with positive findings on standard neuroimaging studies are excluded from The International Conference on Concussion in Sport

guidelines (McCrory et al., 2017), while these cases are classified as moderate TBI by the Department of Defence diagnostic criteria (2015). In general mTBI populations, a proportion of patients will have visible macrostructural changes on CT scans and the most common traumatic lesions are cerebral contusions, subdural hematomas, and subarachnoid haemorrhages (Isokuortti et al., 2018). Older age, falls, chronic alcohol abuse and lower GCS have been associated with a higher risk of intracranial lesions after mTBI (Isokuortti et al., 2018). Diffuse Tensor Imaging (DTI) has been found to be more sensitive to detecting microstructural changes which may not be detected on CT or MRI scans (Shenton et al., 2012), such as diffuse axonal injuries; the straining and shearing of the axons from the acceleration and deceleration of mechanical force in TBIs (e.g., from a strike to the head) (Eme, 2017). These have been suggested as a potential diagnostic criterion for mTBI (Smith & Stewart, 2020). Studies have also identified cerebral changes in patients after mTBI, including reduced brainstem volume (Kim et al., 2021) and white matter microstructural changes (Oehr et al., 2021). Even one year after injury, patients with mTBI have been found to have reduced prefrontal grey matter and lower fractional anisotropy in the anterior corona radiata and internal capsule (Dean et al., 2015). Oehr and Anderson (2017)'s review of DTI research identified associations between injury-related, structural neuropathology and cognition after mTBI. This suggests that the neural disruption associated with mTBI may potentially explain cognitive changes, at least in the acute phase of recovery.

1.2.3 *Complicated Mild Traumatic Brain Injury*

Approximately 5 to 20% of patients with mTBI are estimated to have evidence of intracranial trauma on imaging (Silverberg et al., 2020; Young, 2020). While some argue that cmTBI is associated with worse outcomes than those with uncomplicated mTBI (Levin & Diaz-Arrastia, 2015), the literature is variable. When compared to uncomplicated mTBI groups, cmTBI groups have been reported as having worse cognition in the early stage of recovery (Borgaro et al., 2003; Kurca et al., 2006; Lange et al., 2009). Furthermore, cmTBI and moderate TBI groups have also been found to have similar neuropsychological and functional outcomes at discharge (Kashluba et al., 2008),

three to six months (Voormolen et al., 2020), one year (Kashluba et al., 2008; Van Der Naalt et al., 1999) and long-term (Temkin et al., 2003). In contrast, other studies have reported no association between intracranial trauma and neuropsychological outcomes (Iverson, 2006; Lee et al., 2008; Panenka et al., 2015) or post-concussion symptoms (McCauley et al., 2001). The International Collaboration on mTBI Prognosis summarised, that from reported evidence, CT does not reliably predict early cognitive impairments, with only small to moderate effect size associations (Carroll et al., 2014). In support of this position in older adults specifically, patients with cmTBI did report poorer functional ratings at one week (Karr et al., 2020a) and 12 months post-injury (Nelson et al., 2019), but Nelson et al. (2019) also reported no cognitive differences between cmTBI and mTBI groups at 12 months. Taking into account the overall mixed evidence, and also the advancing techniques for detecting trauma-related pathophysiology (Oehr & Anderson, 2017; Oehr et al., 2021), a potential strategy for current mTBI research is to include patients with cmTBI and then undertake secondary analyses to determine if the presence of intracranial trauma is associated with reduced cognitive performance.

1.2.4 *Incidence and Prevalence*

mTBI is the most common subtype of TBI (60 to 95%) (Cassidy et al., 2004; Maas et al., 2017), with an estimated 42 to 55 million people per year worldwide (Dewan et al., 2019; Mayer et al., 2017). In Australia, mTBI cases accounted for 1.2% of attendances to an Emergency Department over a nine-month period (Pozzato et al., 2020). There are likely double this number in the wider community (Cassidy et al., 2004), given many patients with mTBI present to other health facilities, such as general practitioners, or are not seen at all (Boussard et al., 2014). Epidemiological studies have found it challenging to quantify the global impact of TBI due to a number of methodological challenges (Pozzato et al., 2020), including varying classification of mTBI (Maas et al., 2017). However, there does appear to be consensus regarding the increasing rates of people presenting to emergency departments with mTBI (Cancelliere et al., 2017), particularly in paediatric and older age populations (Lefevre-Dognin et al.,

2021). Higher rates of males are reported in younger cohorts, while higher rates of females are found in older age (Brazinova et al., 2021).

1.2.5 *Mechanism of Injury*

Falls have been reported as the leading cause of mTBI in the US and other high-income countries (Cancelliere et al., 2017; Faul et al., 2010; Skandsen et al., 2018), especially for young children and adults aged 65 and over (Faul et al., 2010; Taylor et al., 2017). Overall, motor-vehicle-accidents are the second most common cause of injury and the leading cause of TBI for young adults (15- to 34-year-olds) (Taylor et al., 2017). Furthermore, they have been the leading cause of TBI-related death in the US, with the highest rates for young adults (Faul et al., 2010). However, more recently, there has been a reported decline in deaths due to traffic-related TBIs and an increase in deaths from fall-related TBIs (Maas et al., 2017), in correspondence with a shift from motor-vehicle-related TBIs to fall-related TBIs per se (Brazinova et al., 2021). These findings demonstrate that fall-related TBIs are a growing global concern.

1.2.6 *Outcomes*

In the early stages, patients with mTBI can experience a wide range of symptoms: (i) physical symptoms (eg., headaches, dizziness, fatigue, and sleep disturbances); (ii) cognitive difficulties (e.g., memory, attention, and executive difficulties); and (iii) emotional symptoms (e.g., anxiety, depression, and irritability) (American Congress of Rehabilitation Medicine, 1993). It has been estimated that one out of five patients with mTBI will experience symptoms that persist for longer than a month (Silverberg et al., 2020). Given the diverse range of symptoms associated with mTBI, outcomes can be divided into the key domains of functional, psychological, and cognitive.

General Functional Outcome. Most of the research investigating outcomes following mTBI use the Glasgow Outcome Scale (GOS) or the Glasgow Outcome Scale-Extended (GOSE), as an index of functional outcome. In a recent study by Falk et al. (2021), 58% (*n* = 205) of patients with mTBI were found to have incomplete recovery on the GOSE at one-month post-injury. In an earlier study by Dikmen et al. (2017), only

patients with cmTBI had functional limitations on the GOS one-month post-injury and patients with mTBI were comparable to controls. Research has also reported that approximately one third of patients with mTBI will be rated as having incomplete recovery on the GOSE at three months (McMahon et al., 2014) and six months post-injury (van der Naalt et al., 2017). Poor quality of life and neurological symptoms may persist two years after mTBI (Carroll et al., 2020), with 28% reporting incomplete recovery on the GOSE at two years after mTBI (Carroll et al., 2020), and reduced community participation four years after mTBI (Theadom et al., 2018). However, the large majority will return to work/normal activities within one year of injury (Losoi et al., 2016). Early identification of the significant minority who will experience ongoing symptoms following mTBI is important for proactive patient management (see risk factors below).

Psychological Outcome. Patients commonly experience psychological symptoms in the acute phase after mTBI and these tend to resolve quickly for most patients (Perry et al., 2016), with Panayiotou et al. (2010)'s review detecting only small effect sizes for emotional symptoms related to mTBI. However, some studies report that approximately 15 to 25% of patients experience symptoms of depression in the first year after mTBI (Lucas et al., 2016) and higher symptoms of depression than controls long-term (Konrad et al., 2011). In TBI cohorts of heterogenous severity, at one-year post-injury approximately 26-30% reported clinical levels of depression (Bombardier et al., 2016; Hart et al., 2011) and 22% reported mild depression (Hart et al., 2011). Characteristics associated with levels of depression included gender (female), age (younger), cause of injury (intentional) (Hart et al., 2011), pre-existing mental health conditions, and substance and/or alcohol abuse (Bombardier et al., 2016; Hart et al., 2011). Pre-existing psychological conditions have been identified as a risk factor for the presence of psychological symptoms after mTBI in both adults (Silverberg et al., 2020; Stein et al., 2019) and paediatric populations (Emery et al., 2016).

Post-concussive Syndrome. Post-concussive syndrome (PCS) has been a term applied when a constellation of symptoms (physical, cognitive, and psychological) persists for more than three months after sustaining a mTBI. Some researchers and

clinicians have argued that PCS may initially be related to acute cerebral dysfunction, but over time becomes compounded by the psychological consequences of head trauma (King, 2003; Mittenberg & Strauman, 2000). However, similar to the diagnostic criteria of mTBI, there is a significant amount of variability in the literature regarding PCS (Young, 2020), including recognition that the symptoms of PCS (fatigue, anxiety, and poor concentration, for example) can also be observed in other non-head injured trauma groups, such as orthopaedic patients (Losoi et al., 2016; Perraut et al., 2020; Ponsford et al., 2011). As such, the prevalence of PCS is difficult to ascertain, though research suggests rates from 11.4% to 38.7% (Voormolen et al., 2018). From the considerable literature investigating PCS, a range of risk factors such as pre-injury psychological issues (Broshek et al., 2015; Ponsford et al., 2012; Ponsford et al., 2019), pre-injury physical health (Ponsford et al., 2012) and coping style (Anderson & Fitzgerald, 2018) have been identified which may assist in the management of patients vulnerable to ongoing difficulties.

Cognitive Outcome. Early research studies suggested the symptoms of mTBI include acute, transient cognitive inefficiencies, which typically resolve within three months (Mittenberg & Strauman, 2000). For example, early changes in attention, memory and executive function are reported (Sussman et al., 2018). Research indicates most cognitive deficits are only present in the first two weeks post-injury (Carroll et al., 2014) and for most individuals, cognitive recovery occurs within three months post injury (Carroll et al., 2004a; Frencham et al., 2005; Karr et al., 2014; Rohling et al., 2011). Research assessing cognition in the acute stage of mTBI (within 24 hours) have reported impairments in memory (de Freitas Cardoso et al., 2019; Kannan et al., 2019; Lecuyer Giguere et al., 2019), language (Lecuyer Giguere et al., 2019), and executive functioning (de Freitas Cardoso et al., 2019). While considerable research has been conducted investigating prospective memory (PM) in patients with more severe TBI (Mioni et al., 2014; Wong Gonzalez & Buchanan, 2019), PM difficulties have also been observed in patients one month (Tay et al., 2010) and approximately two months after mTBI (Lajeunesse et al., 2019). While cognitive symptoms have also been reported by patients

two to four years after mTBI (Carroll et al., 2020; Theadom et al., 2018), emotional, and somatic symptoms have been linked to self-reported cognitive concerns (Stenberg et al., 2020). This demonstrates the need for objective measurement of cognition, rather than self-reports. In summary, individuals with mTBI may experience cognitive difficulties, but these generally resolve by three months (Carroll et al., 2004a; Carroll et al., 2014; Frencham et al., 2005; Karr et al., 2014; Rohling et al., 2011). However, there are risk factors, and a minority of people will continue to experience cognitive difficulties three months after mTBI.

1.2.7 *Risk Factors*

Risk factors can inform clinical practice to assist in the prevention and reduction of adverse outcomes for patients. For example, health initiatives for individuals at risk of sustaining an injury and targeted treatment post-injury for vulnerable patients. Past research has identified sociodemographic characteristics (younger males) (Brazinova et al., 2021; Cassidy et al., 2004), alcohol and substance abuse (Bombardier et al., 2002; Nordstrom et al., 2013; Olson-Madden et al., 2012; Taylor et al., 2003), occupation (e.g., defence members) and sports activity (Bachynski & Goldberg, 2014; Cassidy et al., 2004; Laker, 2011) as potential risk factors for sustaining a mTBI. Genetic risk factors for sustaining a mTBI have also been explored (Panenka et al., 2017).

A range of risk factors for poor outcomes have also been suggested, including pre-existing medical conditions (Yue et al., 2019), reduced resilience (McCauley et al., 2013) and avoidant coping profiles (Maestas et al., 2014). A previous psychiatric history is a primary risk factor for adverse outcomes after mTBI (Booker et al., 2019; Lingsma et al., 2015; Ponsford et al., 2019; Scheenen et al., 2017; Silverberg et al., 2020; van der Naalt et al., 2017) and negatively predicts functional outcome after TBI (Falk et al., 2021; Ritter et al., 2021). Experiencing psychological symptoms early in the recovery phase has been linked to reduced cognition (Terry et al., 2019), including memory (Holthe et al., 2019), as well as functional limitations (van der Naalt et al., 2017) and greater symptoms (e.g., fatigue, insomnia, depression) at six months post-injury (Losoi et al., 2016).

Clearly, the relationship between psychological symptoms and outcomes after mTBI is complex.

Research has found intoxication at the time of injury negatively impacts GCS scores (Schutte & Hanks, 2010; Uccella et al., 2020), thus making it difficult to assess level of consciousness after mTBI. Unfortunately, a large proportion of adults (approximately 45%) are under the influence of alcohol at the time of injury (Skandsen et al., 2018). Alcohol at time of injury can impact functional recovery (Yue et al., 2017) and has been linked to negative outcomes in trauma patients, including mortality (Wang et al., 2021). A history of alcohol and/or substance use has may also be associated with worse cerebral outcomes, including enlarged cerebral ventricles and reduced hippocampal and grey matter volumes (Unsworth & Mathias, 2017).

Age is another of risk factor for poor outcomes after mTBI (Jacobs et al., 2010; Lingsma et al., 2015; Rabinowitz et al., 2015; van der Naalt et al., 2017), with higher rates of mortality (Cheng et al., 2014), and associated with the presence of intracranial trauma, even in those with GCS of 15 (Uchino et al., 2001). Accordingly, older age patients may be particularly vulnerable to adverse outcomes after mTBI and further investigation into this age group is warranted.

1.3 mTBI in Older Age

Older adults are the fastest growing group in the population to experience TBI (Peeters et al., 2015) and have the highest rates of TBI-related hospitalisation and death (Faul et al., 2010; Gardner et al., 2018). Given the worldwide number of older people is expected to triple in the next 40 years (World Health Organisation, 2018), the incidence rates are likely to only increase, suggesting a growing public health crisis (Peters, 2020). Older adults have a higher risk of developing a significant intracranial injury, such as subdural and epidural haematoma (Rathlev et al., 2006). Accordingly, older adults who have experienced TBI, especially mTBI, will require closer consideration in future research studies. Falls are the leading mechanism of injury for TBI in older adults (Cusimano et al., 2020; Hawley et al., 2017; Taylor et al., 2017), the majority of which occur on the same surface level and at home (Harvey & Close, 2012; Hawley et al.,

2017). Furthermore, there are increasing rates of fall-related TBIs for both genders (Cusimano et al., 2020).

1.3.1 *Risk Factors for Older Adults*

In addition to general risk factors for TBI, there are several risk factors unique to older adults which may impact the likelihood of a traumatic event or the outcome post-injury. Factors which increase the likelihood of sustaining a fall-related TBI, include increasing age, poor premorbid health (Kristman et al., 2016) and a higher number of comorbidities (Fu et al., 2017; Karr et al., 2020b), especially mild cognitive impairment and dementia (Seno et al., 2019; Teo et al., 2018) or impaired vision (Thompson et al., 2012). More generally, older adults with TBI are likely to have at least one premorbid condition (Thompson et al., 2012); and, notably, those who have sustained a trauma are at increased risk of subsequent injury (McGwin et al., 2001). High medication use is also a risk factor for falls in older people (Fu et al., 2017; Teo et al., 2018). These medications include pain medication (Yoshikawa et al., 2021), sedatives and hypnotics, antidepressants, anti-inflammatory drugs, and benzodiazepines (Woolcott et al., 2009). Additionally, the combination of these medications may negatively impact the central nervous system which in turn increases the risk of falls (Stocchetti et al., 2012). In other words, the medications prescribed to older adults for comorbidities can increase their risk of having a fall, which in turn may result in a mTBI.

In terms of outcomes, despite less severe injuries based on GCS, older adults have been found to demonstrate greater intracranial trauma than younger adults on CT imaging (Kehoe et al., 2015). Trauma effects include an increased risk of cerebral microbleeds (Toth et al., 2020), and subdural and intracerebral hematomas (Karibe et al., 2017; Rathlev et al., 2006). This cerebral fragility has been linked to age-related structural changes, namely the pulling and weakening of cerebrovascular structures from the dura becoming more adherent to the skull as one ages (Flanagan et al., 2005; Karibe et al., 2017; Thompson et al., 2006) and brain volume shrinkage (Fjell & Walhovd, 2010). Medications, such as anti-coagulants and antiplatelet agents, are also believed to increase the risk of a brain bleed from blunt trauma and worsen cerebral damage (Peck

et al., 2014; Stocchetti et al., 2012). The potential for reduced pre-injury cognitive reserve due to ageing or co-morbidity is another risk factor which may influence post-injury cognition (Schneider et al., 2014). Cognitive reserve has been suggested as a potential protective mechanism in the context of TBI, whereby patients with higher pre-existing cognitive functioning have demonstrated better memory skills following TBI than those with lower cognitive reserve (Krch et al., 2019). However, this relationship was only found in patients at the milder range of severity and not evident in patients who had experienced a severe TBI. This implies that older adults with lower premorbid cognitive capacity have an increased risk of cognitive impairment following mTBI.

1.4 Outcomes following mTBI in Older Adults

1.4.1 *General Functional Outcome*

To date, research has primarily focused on functional outcomes in older adults after mTBI, using clinical instruments such as the GOS and GOSE. Compared to younger adults, equivalent outcomes have been reported (Richey et al., 2020), as well as instances of older adults reporting better outcomes than younger cohorts (Peters et al., 2018; Rapoport & Feinstein, 2001). In a study by Karr et al. (2020a) of adults (≥55 years of age) with complicated mTBI, uncomplicated mTBI and mild head injury (patients who were not referred for CT scans), 56.1% had functional limitations on the GOSE at one week post injury. Although, as noted by the authors (Karr et al., 2020a), the sample included patients with reduced pre-morbid functioning (e.g., with dementia and neurological conditions), which limits the interpretation of the results. However, Kristman et al. (2016) reported similar results, with 59.2% of older adults having incomplete recovery on the GOSE shortly after mTBI and 20.4% having incomplete recovery at six months. More recently, Abdulle and van der Naalt (2020) found that most older adults recovered completely on the GOSE at six months post-mTBI, but 44% did report incomplete functional recovery on the GOSE which persisted one to three years later (Abdulle et al., 2018). At three months, older adults with mTBI have reported significantly lower physical quality of life than community controls and on par with those who had sustained an orthopaedic injury (Kinsella et al., 2014a). However, Kristman et al. (2016)

observed significant improvements in mental and physical quality of life by six months post-injury. Overall, Hume et al. (in press)'s recent meta-analysis found 67.2% of older adults demonstrate full functional recovery long term (6+ months) after mTBI, which is comparable to estimates from younger age cohorts.

1.4.2 *Psychological Outcome*

Past research comparing psychological outcomes in older and younger cohorts after mTBI has been variable. At two weeks post-injury, Abdulle and van der Naalt (2020) found older adults reported psychological symptoms, 15% reported anxiety, 12% reported depression, and 38% reported post-traumatic stress (Abdulle & van der Naalt, 2020). However, in comparison to younger adults, in the acute stage of recovery, older adults have reported lower rates of psychological distress (Rapoport & Feinstein, 2001) and major depression (Rapoport et al., 2003; Richey et al., 2020). Similar patterns have been identified in other studies (e.g., Deb et al., 1998), suggesting that there may be some positive age benefit in terms of fewer psychological symptoms after mTBI. Nevertheless, incomplete functional recovery six months post-mTBI has been associated with higher depression scores (Abdulle & van der Naalt, 2020). Therefore, further research identifying the risks of poor psychological outcome are important in older age cohorts because of the potential impact on functional and cognitive outcome.

1.4.3 *Cognitive Outcome*

As opposed to the potential for an age benefit in buffering poor psychological outcome, cognition may be expected to be more vulnerable to trauma, as outlined in the previous risk factors section. Unfortunately, research investigating cognitive outcomes in older adults with TBI has frequently included patients of heterogenous severity, rather than mTBI, which limits the understanding of the possible risks in recovery specific to mTBI in older age. Nevertheless, studies including adults aged 50 years and older have reported similar cognitive performances by mTBI and community controls at one to two months post injury (apart from verbal fluency) (Goldstein et al., 2001) and one year post injury (Rapoport et al., 2006). However, these samples are younger than typically used in ageing research and older adults may not be as resilient (Rapoport et al., 2006).

Furthermore, there was variability in performances, with not all mTBI patients performing within normal limits (Goldstein et al., 2001). In this respect, evidence on neuroimaging (Goldstein et al., 2001) and lower GCS score (Goldstein & Levin, 2001) were associated with reduced cognition.

The Canadian Longitudinal Study on Aging has reported long-term impairments in PM (Bedard et al., 2018), executive functioning and declarative memory (Bedard et al., 2020) in adults aged 45 to 85 years who have sustained a mTBI with LOC. Compared to controls, patients with mTBI with LOC of 1-20 minutes more than a year prior to assessment were 60% more likely to experience cognitive decline at three year follow up, particularly in measures of executive functioning (Bedard & Taler, 2021). A key strength of this longitudinal study is the large sample size, which ranges from 750 to 1,937 participants who reported mTBI. Even so, this is based on self-report of a mTBI and the date of injury and other key information, like GCS score, PTA, and evidence of intracranial trauma are unknown, raising issues about the reliability of the self-report data.

In an early study by Deb et al. (1998), 62% of older adults were rated as having 'cognitive disability' on the Mini Mental Status Examination (MMSE) one year after mTBI. Although the MMSE is a useful screening tool, to fully establish the extent of cognitive impairments after mTBI additional cognitive testing is necessary, together with consideration of premorbid cognitive status. Kinsella et al. (2014b) explored cognitive outcomes in older adults three months following mTBI using two comparison groups, a group of healthy older adults and a group of older adults who had sustained an orthopaedic injury. The mTBI group demonstrated impaired executive function (set-shifting) and PM when compared to the healthy older adult group. However, this was also observed when the orthopaedic group was compared to healthy controls and with the exception of a small, non-significant effect on PM performance, the two injured groups did not differ on cognitive measures (Kinsella et al., 2014b). These findings suggest that cognitive difficulties following mTBI may not be specific to brain injury, but further investigation using both healthy and injured controls is required. As such, while

the evidence available does indicate older adults may be at risk of cognitive difficulties after mTBI, the full extent of these impairments is unclear and the recovery trajectory currently unknown. Accordingly, future research assessing cognition in this cohort is needed, including comparing outcome to a non-head injured control group.

1.5 Methodological Issues in Current Research on mTBI in Older Age

There are numerous methodological issues when conducting TBI research, some of which apply to patients of all ages and others which are specific to older age samples.

1.5.1 *Definition of 'Older Age'*

Across the field, there have been inconsistent age cut-offs for 'older age' in research, with some studies using ≥50 years (Goldstein & Levin, 2001; Rapoport et al., 2006), or ≥55 years of age (Karr et al., 2020a). Although these low age cut-offs might increase the sample size in individual studies, they are not consistent with current community perceptions of 'older age' nor with the World Health Organisation (WHO; 2011) definition of 'older age' (≥65 years). Discrepancies in the age of patients prevents comparison of findings and standardisation would improve research in the field. As such, the WHO (2011) age range for distinguishing older adults (i.e., ≥65 years) could serve as a useful standard in the formation of cohorts of older people following mTBI.

1.5.2 *Pre-injury Health Status*

Accounting for the presence of pre-morbid health conditions and degenerative disorders are challenges in older cohorts. In a UK-based study, 99% of 505 older adults with TBI had a pre-existing medical condition and 11% had dementia (Hawley et al., 2017). While excluding all patients with a pre-existing medical condition would be virtually impossible, the screening of significant health conditions which are known to impact cognition may offer an approach to allow for a focussed investigation of TBI-related outcomes in older patients after mTBI. Understandably, this will only partially address the issue of pre-injury health status and cognitive performance; for example, the early stages of degenerative disorders (mild cognitive impairment) may be difficult to detect in the screening process. Gardner et al. (2018) raise a valid concern that studies with strict inclusion and exclusion criteria may result in cohorts of older people who are

not representative of the general population. Therefore, ongoing research with older age cohorts will need to carefully account for pre-injury health status in determining post-TBI outcome, either by basing the research on large database studies to control for confounding factors, such as dementia, or by implementing exclusion criteria and comparing pre-injury self-rated health across TBI and control groups. In this latter approach, the impact on generalisation of study findings to larger clinical populations will need to be acknowledged (Gardner et al., 2018).

1.5.3 *Difficulties in Defining mTBI in Older Age*

It can be challenging to diagnose mTBI in older age patients. Firstly, it has been commented that there is a similarity between mTBI symptoms and those commonly attributed to ageing (McCulloch et al., 2020). Pre-existing conditions and cognitive decline, together with medication effects may also impact diagnosis of mTBI (Papa et al., 2012). The validity of the GCS in older age patients with dementia and severe impairments has also been questioned, with scores potentially confounded by pre-existing conditions, e.g., cognitive impairment, hearing loss (Bloch, 2016), suggesting that the expected relationship between severity of brain injury and GCS score has not been well established in older age patients (Kehoe et al., 2015). Therefore, although mTBI in older age may be quite common, it is also possible that it might remain undiagnosed. Therefore, the risk of comorbidities in the older age patient masking the presence of mTBI clearly needs to be accommodated in future studies. This can be achieved, at least partially, by using the current and comprehensive diagnostic guidelines proposed by the working party of the International Collaboration on mTBI (Kristman et al., 2014).

1.5.4 *Choice of Control Groups*

While comparison of younger and older patients with mTBI may clarify age-related differences in recovery, there are numerous factors unique to the older age patient (such as pre-morbid medical conditions), which limit the utility of comparisons with different age groups. Furthermore, whilst non-injured but age-matched community controls are a valuable comparison group, consideration should be given to including

non-brain injured trauma controls (e.g., orthopaedic controls) to account for the general effects that sustaining an injury may have on outcomes (Aharon-Peretz et al., 1997; Kinsella et al., 2014b; Larrabee et al., 2013). Larrabee et al. (2013) contend that reduced neuropsychological test scores can be caused by pre-existing psychological issues, diagnosis threat and expectancy effects, and are not specific to mTBI. As such, Larrabee et al. (2013) recommend the inclusion of trauma (orthopaedic) controls in mTBI research. By including both non-injured controls and non-head injured trauma groups, researchers can determine if the cognitive difficulties exhibited in the mTBI group are unique to those who had sustained a brain injury or also observed in patients who had experienced an orthopaedic injury, for example. In this respect, Kinsella et al. (2014b) found that, similar to a mTBI group, older adults with orthopaedic injuries exhibited lower cognitive performance than healthy controls. As such, both healthy and trauma controls are needed to fully understand any potential impact mTBI has on cognition in older age.

1.6 Chapter Summary

The ramifications of mTBI in our communities have been increasingly recognised through sustained research efforts over the past decades. In contrast, mTBI in older age has attracted less focus, especially in relation to cognitive outcome. Although older age has been identified as a risk factor in achieving optimal recovery following TBI, there have been few studies that have tracked cognitive outcome past the early acute-phase post-injury and additional research is needed. PM has been identified as a potential indicator of everyday memory functioning, and a cognitive behaviour which adults with mTBI (including older adults) have found challenging (Kinsella et al., 2014b; Lajeunesse et al., 2019; Tay et al., 2010). PM has been identified as a potential indicator of everyday memory functioning, and a cognitive behaviour which adults with mTBI (including older adults) have found challenging (Kinsella et al., 2014b; Lajeunesse et al., 2019; Tay et al., 2010). As such, PM may be a useful cognitive outcome measure to estimate everyday functioning in older adults and warrants inclusion in future studies assessing cognition after mTBI. The following chapter discusses PM theory and research in this age group.

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Chapter 2 Prospective Memory in Older Age

2.1 Chapter Overview

Prospective memory (PM), remembering to perform an intended action in the future (McDaniel & Einstein, 2007, 2011; Raskin, 2018), is considered a multidomain complex memory function (Einstein et al., 2005; Kliegel et al., 2008b; Kliegel et al., 2008c; Scullin et al., 2013). This chapter will review the literature regarding PM, including operationalisation, theoretical models, underlying cognitive resources, and additional factors involved in PM. Lastly, the relationship between PM and everyday functioning will be discussed.

2.2 Prospective Memory

PM has been reported as accounting for many everyday memory problems (Kliegel & Martin, 2003). It has been proposed that there are four components or phases of PM: (1) forming an intention; (2) maintaining the intention; (3) initiating the intended action at the appropriate time; and (4) accurately executing the intention (Kliegel et al., 2008b; Kliegel et al., 2002; Kliegel et al., 2000). Ellis (1996) proposed a similar framework with an additional fifth phase where the outcome is evaluated, and the intention is 'deactivated' if successfully performed. It has been demonstrated that cognitive domains (executive function, attention, episodic memory) can be variously recruited over the task phases (Scullin et al., 2013). This complex, multiphase function can be readily understood as relevant to everyday behaviour – if a patient can encode, retain, and then retrieve information to perform an intended task at the appropriate time, they are more likely to be able to carry out activities of daily living with some level of independence (Woods et al., 2014; Woods et al., 2012). Comparatively, PM failures, like forgetting whether they have taken their prescribed medication, could have adverse effects (Sheppard et al., 2020). This indicates why the construct of PM is of interest to not only cognitive researchers but also to health professionals, particularly those assessing a client's capacity to be able to return to independent living or to maintain independence in the home (e.g., in situations of frailty in older age).

2.2.1 *Operationalisation of Prospective Memory*

Research involving PM typically classifies tasks into specific types. *Event-based* tasks involve remembering to perform an action cued by a particular event (e.g., remembering to put on a mask when leaving the house during a pandemic). Remembering to carry out an action at a specific time or after a period of time has lapsed are referred to as *time-based* tasks (e.g., remembering to attend a zoom meeting at 10 am). Tasks which are cued by a specific time period of the day, such remembering to do yoga in the morning, are called *time-of-day* tasks. Historically, the literature has focused on event-based and time-based PM, with time-of-day task being a newer differentiation discussed in the literature (Haines et al., 2020). Researchers have also defined tasks cued by the completion of an activity (e.g., remembering to take the plates to the kitchen after finishing dinner) as *activity-based* PM tasks (McAlister & Schmitter-Edgecombe, 2013; Schmitter-Edgecombe et al., 2009). Activity-based tasks can overlap with event-based PM tasks and are less widely researched. Time-based PM is often considered more difficult than event-based, due to presumed higher demands on executive functioning, attention, and inhibitory control mechanisms (Groot et al., 2002; Raskin et al., 2011). McDaniel and Einstein (2007) made a further distinction of *focal PM* tasks (e.g., cues included in the ongoing task) and *nonfocal PM* tasks (e.g., cues which are not presented in the ongoing task). PM can be measured through subjective approaches (e.g., self-report questionnaires) and/or objective performance tasks carried out either in the laboratory, clinic or within everyday life (naturalistic tasks). These different approaches will be discussed in Chapter 3.

To better understand the processes involved in PM, several research paradigms have been created for use within both laboratory/clinic and naturalistic settings. As tasks have traditionally been designed to measure event-based and time-based PM (as opposed to time-of-day or activity-based), the focus in this chapter will be on those two types of PM.

2.3 Key Theoretical Models of Prospective Memory

Einstein and McDaniel (1990) first described PM as involving two components – retrospective memory to retain the information regarding the future action and when it must be performed; and PM to recall the information at the correct time or event. This was subsequently developed into several theoretical models and frameworks of PM, which can be divided into two general categories: i) monitoring and searching theories; and ii) the multiprocess models (Scullin et al., 2009).

2.3.1 *Monitoring and Searching Theories*

The 'noticing plus search' model of event-based PM was proposed by Einstein et al. (1996) who stated that two processes were involved: (1) a stimulus within the environment is noticed unconsciously; and (2) this noticing triggers a conscious search of memory to ascertain the significance of the stimulus. This theory was based on the notion that stimuli with high familiarity are likely to be noticed as meaningful which in turn can initiate a search for the source of the meaning (McDaniel, 1995). While earlier theories stated PM involved conscious processing (Craik, 1986), this model offered an alternative view that automatic processes also play an important role in PM. That is, encoding a cue within the environment may be an automatic process and prompt the conscious search for the significance of the cue, which can then facilitate retrieval of the intended action. Experimental studies tested this theory by increasing the demands of the task, with the view that this would influence the processing of a cue and probability of responding (Marsh & Hicks, 1998). An issue raised with this model was whether the cue would be noticed, due to familiarity, if non-targets were also familiar (McDaniel et al., 2004). While this model was integral to the current understanding of PM, further development was required to capture the complex nature of prospective remembering.

The '*t*wo-process strategic monitoring' model (Guynn, 2003; Guynn et al., 2001) elaborated on the two processes which may be involved in event-based PM, describing: (1) a retrieval mode (for accurately reinstating the intended activity at the appropriate time), which is maintained by strategic monitoring in the cognitive system and may be mediated by increased activation of the PM cue representation; and (2) a checking mode

(of the external or internal environment) to determine whether the circumstances to execute the intended action are present**.** Guynn (2003) stated strategic monitoring could be described as a preparedness to consider stimuli as cues to retrieve intentions. Guynn (2003) reported that findings from a series of experimental studies suggest the two processes mediate strategic monitoring in event-based PM - one process can be turned on and off relatively easily (i.e., checking); while the other process cannot be turned off as easily (i.e., retrieval mode). That is, one process checks the environment for the target events and another process maintains the cognitive system in a PM retrieval mode. This model provided important contributions to the theoretical framework of PM. However, the supporting evidence was obtained using laboratory PM tasks, rather than tasks performed in real life, which limited the generalisation of the theory.

The *'preparatory attention model'* (PAM; Smith, 2003; Smith & Bayen, 2004) similarly highlighted the importance of monitoring the environment for PM cues, stating the two processes involved in PM were: (1) cognitive processes which enable monitoring of the environment for cues that can prompt the retrieval of PM intentions; and (2) engagement of attention processes in preparation of carrying out the PM task. Smith and Bayen (2004) argued that evidence to support this theory related to the observable cost in response time within an ongoing task when the research participant was instructed of a PM task, thereby inducing expectation that PM cues will occur during the ongoing task. This effect was apparent even if no PM cues were actually presented during the task, which Smith (2003) argue contradicts previous theories that retrieval of intentions can be automatic. The PAM model proposes that resource consuming attentional processes are a crucial component of any successful PM task (Smith & Bayen, 2004). However, the results used to prove the model were obtained from short laboratory tasks and do not explain whether attentional resources can be realistically engaged throughout long delay intervals, often involved in everyday PM tasks.

In a further development of their original model, McDaniel et al. (2004) proposed, the *'discrepancy plus search'* model, which described two processes: (1) cue focussed processes where the discrepancy between the expected and actual information

processed labels the cue as significant, thus initiating a search to ascertain the meaning of the cue (i.e., retrieval of the intention); and (2) reflexive-associative processes that automatically encode cues, interacting with 'memory traces' attached to the cue, which can trigger retrieval of the information related to the cue. McDaniel et al. (2004) stated this theory differed from the earlier *noticing plus search* model in that a cue may not be recognised as significant (or familiar) (thus cannot trigger a search for the source of significance), but can still stimulate a 'reflexive-associative process' which results in the awareness of the intention. However, McDaniel et al. (2004) cautioned that when testing this theory, the results could not be simply explained by two processes, suggesting multiple processes appear to be involved in PM.

2.3.2 *Multiprocess Models of Prospective Memory*

McDaniel and Einstein (2000) had already proposed the *'multi-process model'* to conceptualise PM retrieval. The authors (2000) concurred with existing views that PM retrieval can rely on strategic or attention-demanding processes, including maintaining activation of future intentions (Shallice & Burgess, 1991) and monitoring for cues to trigger prospective remembering (Smith, 2003; Smith & Bayen, 2004). However, McDaniel and Einstein (2000) also proposed the involvement of memory based, automatic processes which are not initiated through strategic or self-initiated processes, but responsive to salient stimuli that trigger the retrieval of PM intentions (Einstein et al., 2005; McDaniel & Einstein, 2000). This can facilitate a spontaneous retrieval process for PM when executive monitoring is not engaged or cannot be engaged. The multi-process model provides a framework for understanding the differing underlying cognitive domains (episodic memory and executive attention) of PM performance. Overall, people can depend on either strategic or relatively automatic processes for PM retrieval and, importantly, do so to varying degrees depending on the conditions of the task. McDaniel and Einstein (2007) outlined a number of factors which may determine whether a PM task will depend on strategic, attention-demanding processes or relatively automatic processes. For example, when the cue is featured in the ongoing task (i.e., focal), it facilitates encoding, and retrieval can be spontaneous. Comparatively, when the cue is

not presented during the ongoing task (i.e., nonfocal), attentional resources must be devoted to retrieval of the PM task. Other factors include: (i) the saliency of the cue, with distinctive cues believed to be associated with better PM; (ii) the association of the PM cue and the intention, with spontaneous retrieval likely to occur if the two are strongly associated; and (iii) the importance of the PM intention, with high importance intentions believed to produce better PM performance (McDaniel & Einstein, 2000, 2007).

The *'dynamic multi-process framework'* (Scullin et al., 2013) developed on the multi-process model by considering naturalistic tasks, as well as laboratory-based tasks. Scullin et al. (2013) propose that monitoring is not continuously engaged, but rather can be selectively engaged or prompted by an environmental cue and these processes likely alternate in everyday tasks that involve long periods of time between the intention being formed and execution. To test this theory, Scullin et al. (2013) incorporated a short (20 minutes) and long retention interval (12 hours) that included nocturnal sleep which prevented participants from monitoring continuously. From their findings Scullin et al. (2013) argue that: (i) when the cue is anticipated, strategic monitoring will be employed; (ii) if the cue is not anticipated, monitoring will be disengaged; and (iii) when monitoring is not engaged, spontaneous retrieval can facilitate prospective remembering. In long retention periods, environmental cues are likely encoded by spontaneous processes, which in turn trigger monitoring (Scullin et al., 2013). Unlike previous models which solely focus on laboratory-based tasks, this theory extends to tasks with long retention intervals, like those in everyday life. This theoretical model can be applied to real life behaviour and facilitates further understanding of why PM failures may occur in everyday activities.

2.3.3 *Delay Theory*

The *'delay theory'* (Heathcote et al., 2015; Loft & Remington, 2013) was proposed as an alternative to the multi-process and PAM models. In this model, individuals accumulate evidence regarding the ongoing task and PM task that is then used to inform responses (Heathcote et al., 2015; Loft & Remington, 2013). In contrast to other models, the delay theory states that the slowing down of response time (i.e., costs)

demonstrated in event-based PM may reflect the accumulation of evidence, rather than the ongoing task and PM task sharing a limited capacity (Heathcote et al., 2015; Loft & Remington, 2013). That is, the responses for the ongoing task and PM are in competition to be selected and when sufficient information has been accumulated, the PM task response will be selected. While the application of mathematical models of cognition, where decision making is based on the accumulation of evidence, is an innovative approach to conceptualising PM, the delay theory is limited to non-focal event-based PM.

2.3.4 *Summary of Theoretical Models*

Considerable research has been devoted to the conceptualisation of PM and the processes which may be involved (Guynn et al., 2001; Kliegel et al., 2002; McDaniel et al., 2004). Anderson et al. (2017)'s review found evidence that both monitoring and spontaneous retrieval processes are involved in PM, indicating a multiple process framework may best describe PM. The theoretical models discussed have been fundamental in advancing our knowledge of PM. They do however have limitations, including a focus on event-based PM and use of laboratory-based measures to test theories, which may not adequately reflect the complex PM tasks performed in real life. How individuals self-initiate the retrieval of intentions when external prompts are absent remains unclear, with Anderson et al. (2017) proposing that individuals use both internal (e.g., metacognitive) and external strategies (e.g., reminders using a smartphone) to perform PM tasks. Overall, the complex nature of PM has been difficult to define within one theoretical model and ongoing frameworks are being developed to characterise PM in real-world situations, as much as in the laboratory.

2.4 Underlying Cognitive Resources

Empirical findings from testing the theoretical models of PM have been instrumental in uncovering the underlying cognitive resources necessary for successful PM. For this thesis, "executive function" is used as an umbrella term encompassing a range of cognitive processes including strategic attention, working memory and behaviour regulation (Kinsella et al., 2020; Miyake et al., 2000; Scullin et al, 2013; Stuss, 2011; Suchy, 2015). In the multi-process model, McDaniel and Einstein (2007) propose

that several components of executive functioning are involved in PM; (i) planning; (ii) working memory; (iii) set shifting (e.g., switching from ongoing task to perform the intended PM task); and (iv) sequencing. Kliegel et al. (2011) further develop on this theory, proposing executive processes are largely involved in the intention formation, intention initiation and execution of intention phases. Comparatively, retrospective memory is crucial for the retention phase of the model with the intention stored in long-term memory while the ongoing task is performed (Kliegel et al., 2011; Kliegel et al., 2002). However, dependent on individual and task characteristics, these cognitive resources are likely to be involved to some degree at each PM phase (Kliegel et al., 2011).

In line with this theory, PM has been linked to both retrospective memory (Burgess & Shallice, 1997; Delprado et al., 2012; McDaniel et al., 1999) and executive functioning (Delprado et al., 2012; Martin et al., 2003; Raskin et al., 2011; Schnitzspahn et al., 2013), with neuroimaging research indicating the potential involvement of the medial temporal networks (Gordon et al., 2011) and prefronto-parietal networks (Burgess et al., 2011; Oksanen et al., 2014), respectively. In TBI studies, significant associations have been reported between PM and retrospective memory (Clune-Ryberg et al., 2011; Groot et al., 2002; Knight et al., 2005; Potvin et al., 2011; Schmitter-Edgecombe & Wright, 2004) and executive function (Clune-Ryberg et al., 2011; Fleming et al., 2008; Groot et al., 2002; Knight et al., 2005; Mioni et al., 2013; Paxton & Chiaravalloti, 2014; Raskin et al., 2012; Schmitter-Edgecombe & Wright, 2004; Shum et al., 2011).

The literature investigating the relationship between PM and these cognitive resources in older adults is less consistent. In healthy older adults, small relationships have been reported (Azzopardi et al., 2015; Kamat et al., 2014; Lee et al., 2018; Rose et al., 2010; Zeintl et al., 2007), while stronger associations have been found with clinical cohorts (Delprado et al., 2012; Lee et al., 2018; Thompson et al., 2010). Compared to younger adults, healthy older adults have demonstrated lower PM performance (Henry et al., 2004; Kliegel et al., 2016; Rendell & Craik, 2000; Rose et al., 2010; Woods et al., 2008b). McDaniel and Einstein (2011) argue that as ageing frequently impacts executive

functioning, PM tasks that are most likely to display age-related decline are those that require planning and strategic monitoring to detect targets, or when execution of the retrieved intention must be delayed briefly.

Investigating the relationship between PM and multiple processes of executive function was beyond the scope of this doctoral research. As such, one discrete construct from the multi-phase model of PM (McDaniel & Einstein, 2007), which has received most experimental investigation, was selected, i.e., attention set-shifting, together with retrospective memory. This provided the basis for justified hypotheses to be generated.

2.5 Prospective Memory in Older Age

Research has focused on PM performance across the lifespan, but performance in older age has been a specific area of research interest. Laboratory-based tasks which involve higher degrees of strategic demands have been found to be particularly challenging for older adults (Henry et al., 2004), or those involving irregular tasks with inconsistent patterns (Aberle et al., 2010), or more attention demanding requirements in the ongoing task (Schnitzspahn et al., 2011). In Uttl (2008)'s review of the literature, age related decline was found to vary depending on a number of factors, including the demands on processing resources (e.g., challenging ongoing tasks). Explanations have included the noted age-related reductions in episodic memory and executive function (Kliegel et al., 2016; McDaniel & Einstein, 2011), associated with neural changes in the hippocampal structures and frontal pathways (Maillet & Rajah, 2013; Martinelli et al., 2013).

There have been additional observations that older adults demonstrate reduced performance on laboratory-based tasks (Kliegel et al., 2016; Rendell & Craik, 2000; Rose et al., 2010; Woods et al., 2008b), but outperform younger adults on naturalistic tasks (tasks performed in their everyday life) (Aberle et al., 2010; Bailey et al., 2010; Schnitzspahn et al., 2011). This pattern of performance on naturalistic tasks is inconsistent with the view that age affects the medial temporal and prefrontal networks involved in PM (Maillet & Rajah, 2013), and has consequently led to a significant amount of research in the area.

A possible explanation for older adults outperforming younger participants on naturalistic tasks is motivation, with Aberle et al. (2010) reporting no age differences when younger participants were provided with monetary incentive. Furthermore, high motivation and good metacognitive awareness have been proposed as factors which may contribute to better performance on naturalistic tasks by older adults (Schnitzspahn et al., 2011). This intrinsic motivation may potentially explain why older adults have been found to outperform younger adults on naturalistic experimenter-generated tasks, but not on self-assigned naturalistic time-based tasks (Schnitzspahn et al., 2020). Other explanations have included the potential use of well-learnt compensatory memory strategies by older adults in naturalistic tasks; for example, creating a shopping list for a weekly visit to the supermarket (Rendell & Craik, 2000; Rendell & Thomson, 1999) or reprioritising tasks (Ihle et al., 2012).

Overall, the higher performances demonstrated by older adults on naturalistic tasks are likely related to a combination of factors, including increased use of compensatory strategies and personal attributes (e.g., motivation and altruism). Research in this area has been important in highlighting the differences between measures of PM, the influence ageing may have on PM, and the contribution of non-cognitive processes to PM performance.

2.6 Additional Factors Involved in Prospective Memory

Research investigating the theoretical models of PM and performance in ageing have been instrumental in developing our understanding of the cognitive factors involved in PM. These include attributes of the tasks themselves such as the extent to which processing overlaps with the ongoing task (task focality) and the pattern in which cues are presented (task regularity) (Kliegel et al., 2008a; McDaniel & Einstein, 2007; Rose et al., 2010). However, there are several non-cognitive factors which potentially impact PM performance. Emotional mechanisms have been raised as possibly contributing to PM performance, namely task valence (Kliegel et al., 2016; Schnitzspahn et al., 2012), the mood state of the individual (Schnitzspahn et al., 2014), perceived importance of the task (Kliegel et al., 2004; McDaniel & Einstein, 2000), social importance (Altgassen et al.,

2009) and motivation to carry out the task (Aberle et al., 2010; Schnitzspahn et al., 2011). Compensatory strategies have also been explored as facilitating PM performance, with approaches categorised into internal (e.g., visual imagery) and external (e.g., smartphones, calendars) (Raskin, 2018). Overall, there are a wide range of variables involved in PM (see Raskin, 2018 for a comprehensive review of factors with respect to clinical populations) and this reflects of the complex nature of this cognitive memory function. For the purposes of examining cognitive outcomes following mTBI, it is important to consider the contextual factors involved in PM, while also prioritising the clinical utility of the PM measures.

2.7 Prospective Memory and Everyday Functioning

Kliegel et al. (2008b) contend that as many everyday tasks involve PM, individuals with PM impairments may have difficulty with independent living. Consistent with this view, Zogg et al. (2012)'s review of the literature found that PM is an important factor of medication adherence. Associations have been found between PM performance and simulated functional tasks (such as reading the directions on medicine bottles) carried out in a laboratory setting, both in healthy older adults (Hering et al., 2018) and in clinical populations (Weber et al., 2019). For example, in a group of 58 healthy older adults, overall performance on a computer-based PM measure (The Virtual Week) was correlated with a laboratory-based task of functional independence (The Instrumental Activities of Daily Living task) (Hering et al., 2018). Hierarchical regression analysis revealed that the Virtual Week was a significant predictor of the functional task, indicating PM performance may be associated with everyday functioning. Associations have been found in other clinical cohorts, with Raskin et al. (2014) reporting correlations between PM performance and performance on a simulation medication management test in patients with schizophrenia.

Self-report questionnaires are an alternative method of obtaining information regarding everyday functioning and well-being. Studies have examined the relationship between PM and subjective measures of functioning. In a study of 50 healthy older adults, the total number of instrumental activities of daily living domains which

participants reported requiring assistance was associated with lower performance on a standardised measure of PM, the Memory for Intentions Screening Test (MIST; Woods et al., 2012). In a study of healthy older adults (aged 50 to 82 years), worse PM was associated with lower quality of life in older adults who reported multiple activities of daily living difficulties (Woods et al., 2015). Woods et al. (2014) also observed an association between self-reported medication adherence and PM in older adults. Tierney et al. (2016) examined the relationship between PM performance (the MIST) in 97 healthy older adults and an activities of daily living questionnaire completed by an informant. Participants were divided into two groups – activities of daily living normal (ADL normal; n =37) and mild activities of daily living problems (mild ADL; n = 60). The mild ADL problems group performed worse on a measure of time-based PM, implying there is an association between PM and everyday functioning. In older adults with mild cognitive impairment, PM performance has been found to predict medication use and household activities (Schmitter-Edgecombe et al., 2009), as well as task sequencing on a naturalistic measure of everyday functioning (Schmitter-Edgecombe et al., 2012). In Beaver and Schmitter-Edgecombe (2017)'s study, PM performance was a significant predictor of six functional measures (two questionnaires, two performance-based tasks and two observation tasks) in a combined group of healthy older adults and older adults with mild cognitive impairment. PM has also been linked to self-reported instrumental activities of daily living in patients with HIV (Woods et al., 2008a). Based on these research findings, there does appear to be a link between PM and everyday activities that is important for older age patients and highlights the potential usefulness of PM as a predictor of everyday cognitive functioning in this age group.

2.8 Chapter Summary

The key topics relating to PM were presented in this chapter, starting with the operationalisation of PM, followed by the main theoretical models. The underlying cognitive resources involved in PM, namely retrospective memory, and executive function, were also discussed. Research investigating PM in older age and the relationship between PM and everyday functioning highlights the clinical relevance of PM

performance. As such, in future studies investigating cognition in older adults following mTBI, PM presents as a clinically useful outcome measure. To further develop understanding of the nature of the construct of PM, it is critical to explore the relationship between PM performance and underlying cognitive resources (retrospective memory and executive function) in older adults following mTBI.

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Chapter 3 Measures of Prospective Memory

3.1 Chapter Overview

PM can be assessed using subjective reports or objective task performance. Self- or informant-reports seek information through responses to questions or questionnaires. In considering approaches to objective measures, Phillips et al. (2008) proposed a framework for classifying PM tasks, based on the context of the setting - (i) laboratory-based, experimental measures which are typically used for research purposes; (ii) clinic-based measures that are used to provide an estimate of 'real-world' ability and to identify those experiencing PM difficulties; and (iii) naturalistic tasks which are performed by examinees in their everyday life. Measures utilizing extended reality technology, such as augmented reality and virtual reality, have also been developed and will be discussed in Chapter 6 of this thesis. This chapter will review both subjective and objective approaches, together with the corresponding benefits and disadvantages of each method.

3.2 Subjective Measures

3.2.1 *Self-reports*

Incorporating self-reports of the lived experience of memory into neuropsychological assessments is important for contributing to differential diagnosis and for promoting client-centred health care. An early subjective measure, the Prospective Memory Questionnaire (PMQ; Hannon et al., 1995) included subscales that assessed; (i) long-term episodic PM (e.g., forgetting to send a birthday card); (ii) short-term habitual PM (e.g., forgetting to lock the door when leaving the house); (iii) internally-cued PM (e.g., driving and temporarily forgetting where you were going); and (iv) techniques to remember PM tasks (e.g., leave reminders in obvious places). Hannon et al. (1995) reported that the PMQ was able to differentiate between patients with significant TBI (defined as LOC, with the majority of patients having been in a coma) and those who had not sustained a TBI. An advantage of the PMQ was that it sampled different types of PM commonly encountered in everyday life, but a disadvantage is that they are culturally specific and as the demands of everyday life change, the

questionnaire items have become increasingly irrelevant to clients' day to day challenges (e.g., stamping and posting letters).

The Prospective and Retrospective Memory Questionnaire (PRMQ; Smith et al., 2000) is a subjective measure of PM and retrospective memory which has been translated into several languages and used in various populations, including Swedish (Ronnlund et al., 2008), Spanish (Gonzalez-Ramirez & Mendoza-Gonzalez, 2011), French (Guerdoux-Ninot et al., 2019), European Portuguese (Pereira & Albuquerque, 2018), Brazilian Portuguese (Piauilino et al., 2010), German (Arnold & Bayen, 2019), Japanese (Gondo et al., 2010), Taiwanese (Hsu & Hua, 2011), and Nigerian (Mefoh et al., 2017). The PRMQ consists of eight items regarding PM failures and eight items concerning retrospective memory failures, with each item defined along three dimensions; (i) either prospective or retrospective memory; (ii) self or external cues, such as time or even-based tasks; and (iii) short or long-term delay (Crawford et al., 2006). The popularity of the PRMQ is, in part, related to its established psychometric properties, including good construct validity, with confirmatory factor analysis establishing a tripartite model consisting of a general memory factor and two orthogonal specific factors of PM and retrospective memory (Crawford et al., 2003). The PRMQ has also been reported as having acceptable internal consistency in both the self-rated version (Cronbach alpha values: Total $\alpha = 0.89$; PM subscale $\alpha = 0.84$; RM subscale $\alpha = 0.80$) (Crawford et al., 2003) and the informant/proxy version (Cronbach alpha values: Total $\alpha = 0.92$; PM subscale $\alpha = 0.87$; RM subscale $\alpha = 0.83$) (Crawford et al., 2006). Another appeal of the PRMQ is the accompanying computer program the authors (2003) provide which allows clinicians to quickly score and analyse PRMQ results. The program transforms individual raw scores into *t* scores, estimated true scores, provides 95% confidence limits for all three scales and tests whether the discrepancy between the two subscales is reliably different and whether the discrepancy is abnormal/rare.

Waugh (1999) developed by the Comprehensive Assessment of Prospective Memory (CAPM) which was subsequently used by Roche et al. (2002) with TBI and control groups. The CAPM consists of three sections; (i) Section A – 39 items regarding

everyday PM failures related to basic activities of daily living (e.g., forgetting to brush your teeth) and instrumental activities of living (e.g., forgetting to buy an item at the grocery store); (ii) Section B – measures the amount of concern regarding these failures (same 39 items); and (iii) Section C – 15 items regarding PM tasks and reasons for failure or success. Each item is scored on a five-point scale (1 = never; 5 = very often) and higher scores indicate more PM failures. While the CAPM provides additional information regarding memory concern and perceived reasons for failures, there are items which may no longer be relevant for patients (e.g., forgetting to get money from the bank). The CAPM has been reported as having acceptable test-retest reliability and internal consistency (Chau et al., 2007) and has been translated for use with Chinese populations (Chan et al., 2010).

The Brief Assessment of Prospective Memory (BAPM; Man et al., 2011) is a short form of the CAPM with 16 items equally divided across a basic activities of daily living subscale and instrumental activities of daily living subscale. While Man et al. (2011) reported the BAPM as having acceptable internal consistency and test-retest reliability, they found no association between responses by patients with moderate to severe TBI and their PM performance. The BAPM has since been used in studies assessing PM following stroke (Hogan et al., 2020; Man et al., 2015).

The issue with less commonly used measures, such as the Time Cued Prospective Memory Questionnaire (Cuttler & Graf, 2009) and Memory Questionnaire (Uttl, 2002; Uttl & Kibreab, 2011) is they do not have the established normative data for both clinical and healthy populations like the PMQ, PRMQ and CAPM. General memory questionnaires are sometimes used, like the Everyday Memory Questionnaire (EMQ; Sunderland et al., 1983) which was developed for patients with head injuries. The EMQ was originally 35 items, but later refined to 28 items (Sunderland et al., 1984). It has since been revised as a 13-item questionnaire for use with clinical populations (Royle & Lincoln, 2008). Although the EMQ was not designed to measure PM specifically, it includes items regarding everyday PM failures, such as remembering a change in daily routine or forgetting to remind someone about something. As only a few selected items

relate to PM, using a general memory questionnaire provides minimal information about everyday PM functioning.

3.2.2 *Informant reports*

As earlier mentioned, concerns have been raised regarding the accuracy of self-reports in some clinical populations and as such, informant reports have been used, either in conjunction, or in lieu of self-report questionnaires. A recent longitudinal study by Bellaali et al. (2021) found memory functioning reported by informants (in this case, spouses), better predicted a partner's memory decline than participant self-reports. Nevertheless, in cross-sectional studies investigating the convergence of self- and informant reports, there is a lack of consensus. While Smith et al. (2000) found similar ratings on the self-report and informant versions of the PRMQ, Thompson et al. (2015) observed no correlations between self-reports by healthy older adults/patients with mild cognitive impairment and informant reports. As such, informant reports appear to be useful for providing information about everyday PM behaviour for patients with dementia but may not be useful for healthy older adults or those with milder memory issues (Blondelle et al., 2020).

In patients with moderate to severe TBI, Fleming et al. (2009) found no association between self-reports on the CAPM and actual PM performance. In contrast, informant reports significantly correlated with patients' performance on two clinic-based measures, suggesting that informant reports may be useful when assessing moderate and severe TBI populations. On the CAPM, significant differences were found between self-reports by patients with severe TBI and informant ratings, suggesting a lack of self-awareness regarding memory failures (Roche et al., 2002). Overall, past research suggests that substituting self-reports with informant reports is a useful strategy when assessing patients with significant cognitive difficulties, such as those with dementia and moderate to severe TBI.

3.2.3 *Limitations and Advantages of Subjective Measures*

There are disadvantages and benefits of subjective measures. Subjective measures do not directly test PM, and some argue they are not an accurate index of

actual performance (Uttl & Kibreab, 2011). Even Crawford et al. (2006) recommend that the PRMQ be used in conjunction with objective measures. This seems particularly important for those with significant memory difficulties, given self-awareness of memory failures can be reduced in these clients (Prigatano & Sherer, 2020; Roche et al., 2002). Furthermore, depressive symptoms have been linked to self-reports of memory complaints (Schweizer et al., 2018; Zlatar et al., 2018) and may amplify a negative self-evaluation of memory (Brailean et al., 2019). Neuroticism (Koller et al., 2019; Pearman, 2020), poor sleep quality (Kang et al., 2017), and worry (Pearman, 2020) have also been linked to subjective memory complaints and may potentially influence responses on a self-report measure. The accuracy of informant reports has also been questioned, as they may be influenced by the stress levels of the informant (Nygaard et al., 2009), as well as caregiver burden and fatigue (Bogod et al., 2003; Fleming et al., 1996).

Nevertheless, subjective measures are simple to administer and therefore, an economical method of assessment (Chau et al., 2007). Self-reports can also provide information which may not be detected by performance measures or overt to others (Shum et al., 2002). For example, there are PM errors that cannot be observed by others, such as intending to tell a grandchild a story when they visit and then forgetting. Subjective memory complaints have been linked to poorer cognitive performance (Brailean et al., 2019) and self-reported memory decline is a key factor in diagnosing amnestic mild cognitive impairment, which is associated with an increased likelihood of Alzheimer's dementia (Jessen, 2014). Accordingly, subjective measures are particularly relevant for older patients when there may be concerns about early changes in memory.

Self-reports measure an individual's beliefs about their memory, metamemory, and how the patient views their memory (Herrmann, 1982). Whilst these beliefs may not be accurate, they will influence the individual's behaviour (Hannon et al., 1995) and have implications for strategy use (i.e., someone who falsely believes they have a good memory is less likely to use a memory strategy). Furthermore, individuals with poor insight may be less willing to engage with treatment (Roche et al., 2002). As such, subjective measures can provide valuable information about patients and managing their

concerns about memory, especially if reviewed in conjunction with objective measures of performance. With respect to informant reports, they appear to be particularly useful in situations where patients present with considerable memory problems, such as dementia or moderate to severe TBI. In situations in which the presence of memory difficulties are milder, self-reports may be as valid as informant reports in offering insights into the client's experience of memory in daily life (Blondelle et al., 2020).

3.3 Objective Measures

3.3.1 *Laboratory-based Tasks*

PM performance can be assessed using laboratory-based tasks. These are typically used for research purposes, addressing specific research questions that require discrete experimental manipulation. Laboratory measures have historically focussed on event-based PM (McDaniel & Einstein, 2011) and are generally computer-based. Event-based tasks require the participant to perform a particular action (such as pressing a key) whenever they encounter a particular target event (such as seeing the word 'cat' when reading a story) during an ongoing activity (McDaniel & Einstein, 2011). A typical laboratory paradigm involves: (1) presentation of instructions and practice trials for an ongoing (distracting) task; (2) presentation of PM task instructions; (3) a delay during which participants perform other activities; (4) reintroduction of the ongoing task without reminding the participant of the PM task; and (5) the embedded PM cues are presented several times in the ongoing task, with participants assessed on the number of times they perform the PM task when the cue is presented (McDaniel & Einstein, 2000). This dual-task paradigm has since been used to assess time-based PM, such as advising the experimenter when 10 minutes has passed (Schnitzspahn et al., 2020) and activity-based PM, such as saying "now" after completing a task with numbers (Brewer et al., 2011).

3.3.2 *Advantages and Limitations of Laboratory-Based Tasks*

The attractiveness of this approach is that the conditions for PM performance can be carefully controlled by the experimenter, enhancing the reliability of the respondent's performance. However, significant issues with laboratory measures have been raised,

one of which is the inability to capture the complexity of everyday PM tasks that often involve a series or set of delayed actions planned to be executed in the future, and sometimes after a significant time delay (Kliegel et al., 2000). Another key criticism is the limited ecological validity of these types of measures, given they often involve arbitrary experimenter-driven tasks that have little resemblance to everyday PM demands (Phillips et al., 2008). Nevertheless, laboratory-based tasks have been fundamental in developing our current understanding of PM performance and continue to be used in research studies (e.g., Arnold & Bayen, 2019; Marcone et al., 2019; Raskin et al., 2018).

3.3.3 *Clinic-based Measures*

From laboratory-based tasks, standardised clinic-based measures of PM have been developed to assist clinicians in detecting PM failures or impairments. Clinicians require psychometrically sound measures with normative data for diagnostic assessments and to inform treatment pathways (Mioni et al., 2014). For example, The Rivermead Behavioural Memory Test (RBMT; Wilson et al., 1985; Wilson et al., 2003; Wilson et al., 2008) is a clinical tool used for the assessment of everyday memory ability which includes three PM items (e.g., remembering an appointment and retrieving a hidden personal item). The RBMT has been adapted for use with children (Wilson et al., 1993) and translated into several languages, such as Turkish (Küçükdeveci et al., 2008), Japanese (Matsuda et al., 2002), Brazilian (Yassuda et al., 2010), Swedish (Johansson & Wressle, 2012) and Spanish (Requena et al., 2019). Although the normative data available for the RBMT is a considerable strength (Fraser et al., 1999; van Balen, 1996), it only has three event-based PM items and does not measure time-based PM. Furthermore, it may have limited sensitivity for detecting moderate or mild deficits (Mathias & Mansfield, 2005).

The Virtual Week (Rendell & Craik, 2000) was developed to be a more realistic approach than typical laboratory tasks and originally used a boardgame format. Participants move around a board that is labelled with times of the day and each lap of the board represents one virtual day. There are 10 tasks for each virtual day; four ‘regular’ tasks which must be performed each day (e.g., taking medication with morning

and evening meals), four ‘irregular’ tasks (e.g., calling the plumber) and two ‘time-check’ tasks (e.g., performing a lung test at specific times). A computerised version of the Virtual Week has since been developed (Rose et al., 2010). The Virtual Week has been reported as having sound psychometric properties including test re-test reliability (Mioni et al., 2015) and sensitive to impairments in clinical and older age cohorts (Rendell & Henry, 2009). It has been used in several research areas including TBI (Mioni et al., 2013), autism spectrum disorder (Henry et al., 2014), substance abuse (Rendell et al., 2007; Rendell et al., 2008), schizophrenia (Henry et al., 2007) and Parkinson’s Disease (Foster et al., 2013). The Virtual Week has been adapted into a cognitive training game (Rose et al., 2015), as well as for Italian (Mioni et al., 2017) and Polish (Niedźwieńska et al., 2016) populations. While the Virtual Week has many positives, such as the variety of PM items, it is still essentially a boardgame and like many clinic-based measures, the administration time is impractical for many settings (e.g., each virtual day takes approximately 10 minutes to complete, administration time for all seven days can be up to 70 minutes).

The Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2005): is a standardized, clinic-based measure of PM which involves participants engaging in several ongoing distractor activities (e.g., puzzles and general knowledge quizzes), whilst simultaneously remembering to perform PM tasks without prompting by the examiner. There are six items in total: three time-based (e.g., in nine minutes time, change task), and three event-based (e.g., passing a book when encountering a particular quiz question) which are carried out while completing the ongoing pencil and paper activities. Scoring is based on both accuracy and timeliness. The CAMPROMPT has been reported as having acceptable psychometric properties, including inter-rater reliability (0.99), test-retest reliability (Kendall’s Tau-ϭ = 0.64) (Wilson et al., 2005) and inter-item reliability (Cronbach α = 0.75) (Delprado et al., 2012). Criticisms, however, have been raised regarding predictive validity (i.e., ability to predict everyday PM performance) (Fish et al., 2010). In an attempt to provide a task that emulates everyday PM situations, the CAMPROMPT allows the use of memory strategies (note taking), but

some have argued that by allowing the use of memory strategies, this confounds the results for assessing ability (Simard et al., 2019). In spite of these limitations, it has been successfully used in a wide range of research areas, including TBI (Clune-Ryberg et al., 2011; Fleming et al., 2008; Raskin, 2009; Shum et al., 2011), stroke (Hogan et al., 2020; Man et al., 2015), substance use (Hadjiefthyvoulou et al., 2011), HIV-associated conditions (Matchanova et al., 2020) and ageing studies (Kinsella et al., 2020; Mioni et al., 2020).

Another frequently used standardised PM measure is the Memory for Intentions Screening Test (MIST; Raskin et al., 2010) which assesses PM performance across eight tasks, while examinees complete a distractor task (word puzzle). The MIST consists of four event-based tasks (e.g., when given a postcard, self-address it) and four time-based tasks (e.g., remind examiner it is break time in 15 minutes time), split across two time points (two minute and 15-minute delay) and mode of response (verbal and action). A multiple-choice recognition scale provides information regarding PM failures (e.g., encoding or retrieval). This is followed by a single naturalistic item where examinees are asked to call the examiner in 24-hours' time. Strengths of the MIST include sound psychometric properties (validity, reliability and specificity) (Raskin, 2009; Woods et al., 2008), a scoring system which allows for errors to be evaluated in greater detail than other clinic-based measures and a naturalistic probe assesses PM over an extended period. The administration time of approximately 30 minutes does limit its inclusion in diagnostic neuropsychological assessments where clinicians often have limited time to test patients. However, this is not such an issue in the context of an assessment which is part of developing a management plan for rehabilitation. The children's version, Memory for Intentions Screening Test for Youth (MISTY; Mills et al., 2021) has a briefer administration time of approximately 20 minutes. The MIST has been used successfully in ageing research, as well as clinical populations (Raskin, 2009) and translated into multiple languages (Belmar et al., 2020; Bezdicek et al., 2014).

The Royal Prince Albert Prospective Memory Test (Radford et al., 2011) is a more recently developed clinic-based measure which was specifically designed to be

incorporated into neuropsychological assessments. It involves both clinic-based and naturalistic tasks which the examinee completes at home. The advantages of this measure are the relatively briefer administration length (approximately ten minutes), three alternate forms and sound psychometrics (inter-rater reliability and sensitivity) (Radford et al., 2011). The Miami Prospective Memory Test is another newer task which has been created for use in clinical assessments (Hernandez Cardenache et al., 2014; Simard et al., 2019). The disadvantage of these promising new measures is there is less normative data available than other more established clinic-based measures.

3.3.4 *Advantages and Limitations of Clinic-Based Tasks*

The key advantages of standardised clinic-based measures are the psychometric properties and the preliminary normative databases which have been developed. Unfortunately, they tend to be time-consuming to administer. Furthermore, they are still confined to a clinic setting, which raises the same issue of limited ecological validity as laboratory-based tasks (Philips, Henry, & Martin, 2008).

3.4 Naturalistic Measures

Naturalistic measures provide an alternative to laboratory and clinic-based tasks and attempt to capture real life ability, including allowance for PM tasks involving hours, days or weeks between intention formation and execution (Kliegel et al., 2000). This is achieved by observing participants carrying out tasks in their everyday environment (Phillips et al., 2008). Naturalistic tasks aim to resolve the issue of limited ecological validity encountered by laboratory and clinic-based measures by increasing the degree of similarity between the demands of the introduced PM task and the demands experienced in everyday life (Chaytor & Schmitter-Edgecombe, 2003).

3.4.1 *Types of Tasks*

A variety of naturalistic tasks have been used. An early version involved instructing participants to mail a stamped postcard on certain days in the future (Meacham & Singer, 1977) and continues to be used in research (McBride et al., 2013). Other naturalistic tasks involve completing a series of experimenter-generated everyday tasks (Au et al., 2018; Bailey et al., 2010; Thompson et al., 2011) or self -generated

tasks (Delprado et al., 2013). Simulating an everyday task in a naturalistic environment is another approach, such as the Multiple Errands Test (Shallice & Burgess, 1991) which involves participants undertaking several simple tasks in a shopping centre.

Time call paradigms are a commonly used type of naturalistic task (i.e., time-logging tasks) and typically involve participants phoning the research laboratory at a specified time (Delprado et al., 2013; Maylor, 1990; Sullivan et al., 2018; Thompson et al., 2011). An early time-logging technique by Rendell and Thomson (1993) was later adapted for an electronic organiser (rather than telephone call) (Rendell & Thomson, 1999). Kvavilashvili and Fisher (2007) used a similar time-based protocol (call the researchers at a pre-specified time) but also incorporated an event-based component, by instructing participants to phone the laboratory after receiving a text message. Delprado et al. (2013) adapted the time-logging task used by Thompson et al. (2011) by allowing participants to use strategies (such as written reminders) and increasing task complexity by instructing participants to leave their name and phone number (as opposed to just calling). Thompson et al. (2011) suggest utilising a time-logging task with multiple time points given the limited reliability of a single probe to measure naturalistic PM. Phillips et al. (2008)'s criteria classify time-logging tasks as familiar, yet artificial tasks performed in real life settings. The paradigm allows manipulation of an everyday task, such as calling four times over a two-week period (Delprado et al., 2013) or once a day for five days (Maylor, 1990). Time-logging tasks have been successfully used with research investigating MCI (Delprado et al., 2013) and dementia (Thompson et al., 2011).

Researchers have also included single-item, 'naturalistic' tasks into assessments, referred to as within-assessment naturalistic tasks. These include reminding the researchers of something at the end of the testing session (Ronnlund et al., 2011), repeating particular words (e.g., "red pencil" or "blue pen") whenever the researcher uses those words (Dobbs & Rule, 1987; Schnitzspahn et al., 2020; Zeintl et al., 2007), removing a token out of a drawer when the researcher says a particular sentence (e.g., "The next task involves digits/The next task concerns memory" (Schnitzspahn et al., 2020; Zeintl et al., 2007), writing initials on an envelope (Huppert et al., 2000) or

requesting an envelope at the end of the session (Lee et al., 2018). Although these tasks have a higher verisimilitude than artificial laboratory and clinic-based tasks, they tend to be single trial items with limited reliability.

3.4.2 *Advantages and Limitations of Naturalistic Tasks*

Ecological validity is the primary advantage of naturalistic tasks. However, there is the potential for extraneous variables to influence performance, unbeknownst to the researcher or clinician. Phillips et al. (2008) identify five levels of ecological validity for PM tasks, Type 1 being the strongest and Type 5 being the weakest. Type 1 level of ecological validity requires the participant to perform their own PM task as part of their everyday routine (i.e., self-generated, naturalistic setting). Type 2 level consists of experimenter generated tasks (e.g., mailing postcards) which are performed by participants in their everyday life and according to Phillips et al. (2008), the majority of research meets this criterion, rather than Type 1 level of ecological validity. Given that these tasks are often meaningless to the participant and relatively familiar and straightforward, the results of studies utilising this approach may not be indicative of PM tasks carried out in everyday day life. Phillips et al. (2008) suggest that tasks should be carried out within the daily life of the participants and conducted over several days to increase the reliability of the data and to counter the limited control of extraneous variables that may impact task performance.

3.5 Relationship between Subjective and Objective Measures

The relationship between subjective and objective measures of PM remains unclear. Whilst some researchers argue that subjective measures do not provide a good estimate of actual performance (Thompson et al., 2015), others have found significant relationships (Crawford et al., 2006; Kliegel & Jäger, 2006; Mäntylä, 2003). Sugden et al. (2021)'s comprehensive review of studies using the PRMQ, CAPM and BAPM found only weak to moderate sized relationships with objective measures of PM. Similarly, the relationships between subjective and objective measures in clinical and healthy samples have been inconsistent. In patients with acquired brain injury (ABI), correlations between self-reports and performance have been low (Fleming et al., 2009; Hannon et al., 1995;

Kim et al., 2009; Man et al., 2011; Raskin et al., 2012; Tam & Schmitter-Edgecombe, 2013), while some have reported significant associations between informant reports on the CAPM and performances by adults with TBI, but not self-reports (Fleming et al., 2009). In Raskin et al. (2018)'s study, no associations were found between self-reports on the CAPM and PM performance in a group of adults with moderate TBI, while a subsection of CAPM (basic activities of daily living) was significantly correlated with total errors on the MIST in the healthy adult group. A contrasting pattern was observed by Hogan et al. (2020), who found significant correlations between PM performance and self-reports in individuals with stroke, but not in the control group. Ultimately, it appears that links between subjective and objective measures of PM are described as weak and inconsistent across both clinical and healthy populations.

Existing studies have primarily compared self-reports to laboratory/clinic-based measures, rather than naturalistic tasks. In the limited research available, weak relationships between subjective and naturalistic measures have been reported (Azzopardi et al., 2015; Hannon et al., 1995; Uttl & Kibreab, 2011). However, research examining the convergent validity of PM will often only include a single naturalistic probe, such as calling the examiner 24 hours after their appointment to report how many hours they slept (Sullivan et al., 2018) or writing their name and date on questionnaires then posting them to the researcher (Hannon et al., 1995). As such, the relationship between subjective measures and more reliable naturalistic tasks is largely uncertain (Uttl & Kibreab, 2011) and further research investigating the convergent validity of subjective and naturalistic measures is necessary.

As a potential explanation for the general low correlation between subjective and objective measures, Man et al. (2011) proposed that these two approaches may be measuring different aspects of PM, with questionnaires assessing more long term, habitual PM behaviours than those assessed using objective measures. Another view is that subjective measures may detect subtle problems occurring within everyday life that can be compensated for by increased effort and reduced distractions within a testing environment (Sullivan et al., 2018). This implies that naturalistic measures may

potentially provide insight into these subtle day to day difficulties which may be not detected in laboratory/clinic-based approaches. Hence, additional exploration with subjective and naturalistic PM measures may be beneficial in understanding the facets of PM which each approach measures.

3.6 Chapter Summary

This chapter outlined the considerable research which has been conducted to develop and improve the way in which PM is measured, both objectively and subjectively (for further discussion see Blondelle et al., 2020; Sugden et al., 2021). While self-reports tell us how the patient views their PM ability (invaluable information for clinical practice), objective measures of PM need to provide clinicians with an accurate estimation of a patient's everyday PM ability. This is a major issue for measures carried out in the clinic, and further development of naturalistic style approaches offers a method to further explore the relationship between subjective and objective tasks of PM (see Chapter 6 of this thesis for the background and development of a naturalistic style measure of PM, based in virtual reality technology, and used in this doctoral research). Given the limitations of the current tools, future studies should consider including both clinic-based and naturalistic performance-based tasks, together with a subjective measure. After the current research and aims are outlined, the first research study exploring the relationship between existing PM measures in older healthy older adults is presented (Chapter 5).

3.7 References

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Chapter 4 Current Research and Aims

For many communities around the world, older people are forming an increasing proportion of society (World Health Organisation, 2011). For example, in Australia by 2050, 22% will be over 65 years of age (Australian Institute for Health and Family Welfare, 2018). This shift in ageing flows to an increasing number of older people presenting to hospital emergency departments following an unexpected fall (Moreland et al., 2020; Shankar et al., 2017). Falls can result in a range of injuries, accounting for approximately 90% of hip and wrist fractures and 60% of TBIs in older adults (Kenny et al., 2017). Severe TBI in older age is acknowledged to be associated with very poor outcome, with high mortality rates (Hawley et al., 2017; McIntyre et al., 2013; Patel et al., 2010; Ramanathan et al., 2012) and restricted functional recovery (Harvey & Close, 2012; Hawley et al., 2017). However, mTBI represents approximately 60 to 95% of the presenting hospital cases of TBI (Cassidy et al., 2004; Maas et al., 2017), and the outlook for these older people is far more positive. It is reported that approximately 50% will be able to return home upon hospital discharge (Fu et al., 2017; Hawley et al., 2017). Nevertheless, there is very limited research specifically investigating cognitive outcome in this group (Hume et al., in press). Although, there is a general view that cognition can recover to normative levels by three months following a single mTBI in young adults, there is also recognition that there are several risk factors associated with achieving this outcome, including older age (Dhandapani et al., 2012; Jacobs et al., 2010; van der Naalt et al., 2017). Therefore, the general objective of this current research was to investigate cognitive function following mTBI in older age.

In assessing cognitive outcome post-TBI, it is important to consider what is the purpose of the assessment. For many older people, resumption of ability to live independently and self-manage daily activities is a primary goal post-hospitalisation, especially if living alone. In this regard, PM has been shown to provide clinicians with a functional index of cognition and can identify older adults at risk of everyday difficulties (Beaver & Schmitter-Edgecombe, 2017). However, as a complex, cognitive function (Einstein et al., 2005; Kliegel et al., 2008; Scullin et al., 2013), PM has proved

challenging to measure. Whilst subjective measures (self-report questionnaires) may provide information regarding long-term PM behaviours and the patient's beliefs about their memory, they tend to have weak relationships with actual performance in a clinical testing setting (Sugden et al., 2021). This low association may be partially related to the observation that it is difficult to replicate everyday PM experience within a testing environment, thereby limiting the ecological validity of many laboratory/clinic-based measures. Naturalistic tasks offer a more ecologically valid option, but further investigation is needed to establish their relationship with subjective measures. Nevertheless, incorporating naturalistic-style PM measures may be beneficial in assessing cognitive functioning in older adults following mTBI.

4.1 Research Aims

The primary aim of this research was to examine the usefulness of naturalistic-style measures of PM for assessing the cognitive outcome of older adults following mTBI. This research took the form of three interrelated studies. Study 1 (Chapter 5) investigated the relationship between subjective and objective measures (clinic-based and naturalistic) in healthy older adults. This study addressed a gap in the literature, as past studies have predominantly focussed on the relationship between laboratory/clinic-based tasks and subjective measures, rather than naturalistic tasks. Study 2 (Chapter 7) extended the naturalistic assessment of PM to include a novel augmented reality task assessing shopping behaviour (development and methodology of this task is provided in Chapter 6). In this study, the focus was to investigate whether naturalistic tasks of PM were more sensitive than clinic-based tasks to identify differences in performance between older adults following mTBI when compared to healthy older adults and older adults who had sustained an orthopaedic injury. There is little existing research assessing cognition in older adults following mTBI and the inclusion of naturalistic style measures provided a novel contribution to the literature. Following the findings of Study 2, formal examination of the validity of the augmented reality task (LIST) was examined in Study 3 (Chapter 8). These two studies provided information about the potential usefulness of augmented reality in the assessment of PM, specifically with older people.

If positive, this information could be used to provide support for the use of immersive platforms in future research.

Given the sample size, it was imperative to minimise experimental variables to ensure adequate statistical power. As such, one discrete construct from the multi-phase model of PM (McDaniel & Einstein, 2007), which has received most experimental investigation, was selected, i.e., attention set-shifting, together with retrospective memory. We prioritised including four measures of PM, given it is the primary focus of this doctoral thesis.

The research presented in this thesis was approved by the Alfred Hospital (**Appendix B**) and La Trobe ethics committees (**Appendix C**) (project ID 382/15). All participants gave written informed consent - Participant Information and Consent Form for healthy older adults (**Appendix D**) and Participant Information and Consent Form for trauma participants (**Appendix E**). Telephone screening was carried out before inclusion in the study (**Appendix F**).

4.2 Research Questions

The overarching research questions for each phase of this doctoral research are below:

Study 1 (Chapter 5)

1. What is the relationship between subjective and objective measures of PM in healthy older adults?
    a. Is self-reported PM related to performance on a naturalistic task, as opposed to performance on a standardised clinic-based measure?
    b. What is the relationship between performance on the clinic-based measure and performance on the naturalistic task?
2. Are the three measures of PM predicted by similar cognitive processes - retrospective memory and executive function?

Study 2 (Chapter 7)

1. Are there any group differences on PM measures when comparing older adults with mTBI to healthy older adults and older adults with orthopaedic injuries at three months post-injury?
2. Does retrospective memory and/or executive function moderate the relationship between severity of brain injury and performance on naturalistic style tasks of PM?

Study 3 (Chapter 8)

1. When compared to standardised and naturalistic tasks, is there evidence of convergent validity for the LaTrobe Itemised Shopping Task (LIST)?
2. Is the LIST sensitive in detecting PM difficulties? Can the LIST differentiate between a sample of healthy older adults and a mixed-trauma sample?

4.3 General Discussion

The final general discussion (Chapter 9) reviews the evidence from the research for further development of naturalistic measures, specifically augmented reality tasks, for assessing PM outcomes following mTBI. It also considers the clinical and practical implications of the research findings to the ongoing management and support of older people following traumatic injury.

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Chapter 5 Assessing Prospective Memory in Older Age: The Relationship between Self-report and Performance on Clinic-based and Naturalistic Tasks

5.1 Chapter Overview

This chapter presents the first empirical study of this thesis which explores the relationship between subjective and objective measures of PM in healthy older adults. Past research has primarily focused on investigating the association between self-report and laboratory-based or clinic-based measures of PM, rather than naturalistic tasks. As such, the aim of this study was to examine the convergent validity between self-report and two performance measures, a naturalistic task, and a clinic-based task.

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5.2 Chapter Summary

The first empirical study of this thesis was presented in this chapter. This study explored the association between self-report (PRMQ) and two objective measures, a standardized clinic-based task (CAMPROMPT) and a naturalistic task (the Telephone Task) in a group of healthy older adults. The results showed that self-reported PM was related to performance on the Telephone Task. A moderate association between the clinic-based and naturalistic tasks was also identified. In summary, this study contributes to the limited research investigating the relationship between subjective and naturalistic measures of PM. Although naturalistic tasks may be a useful tool for obtaining information about patients' everyday experience of PM, a naturalistic measure which can be administered within a clinic environment would minimise extraneous variables.

Chapter 6 Development of an Augmented Reality Task of Prospective Memory: LaTrobe Itemised Shopping Task

6.1 Chapter Overview

As discussed in Chapter 3, ecological validity is important for the assessment of PM. Study 1 demonstrated naturalistic tasks may provide information regarding PM challenges experienced by older adults in their everyday life. Extended reality platforms are another naturalistic approach of assessment which may be useful for detecting cognitive difficulties in older adults following mTBI. This chapter will describe the background and development of the LaTrobe Itemised Shopping Task (LIST), together with the task protocol and scoring criteria. The LIST administration form and scoring form are provided in **Appendix G** and **Appendix H**, respectively.

6.2 Extended Reality

6.2.1 *Definition of Extended Reality*

Parsons et al. (2020) have proposed the use of the term extended reality (XR) as an umbrella term for virtual reality (VR), augmented reality (AR), and other immersive environment technologies. VR platforms have multi-sensory immersive environments, mostly using a headset, while AR uses non-immersive platforms; but both platforms combine naturalistic stimuli, usually highly familiar, and pair with digital technology to create an interactive view of the real world (such as walking along a city street). Mixed-reality platforms use a combination of both VR and AR (Parsons et al., 2020). In early PM research, AR tasks have often been referred to as 'virtual reality' tasks; but, for clarity, the term XR will be used in this chapter when discussing research using these platforms.

6.2.2 *Aims of Extended Reality in Prospective Memory Research*

As outlined in the previous chapters of this thesis, there has been extensive discussion of the advantages and disadvantages of subjective and objective measures of PM (i.e., experimental, clinical, and naturalistic) (Raskin et al., 2018). A potential resolution relates to development of PM tasks which combine aspects of both experimental and naturalistic tasks; and more specifically, XR tasks aim to bridge the

gap between these tasks and everyday behaviour (Parsons, 2015; Titov & Knight, 2005). This technology retains the positive elements of experimental measures, such as experimenter control, whilst incorporating the presentation of naturalistic stimuli to enhance ecological validity (Canty et al., 2014; Knight & Titov, 2009; Parsons & Duffield, 2020; Parsons, 2015; Titov & Knight, 2005). XR assessments allow for improved administration with both consistent presentation of stimuli as well as dynamic control, allowing for manipulation of realistic distractions (Parsons, 2015). XR tasks which closely resemble real-world functions may allow for more accurate prediction of actual abilities (Parsons, 2015), which is especially important in the clinical assessment of PM.

6.3 Literature Review

Early studies successfully used XR platforms to examine a range of cognitive abilities including executive functioning (McGeorge et al., 2001; Pugnetti et al., 1995) and memory (Brooks et al., 2004; Matheis et al., 2003; Morris et al., 2002). Since then, a growing number of XR tasks have been developed to assess PM and everyday functioning: The Jansari Assessment of Executive Function, which assesses action based, event based and time-based PM (Denmark et al., 2019; Horlyck et al., 2021; Jansari et al., 2014), the Virtual City inspired by Paris (Abram et al., 2015; Debarnot et al., 2015; Girardeau et al., 2020), the Children's Cooking Task (Krasny-Pacini et al., 2017), the Virtual Museum (Duivon et al., 2018), and the Virtual Reality Prospective Memory Test (Man et al., 2018; Yip & Man, 2013).

Apart from the various benefits of these tasks in assessing PM in several clinical populations, XR tasks of PM have been found to be sensitive in detecting impairments in TBI populations (Banville & Nolin, 2012; Banville et al., 2010; Canty et al., 2014; Clune-Ryberg et al., 2011; Knight et al., 2006; Lajeunesse et al., 2019; Matheis et al., 2007; Potvin et al., 2011; Renison et al., 2012). Titov and Knight (2000) were one of the first to use an XR measure of PM with patients with brain injuries (including TBI). It involved a video tape showing the view of a person walking through a large department store and participants were instructed to recall the correct action in response to a cue in the footage (e.g., Buy a CD when the music section of the store is shown in the video).

Participants also carried out an *in vivo* procedure of the task in the same large department store. The study found significant correlations between the two tasks, ~~suggesting that XR measures of PM may be valid estimates of real-life performance~~ suggesting that further investigation of XR measures was warranted. From this, the Prospective Remembering Video Procedure (Titov & Knight, 2001) was developed with event-based PM tasks (e.g., purchase a hamburger) in response to cues presented in the video footage of a shopping district (e.g., a streetscape including McDonalds). Similar video-based tasks were later used by the authors in TBI studies (Knight et al., 2005; Knight et al., 2006; Titov & Knight, 2005) and ageing research, with older adults performing worse than younger adults (Knight et al., 2008; McDermott & Knight, 2004). Subsequent TBI studies have reported associations between performance on XR measures of PM and patients' everyday functioning as reported by informants (Canty et al., 2014; Potvin et al., 2011), providing preliminary evidence of ecological validity for this method of assessment. Research using XR measures of PM and younger adult TBI cohorts are also promising (Banville et al., 2010; Lajeunesse et al., 2019; O'Brien & Kennedy, 2018), but further investigation is needed to determine the appropriateness for older adults post-TBI who may be more hesitant about using computer-based technology.

XR measures of PM have been successfully used, however, with healthy older adults (Lecouvey et al., 2017) and older adults with subjective memory decline (Ouellet et al., 2018). Older adults tend to be excluded in the development of XR technology, given it is primarily associated with gaming platforms used by younger adults (Lee et al., 2019). As such, older age patients may present with physical attributes (e.g., physical impairments, visual difficulties) and cognitive characteristics (e.g., low confidence, negative attitudes, fear of technology) that are barriers to engagement with XR platforms (Lee et al., 2019). Including older adults in the development process will help minimise the impact of these factors (Seifert & Schlomann, 2021), though recent findings do suggest XR is feasible for use with community dwelling older adults (Corregidor-Sanchez et al., 2020), as well as those with cognitive and physical impairments (Appel et al.,

2020). Based on the literature available, XR measures appear to be appropriate for use with older adults and may be useful in studies investigating outcomes after mTBI.

6.3.1 *Shopping-based Tasks*

Unlike many everyday tasks, shopping can readily depict the various steps of PM behaviour. For example, at breakfast you notice you are running low on milk and will need to buy some from the supermarket on your way home (e.g., intention formation), you retain this information throughout the workday (e.g., maintain the intention), you stop at the supermarket on your way home (e.g., initiate task) and you purchase milk (e.g., execute intended task). XR technology allows for distractors typically encountered when shopping to be incorporated into the task (e.g., background noise). XR shopping-based tasks of PM have successfully been used in ageing studies (Farrimond et al., 2006; Knight et al., 2008; McDermott & Knight, 2004; Parsons & Barnett, 2017) and general TBI research (Canty et al., 2014; Knight et al., 2005; Okahashi et al., 2014; Okahashi et al., 2013; Potvin et al., 2011; Titov & Knight, 2005). Although these findings indicate shopping-based tasks of PM may be an ecologically valid method of assessment for older adults, investigations have not focused on older age patients who have also sustained a TBI. Therefore, further exploration is required to determine the feasibility of using a shopping-based XR measure of PM with this demographic.

6.4 Development of the LaTrobe Itemised Shopping Task (LIST)

The objective of developing another AR shopping task for the present research cohort was to ensure local relevance and familiarity with the type of supermarket used in the task. The aim was to investigate the viability of using AR with older adults following mTBI, rather than investigation of the specific AR task (LIST) itself.

The LIST was a modification of the Virtual Shopping Trip Task (Kinsella et al., 2009) which involved participants having to remember to ‘buy’ eight shopping items whilst watching an 8-minute DVD of a supermarket trip. The task involved three components: (i) a planning component (participants selected items for a dinner meal and wrote them down on a shopping list which was later removed from sight); (ii) a distractor component (participants were instructed to report each time they saw an item on

'special'); and (iii) a PM component (when the eight items were shown in the DVD footage, participants were asked to say the name of the item and press the space bar to 'buy' the item). The task had two conditions, a low-attention demand condition and a high-attention demand condition. In the high-attention demand, the participant was asked to monitor the time by periodically pressing a clock placed on one side of the screen. The outcome variables were the number of correct items collected in the low-attention condition and in the high-attention condition. The Virtual Shopping Trip Task has since been used in other research studies, most recently in an investigation of memory in community dwelling older adults by Lee et al. (2018).

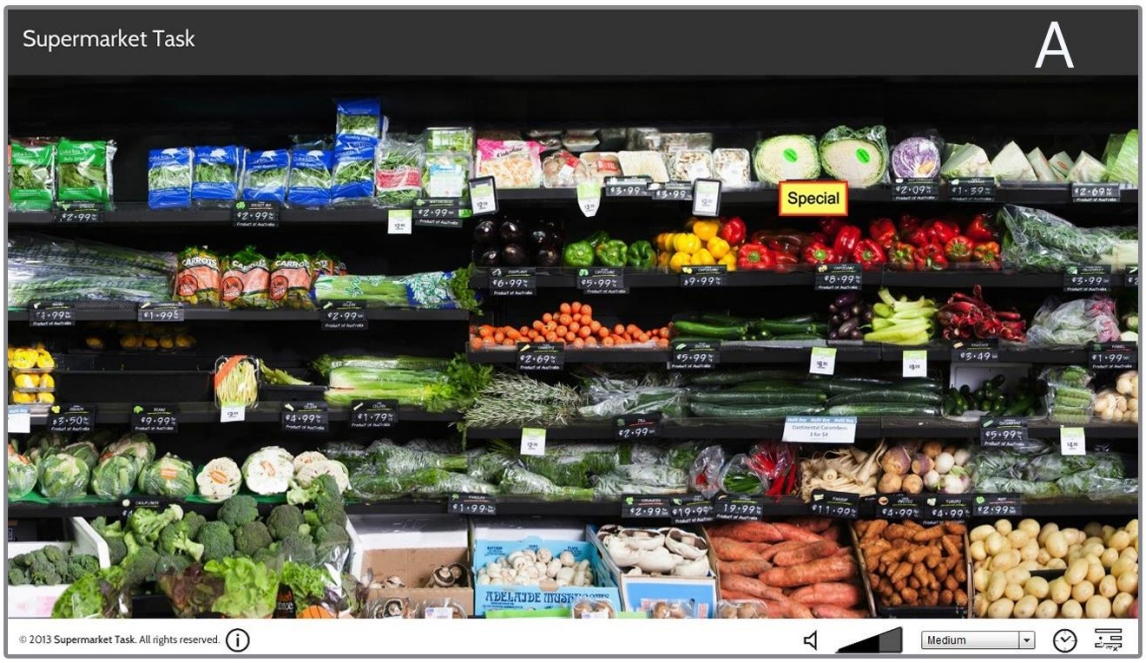
Incorporating advances in technology, the current version (LIST) uses an interactive computer program (in substitution of the DVD component of the original task) and allows participants freedom to dictate the course of the shopping trip. This includes returning to previously visited aisles and controlling the browsing rate of individual aisles. Using an AR platform, the LIST aims to further the ecological relevance of the Virtual Shopping Trip Task and the broader assessment of PM. Compared to the rudimentary DVD video originally used, the LIST digital platform has increased real-world resemblance, not only in terms of appearance, but in the design of the task and the self-directed operation of the measure (rather than experimenter-directed control). The higher the similarity between the LIST and the real-life activity of shopping at a supermarket, the greater likelihood that the findings of the research can be interpreted as a valid indication of everyday memory performance.

The LIST follows a dual-task paradigm of PM (McDaniel & Einstein, 2000) and meets the three basic parameters of a PM task (McDaniel & Einstein, 2007): (i) the task involves the delayed execution of intended actions; (ii) the intended action is performed in the context of an ongoing foreground task (i.e., distractor task); and (iii) the task provides a constrained window of time in which the intention may be initiated and executed. The LIST is a shopping task where participants self-navigate through shopping aisles to find and 'collect' shopping items (by clicking on the item with the computer

mouse). Participants are provided with feedback when an item has been “collected”, a circle briefly appears around the item on the screen and a sound is played (Figure 6.1).

Figure 6.1

Images of the LaTrobe Itemised Shopping Task

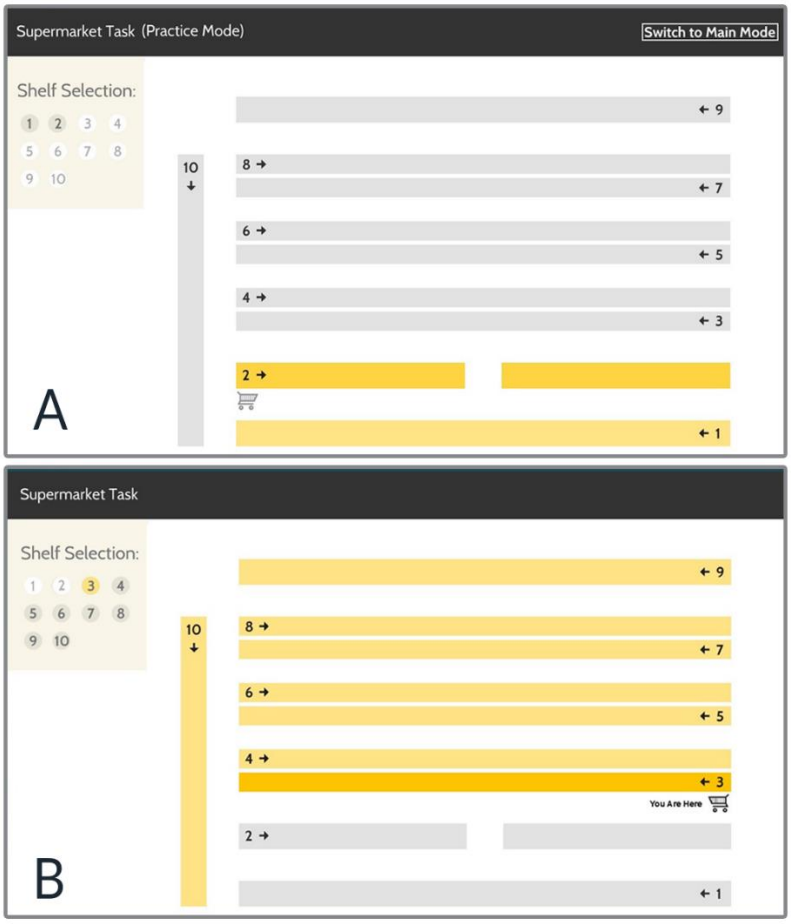


Note. Image A shows a supermarket aisle where participants use the computer keyboard to navigate along the aisle and locate shopping items. Image B shows the participant ‘collecting’ an item by clicking the item with the computer mouse.

The LIST has two PM tasks – collecting shopping items (that are not included on the shopping list) and a naturalistic, within-assessment probe. The distractor task involves collecting items from a shopping list. The program consists of ten shopping aisles and a main menu, which allows navigation between the aisles. Aisles number 1 and 2 are utilised within the practice component of the task (Figure 6.2a), whilst aisles number 3 to 10 are used in the main shopping task (Figure 6.2b). Participants are provided with a demonstration of the task and then complete a practice trail using a practice shopping list (**Appendix I,** page 1) to become familiar with the program. Additional practice and guidance are provided if needed. Participants who can successfully use the program proceed to the next stage of the task.

Figure 6.2

The LaTrobe Itemised Shopping Task homepage.



Note. This is where participants access the shopping aisles during the LaTrobe Itemised Shopping Task. Image A shows the homepage for the practice mode. Image B shows the homepage for the main task.

LIST Distractor Task. The Virtual Shopping Trip Task distractor task of verbally reporting items with a special sign has been altered in the newly developed LIST. Participants are provided with a written shopping list (**Appendix I**, page 2) and instructed to find and collect the 12 items whilst navigating through the simulated supermarket aisles. The items are divided evenly across the aisles. For each shopping item, participants are scored zero if the item is not collected, one point if they initially missed the item but later returned to the aisle and collected the item, and two points for collecting the item. Scores for the distractor task range from zero to 24.

LIST Targets. Like the Virtual Shopping Trip Task, the LIST also requires participants to remember to 'collect' six items whilst navigating through the aisles of the computer simulated supermarket. However, participants 'collect' items by clicking on the desired item with the mouse, rather than verbally reporting the item to the examiner. Participants are instructed, that in addition to collecting the items from the shopping list, they will also need to collect six items for their ill neighbour which they have forgotten to add to their shopping list (target items). As part of the instructions, the six shopping items are provided in a list-learning manner for a maximum of four trials to ensure participants can correctly recall all the items (page 2 of **Appendix H**). The scoring system for the shopping list and target items is the same. Each item is scored out of two, with two points awarded if the item is collected, one point awarded if they missed the item but collected the item at a later point and zero if they failed to collect the item. Scores for each item are summed to create the outcome variable – LIST Targets (scores ranged from zero to 12), with higher scores indicating better PM.

As prospective memory occurs within the context of a cue, internal or external (Scullin et al., 2013), investigating post-test capacity for recognition recall of the to-be-remembered items, as opposed to delayed free-recall, is relevant to establishing baseline capacity to perform the PM task. That is, by the end of PM task, can the participant still recognise the shopping items that they were meant to buy. The post-test forced choice recognition task asks participants to choose between a distractor item (not

included on the shopping list) and a target item, with one point awarded for each correct item.

LIST Credit Card Task. An additional naturalistic style probe of PM was incorporated into the LIST - the Credit Card Task. It is a single PM probe at two time points, with PM and retrospective memory components combined to calculate a total score for the task. The background information for this task is linked to a story about an ill neighbour (see task instructions in **Appendix G**) who requires the shopping items (targets). Participants are instructed to verbally request their neighbour's credit card before commencing 'shopping' and to return the card after completing shopping. The same scoring criteria is used for both the short and delayed components of the Credit Card Task. For the PM component, participants who spontaneously request/return their neighbour's credit card when presented with the cue (i.e., instructions to begin shopping or after shopping is completed) are awarded two points. Participants who do spontaneously request/return their neighbour's credit card within 15 seconds are scored zero. For the retrospective memory component, participants are given two points for correct free recall (i.e., spontaneously requesting the credit card or returning the credit card), one point for correct recall with a prompt (cued recall) and zero for incorrect or no recall. The two time points are combined to form the PM and retrospective memory subscales (scores range from zero to four). The two subscales are summed to create the outcome variable, Credit Card Total (scores range from zero to eight), with higher scores reflecting better PM performance.

The development of the LIST, a shopping-based task of PM was outlined in this chapter. As a newly developed task, an evaluation of the psychometric properties of the LIST will be undertaken in subsequent studies: (i) inter-item reliability (Cronbach's alpha); (ii) convergent validity (Chapter 8); and (iii) test sensitivity (Chapter 8). To ensure inter-rater reliability, a second researcher will score blinded protocols in a retrospective fashion.

6.4.1 *Materials*

The LIST program is installed on a laptop computer with speakers and an external mouse. Other materials required for administration include LIST Instructions for Administration (**Appendix G**), LIST Record Form (**Appendix H**) and LIST Shopping lists (**Appendix I**).

6.4.2 *Procedure*

The laptop is positioned on a desk, approximately 50cm from view, and participants are provided with initial instructions:

> *In a little while you will view the aisles of a supermarket as displayed on the computer. Similar to shopping in everyday life, you will have a list of items to buy and some other tasks to remember. I will demonstrate how to use the program and you can practice in a moment. When you go shopping, you will be able to refer to a list of shopping items and when you see an item from the list, you will be able to 'pick it up' by clicking on the item with the computer mouse. The computer screen will provide you with feedback so that you will know an item has been picked-up. Do you have any questions?*

The researcher carries out a demonstration of the task by entering the supermarket aisles from the menu, navigating left and right along the aisles, and selecting shopping items. Participants are then provided with the practice shopping list and asked to search for the items in aisles 1 and 2. If the participant appears to be having difficulty learning the task, the researcher can provide further instructions and assistance. Once the researcher is satisfied the participant is comfortable with the task, the instructions for the PM targets are provided:

> *There is something else you need to do. Your neighbour is ill, and you need to pick up some items for them. You forgot to add these items to your shopping list before leaving home. Please try to remember to collect these items later when you go shopping. You can click on them just like the other shopping items.*

The researcher verbally presents the six items for the ill neighbour at the rate of approximately one per second. The participant is then asked to recall the items, in any order. This is repeated for a maximum of four trials. The instructions are as follows:

> *I am going to read you a list of the six items for your neighbour. Please listen carefully because when I am finished, I want you to tell me as many items as you can. It can be in any order.*

After the first trial is completed, the researcher provides the following instructions: "*I will read the same list again. Like before, tell me as many items as you can, including ones you have already said, if you can*". These instructions are repeated for the third and fourth trials, if needed. The researcher then provides the instructions for the Credit Card Task:

> *I have something else for you to remember. Can you ask for your neighbour's credit card before you commence shopping? You can say "I would like my neighbour's credit card". Once you have finished shopping, can you remember to return the credit card to me? Do you have any questions?*

The laptop is moved out of the way and the participant is advised: "*We will return to this task later*." At this point there is a five-minute break where another neuropsychological test is administered, such as the Trail Making Test (TMT; Reitan & Wolfson, 1995). Memory tasks should not be administered during this break.

After the break, the laptop is placed in front of the participant. They are provided with the shopping list and instructed to commence shopping (cue for credit card short delay). If participants do not spontaneously ask for their neighbour's credit card within 15 seconds, the researcher provides a prompt: "*You were going to ask me something when we came back to the shopping*."'

After credit card short delay, participants carry out the distractor task (collecting items from the shopping list) and the PM targets (collecting the six items for their ill neighbour).

Once the participant has completed their shopping (cue for credit card long delay), if participants do not spontaneously return their neighbour's credit card within 15

seconds, the researcher provides a prompt: *"You were going to do something after you finished shopping."*

After the credit card long delay, the researcher administers the forced-choice recognition task: "*'Which one of these were items for your ill neighbour? Was it….*"

6.5 Chapter Summary

XR technology offers a promising solution to the assessment of PM which is ecologically valid while allowing for experimental control (Parsons & Duffield, 2020). Shopping activities are commonly performed in everyday life and can be adapted to follow a PM task paradigm. This approach to the assessment of PM may be beneficial in detecting cognitive difficulties experienced by older adults following mTBI and was explored in the following studies.

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Chapter 7 Cognitive Performance in Older Adults at Three Months Following Mild Traumatic Brain Injury

7.1 Chapter Overview

This chapter contains the second empirical study of this thesis. This study investigates cognitive outcomes in older adults following mTBI and incorporates the augmented reality (AR) task developed in the previous chapter. The aim of this study was to assess cognition at three months post-injury and explore any potential relationship cognitive resources may have on PM performance.

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7.2 Chapter Summary

Limited research has been conducted which assesses cognitive performance in older adults following mTBI. This study aimed to address this issue by assessing PM performance at three months post-mTBI. The study included a standardized measure of PM (CAMPROMPT), together with two naturalistic style measures, an augmented reality task (LaTrobe Itemised Shopping Task; LIST) and a naturalistic task (the Telephone Task). Performance was compared to a group of older adults with orthopaedic injuries (OC group) and a group of community-dwelling healthy older adults (CC group). Group comparisons revealed the mTBI group performed significantly worse on the LIST than the CC group, implying naturalistic approaches to assessing PM, particularly AR tasks, may be sensitive to detecting cognitive difficulties in older adults following mTBI. Based on these findings, further examination of the usefulness of the AR task is warranted. Another key finding was the lack of significant differences between older adults who had experienced a mTBI and those who had sustained orthopaedic injuries, suggesting the two groups could be combined to form a mixed-trauma sample. Although the findings of this study are promising, it should be noted that both the mTBI and OC groups performed significant worse than the CC group on a measure of retrospective memory. Moderation analyses revealed retrospective memory performance directly influenced performance on the LIST, therefore demonstrating the critical involvement of retrospective memory in successful prospective remembering. Nonetheless, PM may still have utility in capturing functional memory performance in older adults following an injury.

Chapter 8 Advantages of Augmented Reality in Prospective Memory: Validation of a Novel Measure for Older Adults

8.1 Chapter Overview

The third empirical study is presented in this chapter. The aim of this study was to assess the validity of the LaTrobe Itemised Shopping Task (LIST), the novel AR task developed as part of this thesis. The study examined the convergent validity and sensitivity of the LIST to differentiate between a healthy older adult group and a mixed-trauma group.

Submissions Status. This article was submitted for publication on 18 June 2021 and is currently under peer review. The full citation is:

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Abstract

Prospective memory is important for independent functioning, especially in older age. However, evaluation is challenging. This study examined validity of a new measure of shopping behavior (LIST), using augmented reality (AR). Healthy older adults (HOA group; *n* = 46) and older adults following traumatic injury (Trauma group; *n* = 102) were administered the LIST and compared to paper-and-pencil and naturalistic tasks. Logistic regressions examined the sensitivity of the LIST to discriminate injury groups. Hierarchical regression explored the contribution of pain to performance. The LIST was positively associated with the paper-and-pencil (HOA *r* = 0.34; Trauma *r* = 0.38 - 0.22) and naturalistic (Trauma *r* = 0.21– 0.30) measures and was a unique predictor of group allocation (*β* = -0.11). Pain differed between groups but did not predict the LIST. The findings provide preliminary evidence of the validity of LIST and endorse the use of AR in cognitive assessments with older adults.

Keywords: augmented reality; prospective memory; older adults; traumatic injury; neuropsychology assessment; pain

Prospective memory, remembering to perform an action at the intended time in the future (McDaniel & Einstein, 2011), has been linked to functional independence in older adults (Hering et al., 2018; Woods et al., 2012) and activities of daily living (Tierney et al., 2016), including medical appointment attendance (Raskin et al., 2018; Sheppard et al., 2020). Understandably, health professionals are seeking further information about assessment techniques for measuring prospective memory ability. The degree to which a measure resembles cognitive tasks performed in everyday life is important to both clinicians and researchers. Tasks with greater ecological validity allow the results of test performance to be interpreted as an accurate indication of the individual's ability in everyday life. To date, standardized paper-and-pencil memory measures designed for clinical practice have often been criticized for their limited ecological validity (Phillips et al., 2008). This is largely due to the stimuli utilized by these measures and the setting where they are administered (Potvin et al., 2011).

Although naturalistic measures (i.e., tasks performed in the individual's everyday life) are ecologically valid, they may allow extraneous variables, which cannot be controlled by the clinician to influence performance; for example, use of individualized prompts or cues (Robin & Moscovitch, 2017; Tomaszewski Farias et al., 2018). Therefore, tasks incorporating augmented reality (AR), together with other extended reality (XR) platforms, may provide a more robust method for measuring prospective memory performance. Although tasks like the Virtual Week (Rendell & Craik, 2000) have been adapted for computer-based delivery (Henry et al., 2020), AR tasks simulate the naturalistic environments where every day prospective memory tasks are generally carried out. AR and VR platforms also allow tight experimental control, including easy manipulation of the task and testing conditions, while using real-world, naturalistic imagery; thus, providing the benefits of an ecologically valid, dynamic, and cost-effective assessment (Bohil et al., 2011; Parsons & Phillips, 2016; Rose et al., 2005). Preliminary studies have used AR technology to assess prospective memory in young healthy adults (Gonneaud et al., 2012), younger age patients following traumatic brain injury (TBI) (Banville & Nolin, 2012; Canty

et al., 2014), Alzheimer's disease (Lecouvey et al., 2019) and first-episode schizophrenia (Man et al., 2018).

With the increasing rates of falls in older adults (Moreland et al., 2020) and the subsequent economic burden these place on health systems (Haagsma et al., 2020), older adults who have sustained an unexpected injury (such as from a fall) are a population who may benefit from cognitive assessment, including prospective memory review. Older patients after an injury, even those who have not experienced a brain injury, have been found to perform significantly worse than age-matched community controls on cognitive tasks when assessed at short-term follow-up (Kinsella et al., 2014). This trauma effect was replicated by Gryffydd et al. (2021), but a key finding was the lack of significant difference between those who had sustained a brain injury and those who experienced an orthopedic injury. This suggests that it may be appropriate to use a mixed trauma sample with older adults when investigating cognitive performance.

In the absence of clear evidence of brain injury effects, suggested explanations for these cognitive difficulties have included the distracting impact of pain from orthopedic injury (Anderson, 2020; van der Leeuw et al., 2018), or the presence of heightened psychological distress post-trauma (Glienke & Piefke, 2017; Shields et al., 2017; Szollosi et al., 2018). Given the limited research available in this area, especially in relation to prospective memory, further exploration is needed. Consideration of pain, in particular, may be beneficial in developing our understanding of cognitive outcomes in older adults after an injury and in identifying patients at risk of everyday memory difficulties.

The Supermarket Shopping Trip Task (Kinsella et al., 2009) was an early iteration of an AR prospective memory task and was more recently used by Lee et al. (2018) in an investigation of memory in community dwelling older adults. Building on a dual-task paradigm (McDaniel & Einstein, 2011), the task involved presenting examinees with a DVD video of a real-world supermarket and instructions to "buy" six pre-determined shopping items as the items were presented in the footage. Participants also carried out a distractor task which involved identifying items on "special". The LaTrobe Itemised Shopping Task (LIST; Gryffydd et al., 2021) is a modification of the original task, by using an interactive

computer program in substitution of the DVD component of the original task. This allows participants freedom to dictate the course of the shopping trip, including returning to previously visited aisles and controlling the browsing rate of individual aisles without examiner constraint. The appearance, design, and self-directed operation of the LIST was designed to more closely resemble real-life; thereby increasing the likelihood that the findings can be interpreted as a valid indication of everyday memory performance.

As a newly developed task, the primary objective of this paper was to evaluate the validity of the LIST and more generally, demonstrate the usefulness of extended reality technology in the assessment of prospective memory. In a previous study (Gryffydd et al., 2021), we reported on mild brain injury effects on cognitive performance in older age. Using this same sample, we now focus on further investigation of the measures used in assessing prospective memory. This sample included: (i) a group of healthy older adults (HOA group); and (ii) a mixed sample of older adults who had sustained a traumatic injury three months prior to testing (Trauma group). To assess convergent validity, group performances on the LIST were compared to a standardized prospective memory measure, the Cambridge Prospective Memory Task (CAMPROMPT; Wilson et al., 2005) and a naturalistic prospective memory task, the Telephone Task (Delprado et al., 2013; Gryffydd et al., 2020; Maylor, 1990). We hypothesized the LIST to be positively associated with prospective memory tasks. A logistic regression model was used to investigate the sensitivity of the prospective memory tasks (CAMPROMPT, LIST and Telephone Task) to discriminate between the HOA and Trauma group. Lastly, exploratory analyses were performed with the mixed Trauma group to investigate any potential relationship between pain and performance on the LIST, after controlling for biopsychosocial factors (age and education).

Method

Participants

The sample consisted of two groups of older adults; namely community-based older adults who volunteered to participate in the research and were recruited through local community organizations in Melbourne, Australia (Healthy Older Adult group; *n* = 46), and

older adults who presented to the Emergency Department at The Alfred Hospital, Melbourne for the management of a mild traumatic injury (Trauma group; *n* = 102) (see Gryffydd et al., 2021). The present study is part of a larger research project examining traumatic injury in older adults and was approved by The Alfred Hospital and La Trobe University ethics committees (project ID 382/15). All participants provided written informed consent. Performance validity tests were administered as part of the assessment and did not detect any invalid performances, and at the time of assessment, no participant was seeking compensation for their injuries.

Inclusion and Exclusion Criteria

For all participants, inclusion criteria were: (i) aged 65 years or older, (ii) fluent in English; and (iii) living independently in the community (Lawton & Brody, 1969) and within three hours of Melbourne, Australia. Individuals recruited into the Trauma group if they had sustained a mild brain traumatic injury (mTBI; Kristman et al., 2014) as a result of a fall less than 3 meters or a low-speed traffic accident, for example, and/or orthopedic injury, with injury severity ≤ 3 on the Abbreviated Injury Score (AIS; Gennarelli & Wodzin, 2008). Exclusion criteria for both groups included: (i) presence of a health condition (other than the traumatic injury) likely to impair cognition (e.g., dementia, stroke, bipolar disorder), or report of seeking professional assistance (pre-trauma) due to concern about memory; (ii) score of ≤14 on a telephone-administered screening measure for identifying potential dementia cases (Gatz et al., 1995); (iii) receiving treatment for a life-threatening medical illness (e.g., cancer); and (iv) inability to fully participate in the research because of uncorrected visual or auditory impairment, or injury to the dominant hand.

Materials

Background and Subjective Materials

Demographic information, including gender, age, education and primary occupation during working life (Australian Bureau of Statistics, 2009), were obtained from participants during the telephone screening process. Participants were also administered (i) a 5-point Likert type scale of self-rated general health *"How would you describe your general health compared to other people your age?"* (scores ranged from 0 [poor] to 4

[excellent]); and a similar scale of self-rated memory *"How would you describe your day-to-day memory compared to other people your age?"* (scores ranged from 0 [poor] to 4 [excellent]); (ii) a 5-point Likert type scale of pain *"During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?*" (scores ranged from 1 [not at all] to 5 [extremely]); and (iii) the Depression Anxiety Stress Scale (DASS 21; Lovibond & Lovibond, 1995) total score was used as a measure of general psychological distress (raw scores are multiplied by 2 and range from zero to 120), with larger scores indicating higher levels of psychological distress. Participants were provided with the pain scale and DASS 21 at the end of the testing session and asked to return the completed forms in a self-addressed envelope within the next week.

Prospective Memory Assessments

Augmented Reality Task*.** The LaTrobe Itemised Shopping Task (LIST; Gryffydd et al., 2021) utilizes AR technology to combine images from a real-world supermarket with a digital computer-based platform (see ***Figure 8.1). Founded on the dual-task paradigm of prospective memory (McDaniel & Einstein, 2011), the LIST involves; (i) a distracting ongoing task (Distraction Task), in which participants are asked to locate and collect 12 shopping items from a pre-prepared written shopping list; (ii) two prospective memory tasks – (a) participants are requested to collect a further six examiner-selected shopping items (LIST Targets) which were not included on the written list; and (b) participants are asked to request a credit card from the examiner before commencing 'shopping' and to return the card (without an initial prompt by the examiner) after completing shopping (Credit Card Task); and (iii) a post-test forced-choice recognition task to determine if the participant could recall the LIST target items after a delay. For both the target and distractor items, two points were awarded for correct items, one point for items initially missed but collected when the participant returns to the aisle at a later point, and zero for items that are not collected. Total scores for the Distraction Task are zero to 24. Total scores for the LIST Targets range from zero to 12, and participants are given one point for each correct target item in the post-test recognition task, with a total of six. The Credit Card Task has

two scoring components, reflecting task initiation and task information recall; (i) participants who spontaneously actioned the task at the correct time were given two points, and zero if they did not perform the task within 15 seconds; and (ii) participants were given two points for correct free recall of the task details, one point for correct recall following a prompt and zero for incorrect/no recall. Credit Card Total represents the sum of both time points (scores ranged from zero to eight). Higher scores for the LIST Targets and Credit Card variables are indicative of better prospective memory performance. The LIST outcome variables were found to have acceptable inter-item reliability (Cronbach alpha values: LIST Targets Total α = 0.90; Credit Card Total α = 0.62) (Hair et al., 2010).

Figure 8.1

The LaTrobe Itemised Shopping Task

Note. Image A shows a supermarket aisle where participants use the computer keyboard

to navigate along the aisle and locate shopping items. Image B shows the participant "collecting" an item by clicking the item with the computer mouse.

Standardized Paper-and-Pencil Measure. The Cambridge Prospective Memory Test (CAMPROMPT; Wilson et al., 2005) is a standardized measure which was included to examine the convergent validity of the LIST. It consists of six prospective memory tasks and a distraction task (completing puzzles and general knowledge quizzes) carried out over a 20-minute period. The scoring for each item ranges from zero to six, based on accuracy and timeliness. The scores for the six items are summed to form the outcome variable, CAMPROMPT Total (scores range from zero to 36), with higher scores indicating better performance.

Naturalistic Task. The Telephone Task (Delprado et al., 2013; Gryffydd et al., 2020; Maylor, 1990) is a naturalistic measure of prospective memory which involves; (i) participants contacting the researcher at four times/time periods over the course of a week; and (ii) providing a message (name and phone number) on each occasion (see Gryffydd et al., 2020). For each occasion, participants are scored for the timeliness and accuracy of the message, with scores ranging from zero to four. The four occasions are summed to form the outcome variable, Telephone Task Total (scores range from zero to 16), with higher scores reflecting better prospective memory performance.

Statistical Method

Pearson's product-moment correlations were calculated to investigate the convergent validity between the LIST outcome variables (Targets and Credit Card) and prospective memory measures (CAMPROMPT and Telephone Task). Effect sizes are reported using Pearson *r* with 0.10, 0.30, and 0.50, considered to be small, medium, and large effects, respectively (Cohen et al., 2003).

Multivariate analysis of variance (MANOVA) was conducted to test group differences on the four prospective memory outcome measures (LIST Targets, LIST Credit Card, CAMPROMPT and Telephone Task). This was followed by univariate analyses of variance (ANOVAs), with Holm's method (Holm, 1979) adjustments to control for Type 1 error, with the 0.05 criterion matched in descending order against the effect size (i.e.,

highest effect 0.05/4, lowest effect 0.05/1). A power analysis using G*Power (Faul et al., 2009) for the MANOVA revealed that an *N* of 86 was required to detect a medium effect (f^2 = 0.15) with power set at 0.80 and alpha at 0.05.

Logistic regression analyses were performed with the binary dependent variables; (i) traumatic injury (yes/no) for the first model which included the entire sample; and (ii) mTBI (yes/no) for the second model with only the Trauma group. Logistic regression requires less data assumptions to be fulfilled than discriminant function analysis and is considered a robust test when the primary function is to identify which predictors are related with the binary outcome (Antonogeorgos et al., 2009). The LIST Targets, LIST Credit Card, CAMPROMPT and Telephone Task variables were entered as continuous predictors. We did not have any a priori hypotheses about which prospective memory measures might best separate the groups and therefore, did not use a stepwise approach (Tabachnick & Fidell, 2019). The Tolerance statistic for all predictor variables across all models was well above the 0.20 threshold (Tolerance range 0.77 to 0.98), indicating the assumption of non-multicollinearity was met for the logistic regression (Hair et al., 2010).

Exploratory hierarchical regression analyses were carried out with the Trauma group to explore if pain predicted performance on the LIST (Targets and Credit Card). The predictors in each of the analyses included biopsychosocial factors (age and education) at Step 1, and the pain scale at Step 2. All assumptions for the test were satisfied. Effect sizes for R^2 are reported with 0.01, 0.06 and 0.15 considered small, medium and large effects, respectively (Cohen et al., 2003).

Results

Participant Characteristics

The demographic data and self-report measures are presented in Table 1. Forty-six healthy older adults (HOA group) and 102 trauma patients (Trauma group) were included in this study. Within the mixed Trauma group, 39 had sustained a mTBI. The mixed Trauma group were assessed three months post injury (mTBI: *M* = 108.72 days, *SD* = 12.54, IQR = 98 - 116; non-mTBI: *M* = 104.76 days, *SD* = 11.11, IQR = 98 -113). Time since injury did not differ between the Trauma subgroups, *t* (100) = 1.66, *p* = 0.10.

The socio-demographic characteristics of age, F (1,146) = 0.72, p = 0.40, education, F (1,146) = 0.02, p = 0.88, gender, $\chi 2$ (1, N = 148) = 0.58, p = 0.45, and occupation, $\chi 2$ (6, N =146) = 0.46 did not differ between the HOA and Trauma groups. The groups did not differ in the number of medical comorbidities, F (1, 146) = 0.29, p = 0.60, self-reported general health, F (1, 146) = 0.68, p = 0.41, and self-reported memory, F (1, 146) = 1.97, p = 0.16. Although participants were provided with a reminder two weeks after testing, the DASS 21 and pain scale were not returned by 23 participants (HOA = 3, Trauma group = 20) and 16 participants (HOA = 3, Trauma group = 13), respectively. Preliminary analyses were performed with the reduced datasets. The groups did not differ in psychological distress, F (1,123) = 2.02, p = 0.16, and the proportion of those experiencing clinically significant distress (i.e., distress score ≥60; Lovibond & Lovibond, 1995) did not differ between groups, $\chi 2$ (1, N =125) = 1.42, p = 0.23. The Trauma group reported a significantly higher degree of physical pain than the HOA group, F (1,130) = 12.00, p <0.001.

Table 8.1.

Socio-demographic and General Health Characteristics of the Groups

	HOA (n = 46)		Trauma (n = 102)	
	M	*SD*	*M*	*SD*
Age (years)	73.63	5.14	74.55	6.47
Education (years)	13.43	2.65	13.36	2.60
Gender (Female, %)	27	58.7	53	52
Occup. (Prof/Managerial, %)	22	47.8	52	51
Total number of comorbidities	3.80	2.57	3.59	2.12
General Health	2.76	0.60	2.86	0.74
Subjective Memory	2.15	0.36	2.27	0.49
Psychological Distress[†]	12.51	18.20	13.80	12.53
Physical Pain	2.26	0.88	2.87[#]	0.98

Notes. HOA= healthy older adults; Trauma = patients who had sustained a traumatic injury (with or without brain injury). For gender, 0 = male, 1 = female. Occup. = Occupation (Professional/Managerial) classification as defined by the Australian Bureau of Statistics (ABS, 2009). General Health = subjective health rating on a 5-point Likert-type scale (0 [poor] to 4 [excellent]). Subjective Memory = self-rating on a 5-point Likert-type scale (0 [poor] to 4 [excellent]). Psychological Distress = Depression Anxiety Stress Scale 21 (DASS 21; Lovibond & Lovibond, 1995) Total Distress score; Physical Pain = self-rating of impact physical pain on 5-point Likert-type scale (1 [not at all] to 5 [an extreme amount]).

† Reduced sample due to missing data: HOA group (*n* = 43); Trauma group (*n* =82)
[#]Trauma group (*n* = 89) due to missing data.

Group Performances on Prospective Memory Measures

Performances on the prospective memory measures are presented in Table 2. A one-way MANOVA revealed that the Trauma group performed worse on the prospective measures, F (4, 143) = 3.02, p = 0.02; Pillai's Trace = 0.08; partial η^2 = 0.08. When the measures were considered separately using the Holm's adjusted alpha scores, the Trauma group performed worse on LIST Targets, F (1, 146) = 9.21, p = < 0.01, and LIST Credit Card, F (1, 146) = 6.09, p = 0.015, with the size of the effect moderate (d = -0.54, d = -0.44, respectively). The groups did not differ on the LIST distractor task, F (1, 146) = 0.001, p = 0.97, or LIST forced-choice task, F (1,146) = 1.42, p = 0.24.

Table 8.2

Group Performances on Prospective Memory Measures

	HOA (*n* = 46)	Trauma (*n* = 102)	Cohen's *d*
	M (SD)	*M (SD)*	
Prospective Memory			
LIST Targets	8.89 (3.89)	6.41 (4.88)	-0.54**
LIST Credit Card	5.39 (2.36)	4.39 (2.24)	-0.44*
CAMPROMPT	23.02 (7.26)	21.52 (7.02)	-0.21
Telephone Task	10.33 (4.86)	8.85 (5.76)	-0.27

Notes. * p <0.05; **p < 0.01; HOA = healthy older adult group; Trauma = older adults with traumatic injury (with or without brain injury). LIST Targets = LaTrobe Itemised Shopping Task Targets Total; LIST Credit Card = LaTrobe Itemised Shopping Task Credit Card Total; CAMPROMPT = Cambridge Prospective Memory Test Total; Telephone Task = Telephone Task Total.

Convergent validity

Medium sized, positive correlations between the LIST Targets and CAMPROMPT were found for both groups, with higher scores on the AR task associated with better performance on the standardized measure of prospective memory (Table 3). A small, positive correlation between LIST Targets and the Telephone Task was found in the Trauma group. The LIST Credit Card had a small, positive relationship with the

CAMPROMPT and a medium, positive association with the Telephone Task, but only in the Trauma group.

Table 8.3

Pearson Correlation Results for HOA and Trauma Groups

	LIST Targets	95% CI	LIST Credit Card	95% CI
CAMPROMPT				
HOA group	0.34*	0.05, 0.57	0.28	-0.02, 0.53
Trauma group	0.38**	0.20, 0.54	0.22*	0.02, 0.40
Telephone Task				
HOA group	-0.08	-0.36, 0.22	-0.01	-0.29, 0.29
Trauma group	0.21*	0.01, 0.39	0.30**	0.12, 0.47

Notes. *p = <0.05; **p = < 0.01; HOA = healthy older adult group; Trauma = older adults with traumatic injury (with or without brain injury). LIST Targets = LaTrobe Itemised Shopping Task Targets Total; LIST Credit Card = LaTrobe Itemised Shopping Task Credit Card Total; CAMPROMPT = Cambridge Prospective Memory Test Total; Telephone Task = Telephone Task Total.

Is AR a better predictor of trauma status than other measures of prospective memory?

Logistic regression analysis was conducted to assess the sensitivity of the LIST and other prospective memory measures (CAMPROMPT and Telephone Task) to predict the likelihood of group allocation (Table 4). The model contained four independent variables (LIST Targets, LIST Credit Card, CAMPROMPT and Telephone Task). As a whole, the model was significant, χ^2 (4, N = 148) = 12.30, p = 0.02, explained 11.2% (Nagelkerke R squared) of the variance in group status and correctly classified 66.9% of cases. LIST Targets was the most sensitive indicator of group status (β = -0.11, p = 0.03), with those with poorer performance 10% more likely to come from the Trauma group.

Table 8.4.

Logistic Regression Predicting Likelihood of Experiencing a Traumatic Injury.

	β	*SE*	*Wald*	*df*	*p*	*Odds Ratio*	*95% C.I for Odds Ratio*	
							Lower	Upper
LIST Targets	-0.11	0.05	4.75	1	0.03	0.90	0.82	0.99
LIST Credit Card	-0.11	0.09	1.66	1	0.20	0.89	0.75	1.06
CAMPROMPT	0.01	0.03	0.10	1	0.75	1.01	0.95	1.07

Telephone Task	-0.03	0.04	0.73	1	0.39	0.97	0.90	1.04
Constant	2.28	0.72	9.99	1	<0.01	9.73		

Note. HOA = 0; Trauma group = 1; LIST Targets= LaTrobe Itemised Shopping Task Targets Total; LIST Credit Card = LaTrobe Itemised Shopping Task Credit Card Total; CAMPROMPT = Cambridge Prospective Memory Test Total; Telephone Task = Telephone Task Total.

A secondary binary logistic regression analysis was performed with the Trauma group split into mTBI and non-mTBI subgroups (Yes/No). The model was non-significant, and poorer prospective memory performance was not more likely in either of the subgroups when the predictors were considered collectively, χ^2 (4, N = 102) = 6.05, *p* = 0.20, or separately.

Does pain predict LIST performance in those with an injury?

Hierarchical multiple regression was used to explore if pain was associated with poorer performance on the LIST Targets (Table 5a) or List Credit Card (Table 5b) tasks for participants from the Trauma group. Sociodemographic factors (age and education) were entered in the first step of the models and did not account for a significant amount of variance (as a set or individual predictors in the full model) on LIST Targets. As a set, they accounted for a significant amount of variance on the LIST Credit Card, with age having a unique association with LIST Credit Card, (β = -0.32, *p* = <0.01). Pain was not associated with performance on either of the LIST tasks after controlling for the effects of age and education. Secondary analyses were conducted to investigate any potential differences in pain between the trauma subgroups (mTBI= 34; non-mTBI = 55). Independent t-tests were carried out for subjective pain, *t* (87) = 1.25, *p* = 0.36, *d* = -0.28. The groups did not differ, with only a small non-significant effect found.

Table 8.5

Multiple Regressions Depicting Associations Between Pain with LIST Performance In the Trauma Group.

	(a) LIST Targets				(b) LIST Credit Card			
	Step Summary		Final Summary		Step Summary		Final Summary	
Predictor	*β*	*sr*	$R^2\Delta$	*p*	*β*	*sr*	$R^2\Delta$	*p*
Step 1			0.06	0.07			0.13	<0.01

Age	-0.17	-0.17		0.11	-0.32	-0.31		<0.01
Education	0.14	0.14		0.19	0.12	0.11		0.26
Step 2			<0.01	0.54			0.02	0.19
Age	-0.16	-0.16		0.14	-0.29	-0.28		<0.01
Education	0.14	0.14		0.18	0.12	0.12		0.23
Physical Pain	0.07	0.06		0.54	0.13	0.13		0.19

Note. LIST Targets= LaTrobe Itemised Shopping Task Targets Total; LIST Credit Card = LaTrobe Itemised Shopping Task Credit Card Total; Age and Education in years; Physical Pain = self-rating of impact physical pain on 5-point Likert-type scale (1 [not at all] to 5 [an extreme amount].

Discussion

This study investigated the validity of an experimental AR task for use with older adults. Evidence of construct validity was found, with positive medium sized associations between the AR task (LIST) and the paper-and-pencil measure of prospective memory (CAMPROMPT) for both the HOA and clinical sample (Trauma) groups. Performance on the LIST also positively correlated with performance on the naturalistic prospective memory task (Telephone Task) in the Trauma group, with small to medium sized associations found. Furthermore, unlike the paper-and-pencil and naturalistic measures, poorer performance on the LIST was more likely to discriminate the Trauma from the HOA group, which suggests that AR and extended reality technology may be a sensitive means of assessing prospective memory ability.

The focus in this study was the validity of the AR task in comparison to paper-and-pencil and naturalistic tasks in order to extend clinical findings using the LIST (Gryffydd et al., 2021). As an initial step, the small to medium positive relationships between the LIST Targets and the standardized paper-and-pencil measure (CAMPROMPT) provides evidence for construct validity. The LIST was also associated with prospective memory tasks carried out in everyday life (Telephone Task), with small to medium positive relationships found in the Trauma group. These results are promising and imply the LIST, especially the Targets variable, is measuring the same general construct of prospective memory as the two other measures. However, it should be noted that the associations for the LIST Credit Card variable were less consistent. Probes, like the Credit Card task, have lower reliability and sensitivity (Henry, 2021) and may explain why significant associations

were only observed in the larger Trauma group. Nonetheless, the results are promising, particularly for the LIST Targets which appears to be reliable and sensitive. It was unexpected that the LIST did not correlate with the naturalistic measure (Telephone task) in the non-trauma group, although it did in the Trauma group. This may have resulted from the close to ceiling effects found in the non-trauma group and will require further evaluation in future studies of non-clinical cohorts.

Consistent with previous findings (Gryffydd et al., 2021), the Trauma group performed more poorly than the HOA group on the LIST prospective memory tasks (Targets and Credit Card). The LIST is founded on a dual-task paradigm of prospective memory (McDaniel & Einstein, 2011) and incorporates an ongoing distraction task. There were no group differences on this distraction sub-task of the LIST suggesting that the older adults could adequately use and negotiate the features of the AR program (e.g., 'collect' items from the supermarket shelves as part of the distractor task). Also, the groups did not differ on recognition of the to-be-remembered items at the conclusion of testing. This signifies that although they could encode and retain the LIST task information over a time delay, the Trauma group had difficulty in carrying out intended actions at the appropriate time or event (LIST Targets). A lack of group differences on the CAMPROMPT and Telephone Task implies that extended reality tasks, such as the LIST, may be useful for identifying subtle cognitive difficulties in older adults following an injury (also see Banville & Nolin, 2012; Krasny-Pacini et al., 2017 using XR with younger age cohorts).

As hypothesized, the LIST was found to be sensitive to discriminating between the HOA and the Trauma group, with poorer performance on the LIST Targets, (i.e., lower prospective memory ability) associated with allocation to the Trauma group. These findings further demonstrate the benefits of extended reality technology, including sensitivity to capture subtle prospective memory difficulties in an older age clinical cohort (also see Lecouvey et al., 2019; Lim et al., 2020; Oliveira et al., 2016; Rose et al., 2015). Although the paper-and-pencil (CAMPROMPT) and the naturalistic (Telephone Task) measures were not individual significant predictors of group allocation in this study, they have been found to be sensitive to detecting impairment in older adults with amnestic mild cognitive

impairment (Delprado et al., 2013). As such, while the present findings provide evidence to support the validity of the LIST, these two measures remain potentially useful tools for assessing prospective memory in older adults with varying clinical conditions.

The clinical group used in this study was a cohort of older adults who had experienced traumatic injury (i.e., a mixed trauma sample). Following injury, the presence of pain, often related to orthopedic injury, is commonly reported (Castillo et al., 2016; Clay et al., 2012). Exploratory analyses with the Trauma group did not reveal any strong association between pain and prospective memory performance. This was unexpected as a previous review has reported that the presence of pain can impact attention-demanding memory processes (Mazza et al., 2018). It may be that response to pain and its impact of cognition is more variable in older age or the use of a single-item measure of pain was insufficient to evaluate pain behavior. Anderson (2020) also found no relationship between cognition and a single-item pain scale in a younger age cohort following mild traumatic brain injury; but did report varying associations between cognition and a multidimensional pain measure. Anderson (2020) argued that exploring pain through multidimensional measures may be more informative about the relationship with cognition. Further investigation of this issue will contribute to clinical practice with older adults following trauma.

In summary, by using a prospective memory task based on extended reality (i.e., an AR task), this study provides preliminary support for the utility of such an approach in the clinical assessment of older adults. Extended reality technology enables access to an immersive naturalistic paradigm for assessing everyday prospective memory ability. This addresses the central feature or purpose of prospective memory assessment; to provide an estimate of cognitive ability in everyday tasks and behavior. Although more naturalistic style tasks are being developed (Schmitter-Edgecombe et al., 2020), more traditional paper-and-pencil approaches to assessing prospective memory have been limited by the requirement for manual recording of responses and use of low-dimensional stimuli (Parsons & Duffield, 2020). This has resulted in a problematic gap between performance in the clinic and in the real-world (Manchester et al., 2004). In an era when innovative

approaches to assessing older age patients, including virtual visits for neuropsychological assessments, has become increasingly important in clinical practice (Hantke & Gould, 2020), continued development of measures using extended reality technology offers an avenue for extending effective cognitive assessment.

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Declaration of Conflicting Interests

The authors report no potential conflict of interest.

Methodological Disclosure

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study.

Data Availability Statement

Upon reasonable request, the data supporting the findings of this study is available from B.J.W.

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8.2 Chapter Summary

This chapter presented the third study of this thesis which evaluated the convergent validity and sensitivity of the LIST using a group of healthy older adults and a mixed trauma sample. Evidence of convergent validity was obtained, with moderate, positive associations between the LIST and two measures of PM, a standardized measure (CAMPROMPT) and a naturalistic task (Telephone Task). The LIST was also sensitive to differentiating between the healthy and mixed trauma samples. The findings demonstrate the efficacy of XR technology, like AR, in the assessment of prospective memory.

Chapter 9 General Discussion

9.1 Chapter Overview

This chapter provides an integrated discussion of the findings of this thesis, beginning with a summary of the main research findings. The strengths and limitations of the current thesis are presented, followed by the implications of the findings. Lastly, research challenges and recommendations for future research are provided.

9.2 Summary of the Main Research Findings

Assessment of PM ability may be useful for identifying older adults who are at risk of everyday memory difficulties (Beaver & Schmitter-Edgecombe, 2017; Kinsella et al., 2014a) and could be used to measure cognitive outcome in older age cohorts who have sustained a mTBI, most commonly as a result of a fall. However, given the concerns about the ecological validity of laboratory and clinic-based PM tasks (Phillips et al., 2008), naturalistic style measures may provide an opportunity to capture everyday cognitive ability more closely. This thesis explored PM in three groups of older adults; (i) healthy older adults; (ii) older adults who had experienced a mTBI; and (iii) older adults who had experienced an orthopaedic injury.

The primary research aims were addressed in Studies 1, 2 and 3 (reported in Chapters 5, 7 and 8). Study 1 examined the relationship between subjective and objective measures of PM in 43 healthy community-dwelling older adult volunteers. Study 2 investigated PM in 39 older adults three months after mTBI, together with 63 orthopaedic controls and 46 healthy community-dwelling volunteers. Examination of the validity of an AR PM task was conducted in Study 3 and included 102 older adults with traumatic injury (mixed aetiology) and 46 healthy community-dwelling volunteers.

9.2.1 *The relationship between subjective and objective measures of prospective memory in older adults*

Past research investigating the relationship between self-report and objective measures of PM has primarily focused on laboratory and clinic-based measures, rather than naturalistic tasks. To address this issue, Study 1 (Chapter 5) explored the association between self-report (PRMQ) and two objective measures (a standardized

clinic-based task [CAMPROMPT] and a naturalistic task [the Telephone Task]) in a group of healthy older adults. The results showed that self-reported PM was moderately associated with performance on the naturalistic task rather than the clinic-based task. This suggests that incorporating naturalistic probes of PM into a clinical assessment, whenever possible, may provide a useful means of validating the self-reports of older age clients in terms of their lived experience of PM challenges in everyday activities. This is of central clinical concern in a client-centred neuropsychological assessment. However, it should be noted that the association was moderate and the format of the naturalistic task in this study may be too time consuming to be routinely accommodated in a diagnostic neuropsychological assessment. Therefore, there is a continuing need for developing reliable naturalistic measures which are approximate scenarios of PM in the real-world, and yet can be considered for administration within a controlled clinic environment.

9.2.2 *Prospective memory performance in older adults following mTBI*

Limited research has been conducted which assesses cognitive performance in older adults following mTBI (Hume et al., in press) This gap in the literature was addressed in Study 2 (Chapter 7), which evaluated cognitive outcomes, specifically PM, at three months post-injury. Performances by the mTBI group on a naturalistic task (Telephone Task), a novel, augmented reality task (LIST), and a traditional paper-and-pencil measure (CAMPROMPT) were compared to a group of older adults with orthopaedic injuries (OC group) and a group of community-dwelling healthy older adults (CC group). The mTBI exhibited significantly worse performance on the augmented reality task (LIST) than the CC group. While there was a small-moderate effect found on the naturalistic task, there were no group differences on the paper-and-pencil measure, implying that naturalistic approaches, particularly AR, are sensitive to detecting the cognitive difficulties experienced by older adults following mTBI. The results indicate that older adults who have experienced a mTBI may be vulnerable to cognitive issues and further monitoring is recommended to determine if neuropsychology input is required. As the assessments were completed at three-month post-injury, it will be important for

further review to determine if cognitive recovery is simply delayed or if difficulties persist, thereby requiring referral for community support. This study also provides preliminary evidence for the viability of AR measures when assessing older adults in relation to cognitive performance.

9.2.3 *Examination of the LaTrobe Itemised Shopping Task*

The findings of the previous investigation (Study 2) informed the conceptualisation of Study 3. This study examined the validity of an AR task (LIST) and sought to demonstrate the potential usefulness of this approach for assessing PM in older adults. Based on the absence of any significant differences between the mTBI and OC groups in Study 2, these participants were combined to form a mixed-trauma sample. Using this mixed-trauma sample and a group of healthy older adults, this study evaluated the convergent validity and sensitivity of the LIST. Evidence of convergent validity was obtained, with moderate, positive associations with both a traditional paper-and-pencil measure (CAMPROMPT) and a naturalistic task (Telephone Task). The LIST was found to be the most sensitive of the three PM measures and was able to differentiate between the healthy and mixed trauma samples. Although the presence of pain was greater in the mixed-trauma group, pain was not associated with LIST performance. This study further demonstrated the potential of XR technology, like AR, in the assessment of PM in older people following a traumatic injury.

9.3 Strengths and Limitations of the Current Thesis

The present body of research is supported by several strengths. Due to the worldwide ageing population and increasing rates of falls, older adults with mTBI represent an important research group. Study 2 and 3 involved extensive multidisciplinary screening and assessment to determine participant eligibility and allocation to the mTBI or OC groups/mixed trauma sample (see Figure 9.1). For the trauma groups, injury information was obtained from hospital medical records (rather than self-report), as well as medical history, comorbidities, surgery involving general anaesthesia and CT brain imaging results for all participants with mTBI.

While the criteria used for OC groups in previous studies has been somewhat ambiguous, the present research used AIS scores and peripheral ISS scores to ensure the two trauma groups matched. To further minimise the potential influence of the confounds of age, education, and gender, two matched comparison groups were formed, a healthy sample and orthopaedic group. All participants were screened for pre-existing cognitive issues, clinically significant psychological symptoms and numerous other factors that may potentially impact cognition. Accordingly, the thorough selection process, which resulted in three well-matched older age samples (mTBI, OC and CC) are methodological strengths of this thesis. The study also adhered to a strict timeline for three-month assessments to ensure the length of time since injury was consistent.

When exploring outcomes following mTBI, past research studies with older participants have typically focussed on functional outcome using self-report measures, like the GOSE. A key strength of this thesis was to extend outcome measurement to a neuropsychological assessment conducted at three months post-injury. The multiple PM measures and additional neuropsychological tests allowed for estimation of cognitive outcome, as well as investigation of associations and moderating relationships. The AR task developed and used for the first time in this research demonstrated the efficacy of this approach for the assessment of older adults. The data collected in this study contributes to the limited literature assessing cognitive outcomes in older adults following mTBI and can be used in future meta-analyses to integrate discrete study findings in a meaningful way.

Although the rigorous screening of participants was a key strength of the research presented in this thesis, it also significantly reduced the number of eligible participants and sample size. This is consistent with previous research which found only 2.5 – 4.9 % of patients screened satisfied enrolment criteria (Isokuortti et al., 2016; Luoto et al., 2013). It also resulted in a pre-injury healthy sample of older adults that may not be representative of the general population. As such, the current results may underestimate the cognitive difficulties experienced by older adults with mTBI. If this pre-injury healthy sample exhibit cognitive difficulties at three months, it is likely that patients with pre-

existing conditions, such as mild cognitive impairment, will be at increased risk of cognitive challenges post-injury. Similarly, participants with significant psychological conditions were excluded which limits the generalisation of the findings. To ensure participants could provide informed consent and understand the instructions of the neuropsychological tests, fluency in English was an inclusion criterion. This resulted in a predominately Caucasian sample and in line with previous findings suggesting that language is a key barrier to recruiting culturally and linguistically diverse participants (Smith et al., 2018). Including informed consent forms in multiple languages and utilising neuropsychological measures which require minimal language skills should be considered in future research studies to ensure a diverse sample which is reflective of the multicultural society of Australia. The strict inclusion and exclusion criteria in geriatric TBI research will be discussed in detail in future directions later in this chapter (9.8).

As used in this study and others, simple moderation analyses provided a useful approach to further understanding the complex relationship between cognition and mTBI in older age patients. Whilst the study was adequately powered to detect medium size effects, the sample size prevented the use of more sophisticated statistical analyses, and a larger sample would have allowed for multiple-moderation analyses to be performed.

Although there are many advantages to using AR measures, it will be some time until normative data is available to guide clinicians involved in neuropsychological assessments. As such, this method of assessment will continue to be most useful in the clinical research area, but also has been increasingly applied in intervention or training programs (Alashram et al., 2019; Georgiev et al., 2021; Pike et al., 2021). It should also be noted that 7% (*n* =8) of the available sample at 3-months post-injury (*N* = 110 combined-trauma participants) chose not to complete the AR task, suggesting a lack of confidence in engaging with the technology. This was expected in an older age cohort (65-91 years age range), but this hesitancy will also likely decrease as familiarity with the relevant technology increases in older age. The majority of the cohort, who did engage with the task, responded to the task positively and were clearly engaged.

9.4 Clinical and Theoretical Implications of the Current Thesis

9.4.1 *Cognition in Older Adults following Mild Traumatic Brain Injury*

Research investigating mTBI across the lifespan suggests cognition is generally fully recovered by three months, unless there are specified risk factors (Carroll et al., 2004; Karr et al., 2014). Increasing age has been cited as one of the risk factors for recovery (Jacobs et al., 2010; Rabinowitz et al., 2015), but at the same time less is known about older age (65+ years) patients due to the limited research investigating this cohort (Hume et al., in press). The findings of the present research indicate that older adults following mTBI may experience cognitive difficulties when assessed at three months post-injury. Furthermore, these difficulties were not associated with the presence of intracranial trauma on CT imaging (i.e., cmTBI). This concurs with the growing body of literature querying the value of CT imaging as a prognostic index (Karr et al., 2020; Panenka et al., 2015). This may be due to the imaging technology, and more recent imaging approaches, such as diffusion tensor imaging (DTI) techniques, have shown evidence of widespread diffuse axonal injury in patients with mTBI (Churchill et al., 2017; Mayer et al., 2017; Wu et al., 2018). Taking into account previous findings linking reduced cognition and white matter microstructural changes (Oehr & Anderson, 2017), which have now been observed six to 12 weeks after mTBI (Oehr et al., 2021), these may be contributing to the cognitive difficulties exhibited by the mTBI group when assessed at three months.

The reduced cognitive performance demonstrated by this older age mTBI group may also be linked to increased vulnerability due to age-related structural changes, such as weakening of cerebrovascular structures (Flanagan et al., 2005; Karibe et al., 2017; Thompson et al., 2006) and reduced brain volume (Fjell & Walhovd, 2010). Reduced cognitive reserve could be another contributing factor (Krch et al., 2019; Schneider et al., 2014), and the interaction of all these age-related changes creates the substrate for less neural resilience in the event of traumatic injury.

Notwithstanding these structural contributions to cognitive outcome, the reduction in cognition is not clearly distinct from trauma, as evidenced by the lack of significant

differences between the mTBI and OC groups. This is in line with previous findings (Aharon-Peretz et al., 1997; Kinsella et al., 2014b) and demonstrates the multifactorial nature of cognition after an injury, i.e., neurological, physical, psychological, emotional and social (Landre et al., 2006; Vanderploeg et al., 2019). Explanations for this trend include predisposition to injury and the general effects that an injury may have on cognition (Aharon-Peretz et al., 1997; Kinsella et al., 2014b; Larrabee et al., 2013).

In the present research, while pre-injury cognitive differences between the trauma and control groups is plausible, participants were screened for pre-injury cognitive difficulties and pre-morbid conditions likely to impact cognition. As such, the findings may be related to factors associated with experiencing an unexpected injury that may impact cognition, such as sleep (Leong et al., 2019; Xu et al., 2020) and medications (Do & Schnittker, 2020; Siddiqui et al., 2020). Furthermore, participants may have been taking pain medications which ameliorated the experience of pain, but negatively impacted cognitive performance (Schultz et al., 2018). Although there were no group differences in psychological distress, stress can impact cognition (Crosswell et al., 2021; Plieger & Reuter, 2020) and may have potentially played a role (direct or interaction) in cognitive performance. As such, investigating potential moderators will be informative in further developing our current understanding of cognition in older adults after an injury.

9.4.2 *The Value of Prospective Memory for Older Adults Post-Injury*

The paradigm of PM is useful for assessing cognition following mTBI, as by definition cognitive outcome would be expected to be ‘mild’ and sometimes difficult to detect on screening cognitive tests. PM relies on an interaction of multiple cognitive domains and thereby more liable to error in task completion. Typically, PM recruits both executive function and retrospective memory in task performance (Kliegel et al., 2011; Kliegel et al., 2002), hence deficits in either or both domains of cognition will disrupt PM function. Both domains of cognition have been frequently identified as disrupted in the acute stage following TBI (de Freitas Cardoso et al., 2019; Kannan et al., 2019; Lecuyer Giguere et al., 2019), but measurement of performance on single domain neuropsychological tests are difficult to equate to actual cognitive performance in

everyday activities (Parsons & Duffield, 2020). In this respect, PM can provide clinicians with an index of everyday cognition which is particularly useful for assessing cognitive outcome in older age patients where there may be concerns about capacity for independent living.

Naturalistic approaches, including AR, appear especially useful for assessing PM. Naturalistic tasks may provide clinicians with valuable information regarding patients' day to day experience of PM challenges, and XR platforms provide a promising tool for the assessment of these complex cognitive skills (Parsons, 2015). Cognitive rehabilitation using XR technology has already been used with younger patients following TBI (Alashram et al., 2019) and older adults with mild cognitive impairment or dementia (Kim et al., 2019). Accordingly, immersive VR cognitive rehabilitation may be effective with older adults after mTBI if cognitive deficits persist.

9.4.3 *Cognitive Resources for Prospective Remembering*

In respect to the cognitive resources required for PM, it is generally accepted that PM is distinguished from delayed free-recall (retrospective) memory by occurring in the absence of a direct cue from the examiner for retrieval of information (Einstein & McDaniel, 1990). Therefore, we considered that investigating post-test capacity for recognition recall of the to-be-remembered items, as opposed to delayed free-recall, as highly relevant to examining potential group differences in baseline capacity to perform the PM task. That is, by the end of the PM task, can the participant still recognise the shopping items that they were meant to buy. In this manner we were able to establish that there were no group differences in this baseline ability. Nevertheless, as expected, our clinical groups did display lower performances as compared to the community control group on the more demanding index of retrospective memory (delayed free-recall). Importantly, using this information, we also demonstrated that delayed free-recall (retrospective memory) moderates the association between severity of injury (GCS) and PM performance. This underlines retrospective memory (under demanding conditions) as a critical resource for PM performance, especially in clinical populations where retrospective memory may be compromised.

In relation to executive function, it is important to acknowledge that in this thesis the term has been used as an umbrella term to refer to a number of interrelated processes that are recruited for goal directed activity. The possible distinction between attention and executive function has been underspecified in the PM literature; rather, the concept of executive function as a general term to indicate several processes involved with attention control and flexible regulation of behaviour (Miyake et al., 2000; Suchy, 2015) has been used (Scullin et al, 2013). Specifically, Suchy (2015) uses the term executive cognitive skills as referring to capacity for goal-directed retrieval of information, manipulation of information in working memory, and flexible application of information to a task at hand; these are all critical skills for prospective memory tasks (Kliegel et al, 2000; Scullin et al, 2013). Therefore, the thesis adopted the approach of using 'executive function' as an umbrella term to refer to a complex of processes involved in strategic goal-directed behaviour, as required in PM. It could be hypothesised that different processes of executive function are required at different steps in a complex PM task (see Kliegel et al., 2000 or Scullin et al, 2013 for further discussion). Therefore, future studies will be needed to investigate the fractionated roles of executive function in PM.

9.5 Practical Implications of the Current Thesis

The prevailing view among medical professionals has been described as optimistic towards recovery following mTBI in younger age populations (Korley et al., 2019). However, older adults who present to the Emergency Department after an unexpected injury (with or without brain injury) need a careful review of cognition, especially if they are living alone. It is recommended that patients receive neuropsychological input at three months post-injury to monitor cognitive outcome and patients exhibiting cognitive difficulties followed up at six months post injury. If ongoing cognitive problems did emerge at review, referral for community support services could be considered.

It has long been recommended that patients with mTBI be provided with early educational information about the injury and potential symptoms (Borg et al., 2004; Boussard et al., 2014). The current research supports this position on psychoeducation

and extends it to include any older patient who has experienced a traumatic injury (orthopaedic or brain injury). Providing patients and carers with psychoeducation, together with an information leaflet, prior to discharge is a practical and cost-effective option (Hart et al., 2018; Kempe et al., 2014). Patients at risk of poor outcomes could also benefit from additional psychoeducation and rehabilitation during the acute phase of recovery (Audrit et al., 2020; Caplain et al., 2019). Digital memory training tools may be of benefit, such as ProspectFit, a PM intervention program available on smartphones designed for older adults (Chan et al., 2019). More general memory systems, like MyMemory, which was designed for patients with TBI (Chang et al., 2018), may also be appropriate, as well as programs for improving functional independence (Corregidor-Sanchez et al., 2020).

9.6 Research Challenges and Recommendations for Future Research

While the specific limitations for each of the studies have been outlined, the methodological challenges of conducting research in this area will be discussed below.

The recruitment and data collection phases of research in this area can be prolonged and time-consuming. Even for modest sized samples as reported in this thesis, the recruitment and data collection phases spanned over three and a half years. In this study, the recruitment process for the trauma groups, as required by the Ethics Committees, involved reviewing Emergency Department reports and medical files, sending out letters and contacting potential participants via telephone, rather than direct contact in the Emergency Department. This resulted in significant attrition as potential participants were often difficult to locate. A large number of potentially eligible patients were also lost because of insufficient English to complete the assessments without the aid of interpreters (see Figure 9.1 above). The recruitment process for the healthy older adult group was also challenging as the benefits of participating in studies of this type are mainly based on altruism ("*it could happen to me*" or "*my best friend had a fall last year*…"). Unfortunately, the lengthy recruitment and data collection phases required to obtain sufficient sample sizes may continue to be a challenging issue when carrying out research in this area.

To minimise the length of the neuropsychological assessment, participants were provided with questionnaires at the end of the testing session and asked to return the completed questionnaires the following week. Despite attempts to contact participants with outstanding paperwork, 23 participants failed to return the questionnaires. This reduced the sample size for the self-reported measure of PM and limited investigation into the role psychological status may have on PM performance following mTBI. In future, researchers should consider incorporating the questionnaires into the assessment process to minimise the risk of missing data, even though it would extend the length of the assessment.

9.7 Directions for Future Research

This thesis contributes to the limited research assessing cognition in older adults following mTBI and highlights the need for ongoing investigation in this area. To ensure research cohorts are representative of the general population, Gardner et al. (2018) propose shifting away from strict exclusion and inclusion criteria, which result in “pure” TBI samples, and instead control for confounding variables in statistical analysis. This would not only increase sample sizes, but also produce findings which can be generalised to the wider ageing population. However, this model of research design is best suited for database studies as lengthy individualised assessments of very large cohorts would also require substantial research budgets.

Although there continues to be differences in how mTBI is defined, the increasing use of the International Collaboration on mTBI Prognosis guidelines (Kristman et al., 2014) is allowing greater comparisons and sharing of data across studies. This will allow future meta-analyses to investigate the available data more effectively from multiple studies and evaluate questions about moderators of outcome. This could include the controversial area of cmTBI and whether it is associated with poorer outcome.

As evident in the present research, older adults may experience cognitive difficulties following an injury, even those without brain injury per se. To account for the general effects of experiencing an injury, as well as predisposition (e.g., falls risk), it will be important to include orthopaedic comparison groups in future studies. This will

facilitate a deeper understanding of outcomes for older adults following an injury, including mTBI.

Methodologically, multiple assessments would allow researchers to map any changes in cognition, as well as psychosocial factors. Incorporating a six month follow up assessment in future studies will be important in developing an accurate understanding of cognitive outcomes for older adults following mTBI. It may be that the cognitive difficulties identified at the three-month assessment reflect a slower recovery than that expected for younger age cohorts, i.e., by six month review cognitive performances might become normative. If difficulties persist, it will be important to review the earlier (baseline) assessments to determine predictors of outcome.

A biobehavioural approach to tracking outcome following TBI to bridge the gap between biological and behavioural fields of research has been recommended (Larrabee et al., 2013; Mashima et al., 2019). This seems particularly relevant in older age cohorts where the injury can occur in the context of multiple comorbidities (Kumar et al., 2018; Thompson et al., 2012). For instance, a multi-disciplinary consortium would be ideal to address the myriad of issues involved and consider potential factors, such as blood biomarkers (Peltz et al., 2020), MRI biomarkers (Puig et al., 2020) and inflammation (Chaban et al., 2020; Sun et al., 2019).

Future research investigating cognitive outcomes in older adults following mTBI should also consider including immersive VR measures. Cybersickness, nausea due to visual perception of motion and vestibular feedback incongruence (Kennedy et al., 2000; Keshavarz & Hecht, 2011), was previously the key concern with using immersive virtual environments. However, with advances in technology and development of techniques to address this issue (Groth et al., 2021; Kemeny et al., 2017), immersive VR is generally well tolerated in older adults (Huygelier et al., 2019), including those with cognitive and physical impairments (Appel et al., 2020).

9.8 Overall Conclusions

Older adults with mTBI, primarily due to falls, are a growing public health concern and yet, there is limited research investigating cognitive outcomes. This is important as

maintaining optimal cognition into older age provides a significant contribution to sustaining independent living. In the present research, the noted cognitive challenges exhibited by older adults three months post-mTBI highlights the need for targeted intervention. The study findings suggest that PM can provide a useful paradigm for assessing cognition due to its relevance to everyday cognitive function. Furthermore, the next generation of cognitive performance tests, using XR technology, appear appropriate for use with older people; and offers an approach that has the potential to capture performance as experienced in real-world activities. Thereby, drawing clinical assessment closer to everyday performance.

9.9 References

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Appendix A: Alternative Thesis Format

Thesis by Published and Unpublished Papers

Candidates also have the option of submitting their thesis via the 'alternative publication format' method. A decision to submit by this method should first be discussed with your supervisor(s). Submission of a thesis by this method must conform to the Higher Degrees Committee's (Research) following points:

1. As an alternative to the traditional format for a higher degree thesis, it is permissible for candidates to submit a thesis in the form of a series of articles arising from the candidate's higher degree research. These must be along a central theme and may or may not be already published. The presentation of the articles should take into account current regulations for PhD, Professional Doctorates and Masters by Research (see http://www.latrobe.edu.au/researchers/higher-degrees-by-research/guidelines-andsupport/hdr-guidelines). Where the thesis includes work of joint authorship the candidate shall include in the thesis a signed declaration for each article, stating the extent and nature of his or her contribution and justifying the inclusion of the material. A signed declaration from at least one of the co-authors should also be included, verifying the extent and nature of the candidate's contribution.
2. It may be that all articles are in press, but it is required that at least one must be in press. The remaining articles may be submitted for publication or in a form that is ready to be submitted for publication.
3. The presentation of a thesis as a collection of articles must include at least one substantial integrating article or preferably a separate introduction, and general discussion and conclusion that in combination provide an integration of the material presented.
4. The number of articles to be included will depend on the content and length of each and should take full account of the University's requirements for the degree as well as the amount of research expected for the degree in that discipline. However, as a broad guideline, it can be suggested that a masters by research and doctoral (coursework) thesis include at least two papers, and a doctoral (research) and PhD research thesis include at least 3 papers. The aim should be to achieve papers of potential high impact rather than multiple papers with potential low impact. The student and supervisor will collaboratively take responsibility in deciding on the number and form of papers that will be necessary to achieve a level of research output sufficient for award of the degree.

5. With respect to the regulation governing the completion of work undertaken during candidature, (see point 1), it is expected that unless written approval is given to include work undertaken prior to candidature at La Trobe University, e.g., a small proportion of data collected during the Honours degree to be re-analysed, all work will have been completed during the period of candidature. Work published prior to commencement of candidature must **not** be included in the thesis, although reference to such material is permitted.
6. With respect to the regulation governing joint authorship (see point 1) the candidate would have been expected to have made a significant and leading contribution to the work reported, equivalent to that expected for a traditional thesis.
7. A published book can also be submitted as a thesis for a Masters, PhD or professional doctorate, provided that it fulfils the requirements set out in the above six clauses of these guidelines.
8. The thesis will be examined in the normal way and according to the normal requirements set out for the degree. (see Appendix A and Appendix D of the Handbook for Candidates and Supervisors for Masters Degrees by Research and Doctoral Degrees issued by RSO at enrolment.) Examiners of a thesis by published and unpublished papers will be given a copy of these guidelines.
9. The decision to submit a thesis in the form of a series of published or unpublished articles should be given careful consideration. In particular candidates should note that submitting a series of articles is not a universally accepted practice. Moreover, it is likely, especially with published articles along one theme, that there may be considerable repetition across the articles which may detract from the presentation of the thesis. Occasionally, due to the word length constraints of published articles, students may choose to include an additional section on methodology which provides more information about the specifics of how the research was conducted. For these reasons, it may be more appropriate to prepare the thesis in the traditional format, including reprints of any published articles arising from the thesis in an appendix. A clear statement must be included in the thesis indicating which chapters are based on published articles, full publication details of these articles, and details of the relative contributions of all authors if the publications are multi-authored, as follows:
    a. Where the thesis includes work of joint authorship the candidate shall sign a declaration for each article, stating the extent and nature of his or her contribution and justifying the inclusion of the material. A signed

declaration from at least one of the coauthors should also be included, verifying the extent and nature of the candidate’s contribution.

Appendix B: Alfred Ethics Approval

TheAlfred

ETHICS COMMITTEE CERTIFICATE OF APPROVAL

This is to certify that

Project No: 382/15

Project Title: Cognitive Consequences of Mild Traumatic Injury in Older Adults

Principal Researcher: Professor Glynda Kinsella

Protocol Version 1 **dated:** 2-Sep-2015

Participant Information and Consent Form (Trauma) Version 3 **dated:** 13-Aug-2015
Participant Information and Consent Form (Control) Version 3 **dated:** 13-Aug-2015

was considered by the Ethics Committee on ***27-Aug-2015****, meets the requirements of the National Statement on Ethical Conduct in Human Research (2007) and was* ***APPROVED*** *on* ***9-Sep-2015***

It is the Principal Researcher's responsibility to ensure that all researchers associated with this project are aware of the conditions of approval and which documents have been approved.

The Principal Researcher is required to notify the Secretary of the Ethics Committee, via amendment or progress report, of

- Any significant change to the project and the reason for that change, including an indication of ethical implications (if any);
- Serious adverse effects on participants and the action taken to address those effects;
- Any other unforeseen events or unexpected developments that merit notification;
- The inability of the Principal Researcher to continue in that role, or any other change in research personnel involved in the project;
- Any expiry of the insurance coverage provided with respect to sponsored clinical trials and proof of re-insurance;
- A delay of more than 12 months in the commencement of the project; and,
- Termination or closure of the project.

Additionally, the Principal Researcher is required to submit

- A Progress Report on the anniversary of approval and on completion of the project *(forms to be provided)*;

The Ethics Committee may conduct an audit at any time.

All research subject to the Alfred Hospital Ethics Committee review must be conducted in accordance with the National Statement on Ethical Conduct in Human Research (2007).

The Alfred Hospital Ethics Committee is a properly constituted Human Research Ethics Committee in accordance with the National Statement on Ethical Conduct in Human Research (2007).

SPECIAL CONDITIONS

Non-Alfred staff without honorary appointment must not access hospital medical records.

SIGNED:

[redacted]

Professor John J. McNeil
Chair, Ethics Committee

Please quote project number and title in all correspondence

TheAlfred

Ethics Committee

Certificate of Approval of Amendments

This is to certify that amendments to

Project: **382/15 Cognitive Consequences of Mild Traumatic Injury in Older Adults**

Principal Researcher: **Professor Glynda Kinsella**

Amendment:
Changes to 3-month and 6-month assessment session

Attachments:
Protocol version **2** dated **17-Mar-2016**

have been approved in accordance with your amendment application dated **19-Feb-2016** on the understanding that you observe the National Statement on Ethical Conduct in Human Research.

It is now your responsibility to ensure that all people associated with this particular research project are made aware of what has actually been approved and any caveats specified in correspondence with the Ethics Committee. Any further change to the application which is likely to have a significant impact on the ethical considerations of this project will require approval from the Ethics Committee.

[redacted]

Professor John J. McNeil
Chair, Ethics Committee

Date: **21-Mar-2016**

All research subject to Alfred Hospital Ethics Committee review must be conducted in accordance with the National Statement on Ethical Conduct in Human Research (2007).

The Alfred Ethics Committee is a properly constituted Human Research Ethics Committee operating in accordance with the National Statement on Ethical Conduct in Human Research (2007).

theAlfred

Ethics Committee

Certificate of Approval of Amendments

This is to certify that amendments to

Project: **382/15 Mild Injury in Older People**

Principal Researchers: **Professor Glynda Kinsella, A/Professor Biswadev Mitra & A/Professor Ben Ong**

Amendment:

Change to title of study from 'Cognitive Consequences of Mild Traumatic Injury in Older Adults' to 'Mild Injury in Older People'

Documents:
Initial letter to participants (trauma) dated: **8-Sep-2016**
Initial letter to participants (controls) dated: **8-Sep-2016**
Participant Information and Consent Form (trauma) **Version 4** dated: **8-Sep-2016**
Participant Information and Consent Form (controls) **Version 4** dated: **8-Sep-2016**
Research Protocol **Version 3** dated: **8-Sep-2016**

have been approved in accordance with your amendment application dated **23-Jun-2016** on the understanding that you observe the National Statement on Ethical Conduct in Human Research.

It is now your responsibility to ensure that all people associated with this particular research project are made aware of what has actually been approved and any caveats specified in correspondence with the Ethics Committee. Any further change to the application which is likely to have a significant impact on the ethical considerations of this project will require approval from the Ethics Committee.

[redacted]

Professor John J. McNeil
Chair, Ethics Committee

Date: **22-Sep-2016**

All research subject to Alfred Hospital Ethics Committee review must be conducted in accordance with the National Statement on Ethical Conduct in Human Research (2007).

The Alfred Ethics Committee is a properly constituted Human Research Ethics Committee operating in accordance with the National Statement on Ethical Conduct in Human Research (2007).

Appendix C: La Trobe University Ethics Approval

LA TROBE UNIVERSITY

University Human Ethics Committee

RESEARCH OFFICE

MEMORANDUM

To:	**Professor Glynda Kinsella, School of Psychology and Public Health, College of SHE** **Lei Gryffydd, School of Psychology and Public Health, College of SHE**
From:	**Executive Officer, La Trobe University Human Ethics Committee**
Subject:	**UHEC acceptance of The Alfred HREC approved project – 382/15**
Title:	**Cognitive Consequences of Mild Traumatic Injury in Older Adults**
Date:	**25 September 2015**

Thank you for submitting the above protocol to the University Human Ethics Committee (UHEC). Your material was forwarded to the UHEC Chair for consideration. Following evidence of a full review and subsequent final approval by the **The Alfred HREC**, the UHEC Chair agrees that the protocol complies with the National Health and Medical Research Council's *National Statement on Ethical Conduct in Human Research* and is in accordance with La Trobe University's *Human Research Ethics Guidelines*.

Endorsement is given for you to take part in this study in line with the conditions of final approval outlined by **The Alfred HREC.**

Limit of Approval. La Trobe UHEC endorsement is limited strictly to the research protocol as approved by **The Alfred HREC**.

Variation to Project. As a consequence of the previous condition, any subsequent modifications approved by **The Alfred HREC** for the project should be notified formally to the UHEC.

Annual Progress Reports. Copies of all progress reports submitted to **The Alfred HREC** must be forwarded to the UHEC. Failure to submit a progress report will mean that endorsement for your involvement this project will be rescinded. An audit related to your involvement in the study may be conducted by the UHEC at any time.

Final Report. A copy of the final report is to be forwarded to the UHEC within one month of it being submitted to **The Alfred HREC.**

If you have any queries on the information above please e-mail: **humanethics@latrobe.edu.au** or

contact me by phone.

On behalf of the La Trobe University Human Ethics Committee, best wishes with your research!

Kind regards,

Sara Paradowski
Senior Human Ethics Officer
Executive Officer – University Human Ethics Committee
Ethics and Integrity / Research Office
La Trobe University Bundoora, Victoria 3086
P: (03) 9479 – 1443 / F: (03) 9479 - 1464
http://www.latrobe.edu.au/researchers/ethics/human-ethics

LA TROBE UNIVERSITY

University Human Ethics Committee

RESEARCH OFFICE

MEMORANDUM

To: **Professor Glynda Kinsella, School of Psychology and Public Health, College of SHE**
Lei Gryffydd, School of Psychology and Public Health, College of SHE

From: **Senior Human Ethics Officer, Ethics and Integrity**

Subject: **UHEC acceptance of The Alfred HREC approval of a modifications to project - 382/15**

Title: **Mild Injury in Older People**

Date: **12 December 2016**

Thank you for submitting information relating to modification of the above project, which has received ethical approval by the **Alfred HREC,** and for complying with the requirement to seek continuing endorsement by the La Trobe University Human Ethics Committee (UHEC). Your request was received by the Chair of the UHEC, who agrees that the project continues to comply with the National Health and Medical Research Council's *National Statement on Ethical Conduct in Human Research* and with University *Human Research Ethics Guidelines*, and notes the modifications as described in the letter **dated 21 March 2016 and 22 September 2016 from Alfred HREC.**

The following conditions apply to La Trobe UHEC acceptance of the modifications approved by **Alfred** HREC:

Limit of Approval. La Trobe UHEC endorsement is limited strictly to the research protocol as approved by **The Alfred** HREC.

Variation to Project. As a consequence of the previous condition, any subsequent modifications approved by **The Alfred HREC** for the project should be notified formally to the UHEC.

Application of Approval. As outlined in the original final approval letter, all conditions of approval continue to apply.

If you have any queries on the information above please e-mail: humanethics@latrobe.edu.au or contact me by phone.

On behalf of the La Trobe University Human Ethics Committee, best wishes with continuing your research!

Kind regards,

Ms Sara Paradowski
Senior Human Ethics Officer
Executive Officer – University Human Ethics Committee
Ethics and Integrity / Research Office
La Trobe University Bundoora, Victoria 3086
P: (03) 9479 – 1443 / F: (03) 9479 - 1464
http://www.latrobe.edu.au/researchers/ethics/human-ethics

Appendix D: Control Participant Information and Consent Form

Participant Information and Consent Form

Version 4 (Control) Dated: 08/09/2016

MILD INJURY IN OLDER PEOPLE

Research Team

- **Prof Glynda Kinsella**, Psychology, Caulfield Hospital (Telephone: 9479 2409; email: g.kinsella@latrobe.edu.au).
- **A/Prof Biswadev Mitra,** Emergency Medicine, Alfred Hospital
- **A/Prof Ben Ong**, Psychology, La Trobe University.
- **Lei Gryffydd**, Psychology, La Trobe University.
- **Camilla Hordvick Hume**, Psychology, La Trobe University.

This form is 5 pages long. Please make sure you have all the pages.

1. Your Consent

You are invited to take part in this research project.

This Participant Information Sheet contains detailed information about the research project. Its purpose is to explain to you as openly and clearly as possible all the procedures involved in this project before you decide whether or not to take part in it.

Please read this Participant Information Sheet carefully. Feel free to ask questions about any information in the document. You may also wish to discuss the project with a relative or friend or your local health worker. Feel free to do this.

Once you understand what the project is about and if you agree to take part in it, you will be asked to sign the Consent Form. By signing the Consent Form, you indicate that you understand the information and that you give your consent to participate in the research project. You will be given a copy of the Participant Information Sheet and Consent Form to keep as a record.

2. Purpose and Background

This project aims to investigate memory, thinking and activities of daily life of older people who have experienced an injury. Although a significant amount of previous research has investigated the effects of injuries in younger adults, there is little research available that addresses the outcome and recovery specifically in older people. Such information may have implications for current medical practice in terms of strategies for rehabilitation and management techniques.

The results from participants who have experienced an injury will be compared with those of older adults, living in the community, who have not experienced an injury. **You are invited to participate** in this research project because you are aged over 65 years, normally living in the community and have not had a recent injury.

3. Procedures

If you agree to participate, we will also ask you to complete some questionnaires about your health and everyday activities.

Following a telephone call to check that you are eligible to take part in this study, we will arrange a convenient time for you to attend a testing session which will last approximately 90 minutes. The session will be completed at 3 months following the initial phone call. We will call you a week prior to the appointment to remind you. The assessments can be conducted in your own home (with your permission), or at the Alfred Hospital. You will be asked to complete some pen and paper tasks that assess various aspects of thinking and memory and usually take less than an hour to complete. We will ask you to respond to a series of questionnaires about your everyday activities and emotional health and these will require a further 20 minutes to complete. Following the assessment session, we will ask you to complete some tasks in your own home. These will take approximately 5 to 10 minutes each day for one week. At six months, we will send out the same questionnaires for you to complete and return to us. We will also ask you to complete the same tasks in your own home. Again, these will take approximately 5-10 minutes each day for one week.

4. Possible Benefits

You will be able to learn and understand more about the changes and recovery in memory, attention, and performance of everyday tasks that people may experience following an injury. In addition, the findings of this study may benefit others in the future who suffer an injury, in terms of improving rehabilitation and management strategies.

5. Possible Risks

There are no potential harms of participation; however, some people can find that a few of the tasks may be challenging or difficult. If this occurs, you can take a break in the assessment and then either resume the assessment, or withdraw from the study and/or discuss any concerns with the researchers.

6. Privacy, Confidentiality and Disclosure of Information

Any information obtained in connection with this project and that can identify you will remain confidential. To ensure confidentiality, all information collected will identify you by a number only and will be stored securely in password protected files for 7 years. We plan to publish the results in a scientific journal and in addition, if you give us your permission by signing the Consent Form, we will preserve your data for use in future studies by the research team. However, any data used in future research projects will be approved by a Human Research Ethics Committee and will be re-identifiable (coded). Any publication arising from this research will include group data only and individual privacy will not be compromised. The results of this research will also be used by two student researchers to obtain an academic degree.

7. New Information Arising During the Project

During the research project, new information about the risks and benefits of the project may become known to the researchers. If this occurs, you will be told about this new information. This new information may mean that you can no longer participate in this research. If this occurs, the persons supervising the research will stop your participation. In all cases, you will be offered all available care to suit your needs.

8. Results of Project

Upon request, a summary of the research outcomes will be mailed to you following completion of the project. If you wish to find out more about your individual results, these can be discussed with you following completion of assessment but will not represent a comprehensive clinical neuropsychological assessment.

9. Further Information or Any Problems

If you require further information or if you have any problems concerning this project you can contact the principal researcher, Professor Glynda Kinsella (Ph: 03 9479 2409).

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact Ms Emily Bingle, Research Governance Officer, Office of Ethics & Research Governance, Alfred Health, ph: 03 9076 3619, email: research@alfred.org.au; or the Ethics Liaison Officer, Human Ethics Committee, La Trobe University, Victoria, 3086, (ph: 03 9479 1443, email: humanethics@latrobe.edu.au).

10. Participation is Voluntary

Participation in any research project is voluntary. If you do not wish to take part you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. Please complete the "Revocation of Consent Form" or notify a member of the research team by email or telephone that you wish to withdraw your consent for your data to be used in this research project.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect any future routine treatment or relationship with the Alfred Hospital.

Before you make your decision, a member of the research team will be available to answer any questions you have about the research project. You can ask for any information you want. Sign the Consent Form only after you have had a chance to ask your questions and have received satisfactory answers.

11. Ethical Guidelines

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)* produced by the National Health and Medical Research Council of Australia. This statement has been developed to protect the interests of people who agree to participate in human research studies.

The ethical aspects of this research project have been approved by the Human Research Ethics Committee of the Alfred Hospital and La Trobe University.

CONSENT FORM
Version: 4 (Control) Dated 08/09/2016

MILD INJURY IN OLDER PEOPLE

I have read and I understand the Participant Information, Version 4 (Control), dated 08/09/2016. Any questions I have asked have been answered to my satisfaction.

I freely agree to participate in this project according to the conditions in the Participant Information, realising that I may withdraw at anytime.

I will be given a copy of the Participant Information and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details if information about this project is published or presented in any public form. I understand that my data may be used for further studies but my information will remain confidential and be identified by number only.

Participant's Name (printed) .....

Signature Date

Declaration by researcher: I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Researcher's Name

Signature Date

Note: all parties signing the consent section must date their own signature.

☐ *I give my consent for my contact details to be stored so that I may be contacted about other research projects in the future* ***(optional).***

☐ *I agree to my data being stored for possible future use in another project by the research supervisors* ***(optional).***

REVOCATION OF CONSENT FORM

Version: 4 (Control) Dated 08/09/2016

MILD INJURY IN OLDER PEOPLE

I hereby wish to WITHDRAW my consent to the use of data arising from my participation. Data arising from my participation must NOT be used in this research project as described in the Information and Consent Form.

I understand that this notification will be retained together with my consent form as evidence of the withdrawal of my consent to use data I have provided specifically for this project.

I understand that withdrawal form this project WILL NOT jeopardise any treatment or my relationship with the Alfred hospital.

Participant's Name (printed) .....

Signature Date

Appendix E: Trauma Participant Information and Consent Form

Participant Information and Consent Form

Version 4 (Trauma) Dated: 08/09/2016

MILD INJURY IN OLDER PEOPLE

Research Team

- **Prof Glynda Kinsella**, Psychology, Caulfield Hospital (Telephone: 9479 2409; email: g.kinsella@latrobe.edu.au).
- **A/Prof Biswadev Mitra,** Emergency Medicine, Alfred Hospital.
- **A/Prof Ben Ong**, Psychology , La Trobe University.
- **Lei Gryffydd**, Psychology, La Trobe University.
- **Camilla Hordvick Hume**, Psychology , La Trobe University.

This form is 5 pages long. Please make sure you have all the pages.

1. Your Consent

You are invited to take part in this research project.

This Participant Information Sheet contains detailed information about the research project. Its purpose is to explain to you as openly and clearly as possible all the procedures involved in this project before you decide whether or not to take part in it.

Please read this Participant Information Sheet carefully. Feel free to ask questions about any information in the document. You may also wish to discuss the project with a relative or friend or your local health worker. Feel free to do this.

Once you understand what the project is about and if you agree to take part in it, you will be asked to sign the Consent Form. By signing the Consent Form, you indicate that you understand the information and that you give your consent to participate in the research project. You will be given a copy of the Participant Information Sheet and Consent Form to keep as a record.

2. Purpose and Background

This project aims to investigate memory, thinking and activities of daily life of older people who have experienced an injury. Although a significant amount of previous research has investigated the effects of injuries in younger adults, there is little research available that addresses the outcome and recovery specifically in older people. Such information may have implications for current medical practice in terms of strategies for rehabilitation and management techniques.

The results from participants who have experienced an injury will be compared with those of older adults, living in the community, who have not experienced an injury. **You are invited to participate** in this research project because you have recently experienced an injury.

3. Procedures

If you agree to participate, we will also ask you to complete some questionnaires about your health and everyday activities.

Following a telephone call to check that you are eligible to take part in this study, we will arrange a convenient time for you to attend a testing session which will last approximately 90 minutes. The session will be completed at 3 months following your injury. We will call you a week prior to the appointment to remind you. The assessments can be conducted in your own home (with your permission), or at the Alfred Hospital. You will be asked to complete some pen and paper tasks that assess various aspects of thinking and memory and usually take less than an hour to complete. We will ask you to respond to a series of questionnaires about your everyday activities and emotional health and these will require a further 20 minutes to complete. Following the assessment session, we will ask you to complete some tasks in your own home. These will take approximately 5 to 10 minutes each day for one week. At six months, we will send out the same questionnaires for you to complete and return to us. We will also ask you to complete the same tasks in your own home. Again, these will take approximately 5-10 minutes each day for one week.

4. Possible Benefits

You will be able to learn and understand more about the changes and recovery in memory, attention, and performance of everyday tasks that people may experience following an injury. In addition, the findings of this study may benefit others in the future who suffer an injury, in terms of improving rehabilitation and management strategies.

5. Possible Risks

There are no potential harms of participation; however, some people can find that a few of the tasks may be challenging or difficult. If this occurs, you can take a break in the assessment and then either resume the assessment, or withdraw from the study and/or discuss any concerns with the researchers.

6. Privacy, Confidentiality and Disclosure of Information

Any information obtained in connection with this project and that can identify you will remain confidential. To ensure confidentiality, all information collected will identify you by a number only and will be stored securely in password protected files for 7 years. We plan to publish the results in a scientific journal and in addition, if you give us your permission by signing the Consent Form, we will preserve your data for use in future studies by the research team. However, any data used in future research projects will be approved by a Human Research Ethics Committee and will be re-identifiable (coded). Any publication arising from this research will include group data only and individual privacy will not be compromised. The results of this research will also be used by two student researchers to obtain an academic degree.

7. New Information Arising During the Project

During the research project, new information about the risks and benefits of the project may become known to the researchers. If this occurs, you will be told about this new information. This new information may mean that you can no longer participate in this research. If this occurs, the persons supervising the research will stop your participation. In all cases, you will be offered all available care to suit your needs.

8. Results of Project

Upon request, a summary of the research outcomes will be mailed to you following completion of the project. If you wish to find out more about your individual results, these can be discussed with you following completion of assessment but will not represent a comprehensive clinical neuropsychological assessment.

9. Further Information or Any Problems

If you require further information or if you have any problems concerning this project you can contact the principal researcher, Professor Glynda Kinsella (Ph: 03 9479 2409).

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact Ms Emily Bingle, Research Governance Officer, Office of Ethics & Research Governance, Alfred Health, ph: 03 9076 3619, email: research@alfred.org.au; or the Ethics Liaison Officer, Human Ethics Committee, La Trobe University, Victoria, 3086, (ph: 03 9479 1443, email: humanethics@latrobe.edu.au).

10. Participation is Voluntary

Participation in any research project is voluntary. If you do not wish to take part you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. Please complete the "Revocation of Consent Form" or notify a member of the research team by email or telephone if you wish to withdraw your consent for your data to be used in this research project.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect any future routine treatment or relationship with the Alfred Hospital.

Before you make your decision, a member of the research team will be available to answer any questions you have about the research project. You can ask for any information you want. Sign the Consent Form only after you have had a chance to ask your questions and have received satisfactory answers.

11. Ethical Guidelines

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)* produced by the National Health and Medical Research Council of Australia. This statement has been developed to protect the interests of people who agree to participate in human research studies.

The ethical aspects of this research project have been approved by the Human Research Ethics Committee of the Alfred Hospital and La Trobe University.

CONSENT FORM
Version: 4 (Trauma) Dated 08/09/2016

MILD INJURY IN OLDER PEOPLE

I have read and I understand the Participant Information Sheet, Version 4 (Trauma), dated 08/09/2016. Any questions I have asked have been answered to my satisfaction.

I freely agree to participate in this project according to the conditions in the Participant Information Sheet, realising that I may withdraw at anytime.

I will be given a copy of the Participant Information Sheet and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details if information about this project is published or presented in any public form. I understand that my data may be used for further studies but my information will remain confidential and be identified by number only.

Participant's Name (printed) .....

Signature Date

Declaration by researcher: I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Researcher's Name

Signature Date

Note: all parties signing the consent section must date their own signature.

☐ *I give my consent for my contact details to be stored so that I may be contacted about other research projects in the future* ***(optional).***

☐ *I agree to my data being stored for possible future use in another project by the research supervisors* ***(optional).***

REVOCATION OF CONSENT FORM

Version: 4 (Trauma) Dated 08/09/2016

MILD INJURY IN OLDER PEOPLE

I hereby wish to WITHDRAW my consent to the use of data arising from my participation. Data arising from my participation must NOT be used in this research project as described in the Information Sheet and Consent Form.

I understand that this notification will be retained together with my consent form as evidence of the withdrawal of my consent to use data I have provided specifically for this project.

I understand that withdrawal form this project WILL NOT jeopardise any treatment or my relationship with the Alfred Hospital.

Participant's Name (printed) .....

Signature Date

Appendix F: Telephone Screening Document

ID: _____ Date: _____

Telephone Screening Introductory Script

Good morning/afternoon, this is *(associate researcher's name)* from the Alfred Hospital. May I please speak with *(potential participant's name)*?
I am calling because you were recently admitted to the Alfred Hospital following an accident. The Alfred Hospital is carrying out a research study on trauma and older adults. Is this a convenient time to discuss the study – it will probably take 10 minutes? (*if not, schedule a mutually convenient time)*.
The research study aims to investigate cognition and everyday functioning following traumatic injury. The results from this study will be used to inform and hopefully improve, services provided to older adults after they experience trauma. The study involves a 2 hour session at 3 months from your injury. This will be conducted at Alfred Hospital at a time that is convenient for you (*if extenuating circumstances, the session can be conducted at their home*). Given that your injury was (*date*), the session would be in approximately (*provide time frame*). During this session, we will be asking you to do tasks that look at attention, memory and cognition. The point of this session is to see how you are going after your injury. We will send out some information to you in the mail along with some questionnaires that we ask you to complete prior to the session. At six months from your injury, we will send out some questionnaires for you to complete and return to us. The questionnaires will ask you about your mood, memory and everyday functioning.
Do you have any questions? Participation in this study is voluntary and will not impact the service you receive from the Alfred Hospital. Does this sound like something you would be interested in participating in? (*if no, thank them for their time; if yes continue*) Okay, I need to get some basic details from you.
(Do screening Questionnaire then organise a mutually convenient time to carry out the session at approximately 3 months post injury. If unsure, tell them you will call them back)

ID: _____ Date: _____

Demographic Details

1. **Full Name:**
2. **Date:** .....
3. **Gender** (Please circle): MALE FEMALE
4. **Date of Birth:** .....**Age:** .....
5. **How old were you when you left school?**.....
6. **How many years of education have you completed?** (please enter exact number)

0 years	No schooling	☐
1-7 years	Primary School Only (includes prep)	☐
	Final year completed _____	
8 years	Completed Year 7	☐
9 years	Completed Year 8	☐
10 years	Completed Year 9	☐
11 years	Completed Year 10	☐
12 years	Completed Year 11	☐
13 years	Completed Year 12	☐
14-15 years	Some University, College or TAFE	☐
	Course name & duration (years) _____	
16+ years	Completed University, College	☐
	Course name & duration (years) _____	

7. **What was your main occupation? (i.e. the job that you spent the longest period of your working life in)**.....

ID: _____ Date: _____

8. **In the past six months have you undertaken…**

☐ Full-time paid work

☐ Part-time paid work

☐ Full time volunteer work

☐ Part time volunteer work

☐ Not working / retired

☐ Full-time paid work and part-time volunteer work

☐ Full-time volunteer work and part-time paid work

9. **Have you ever been diagnosed or treated for any of the following? (please circle & provide details):**

		Details (when, type, severity, treatment)
Head Injury, Concussion or any accident in which you lost consciousness.	Yes / NO	
Stroke or any transient effects of stroke	Yes / No	
Heart problems (e.g., heart attack, coronary heart disease, atrial fibrillation, myocardial infarction)	Yes / No	
High cholesterol	Yes / No	
Schizophrenia	Yes / No	
Bipolar disorder	Yes / No	
Dementia	Yes / No	
Cerebral palsy	Yes / No	
Epilepsy	Yes / No	
Cancer	Yes / No	
Severe pulmonary disease	Yes / No	
Severe liver disease	Yes / No	
Severe kidney disease	Yes / No	
Multiple sclerosis	Yes / No	
Parkinson's disease	Yes / No	
High blood pressure (hypertension)	Yes / No	
Depression	Yes / No	
Anxiety	Yes / No	
Angina	Yes / No	
Diabetes or 'sugar'	Yes / No	
Alcohol or drug dependency	Yes / No	
History of falls	Yes / No	
Thyroid/ parathyroid disease	Yes / No	
Other neurological conditions	Yes / No	
Other psychiatric disorders	Yes / No	
Other medical conditions	Yes / No	

ID: _____ Date: _____

10. Medication

Please list the medication/drugs you use regularly, how often you take them, and how long you have been taking them for.

Name of medication/ drug	Dose if known (e.g., 50mg)	How often you take it (e.g., once per day)	How long have you been taking this?

11. Are you currently taking any of the following medications?

Donepezil (Aricept) YES ☐ NO ☐

Rivastigmine (Exelon) YES ☐ NO ☐

Galantamine (Reminyl) YES ☐ NO ☐

Memantine (Ebixa) YES ☐ NO ☐

ID: _____ Date: _____

12. **Do you have any form of visual impairment?**

☐ No

☐ Yes, please specify:_____

13. **Do you have any form of hearing impairment?**

☐ No

☐ Yes, please specify:_____

14. **How often do you drink alcohol** (please tick)?

Every day	☐
Most days, but not everyday	☐
Weekly	☐
Monthly	☐
Less than monthly	☐
Never	☐

15. **On average, how many standard drinks containing alcohol do you have per day?**

□ 0 □ 1 □ 2 □3 or 4 □ 5 or 6 □ 7 to 9 □ 10 or more

16. **How often do you have six or more drinks on one occasion?**

ID: _____ Date: _____

17. **Has anyone in your family been diagnosed with dementia or memory problems in the past?** YES ☐ NO ☐

If yes, please specify the diagnosis and relation: _____

_____

18. **How would you describe your general health compared to other people your age? (please circle one)**

Poor Below Average Average Above Average Excellent

19. **How would you describe your day-to-day memory compared to other people your age?**

Poor Below Average Average Above Average Excellent

ID: _____ Date: _____

Telephone Screening: TELE & MAC-Q

1. What hand do you write with? R / L

2. Can I check the spelling of your name? (1)

3. What is your date of birth? (1 for year)
(1 for day & month)

4. How old are you? (1)

5. Do you have any difficulties reading or writing English? **YES (describe)** **NO**

6. Do you have any problems seeing or hearing? **YES (describe)** **NO**

7. In terms of your medical history, have you ever been in hospital or had any significant medical issues or complications? **YES (describe)** **NO**

   Have you ever been diagnosed with a psychiatric disorder? **YES (describe)** **NO**

   Major Depressive Disorder in the last 24 months?
   YES (describe) **NO**
   Any treatment?

8. Have you ever seen your doctor or had any investigations regarding your sleep?
   YES (describe) **NO**

   Do you have a diagnosis of sleep apnoea? **YES (describe)** **NO**

   Any treatment?

9. Have you ever seen your doctor or had any investigations regarding your memory?
   YES (describe) **NO**

10. How would you say your memory is at the moment compared to people of the same age?

ID: _____ Date: _____

11. Complete the MAC-Q (memory complaint questionnaire)

MAC-Q

As compared to when you were in high school or college, how would you describe your ability to perform the following tasks involving your memory?

	Much better now (1)	Somewhat better now (2)	About the same (3)	Somewhat poorer now (4)	Much poorer now (5)
Remembering the name of a person just introduced to you					
Recalling telephone numbers or postcodes that you use on daily or weekly basis					
Recalling where you have put objects (e.g., keys) in your home or office					
Remembering specific facts from a newspaper or magazine article you have just finished reading					
Remembering the item(s) you intend to buy when you arrive at the supermarket or pharmacy					
In general, how would you describe your memory as compared to when you were in high school?	(2)	(4)	(6)	(8)	(10)

Total score: _____

I would like to ask some questions now that require use of your memory.

12. Firstly, can you please tell me the:
    (a) Year (1)
    (b) Season (1)
    (c) Month (1)
    (d) Date (1)
    (e) Day of the week (1)

ID: _____ Date: _____

13. Please listen carefully to these 3 words and repeat them to me after I say them to you. The 3 words are 'key, toothbrush, lamp'. Could you tell me the words now.

    (Record first trial only, but if they do not get all 3, then give them two more trials) (1)

14. Can you please count backwards from 20 by threes?

    (17, 14, 11, 8, 5, 2) (0.5 per correct response, max 3)

    (If unable then cue e.g., what is 20 take away 3? And then if you take away 3 more ... Record if a cue is used)

15. Who is the current Prime Minister of Australia? (1)

16. Who was the previous Prime Minister? (1)

17. A few minutes ago, I asked you to remember 3 words. Could you tell me now what they were: (1 point per correct word, max 3)

    If they miss any of the three words:

    (a) If they don't say 'key': I'm going to read you a list of words. Tell me which words were the ones from before:
    Key Ring Chair (0.5)

    (b) If they don't say 'toothbrush': I'm going to read you a list of words. Tell me which words were the ones from before:
    Picture Toothbrush Door (0.5)

    (c) If they don't say 'lamp': I'm going to read you a list of words. Tell me which words were the ones from before:
    Pen Table Lamp (0.5)

ID: _____ Date: _____

18. Now, I am going to say two things that are similar to each other in one or more ways. I would like you to tell me the greatest similarity between them.

    (a) For example, in what way are an orange and banana similar to each other?

(right: both are fruit; 1)
(partially right: both are food, have peels, same colour; 0.5)
(wrong: both contain calories, or gives a difference such as "one is round"; 0)

    (b) In what way are a table and a chair similar to each other?

(right: both are furniture; 1)
(partially right: both found in kitchen, used when you eat a meal; 0.5)
(wrong: both have 4 legs, made of wood, gives a difference such as "you sit on one"; 0)

TOTAL (TELE) **/20**

Thanks for that. The next thing to do is organise a mutually convenient time and place for the assessment. Would you prefer for the tasks to be conducted at the Alfred or your place? And when would be a convenient time for you?

Thank you for your interest and time. I have all the information I need from you at the moment; do you have any other questions for me?

Appendix G: LIST Instructions for Administration

LaTrobe Itemised Shopping Task (LIST) Instructions

Prior to starting the broader assessment, set up the laptop and position to the side.

Set-up for the LIST

Ensure the laptop is positioned on the desk and provide participants with initial instructions:

In a little while you will view the aisles of supermarket as display on my computer. Similar to shopping in everyday life, you will have a list of items to buy and some other tasks to remember. I will demonstrate how to use the program and you can practice in a moment. When you go shopping, you will be able to refer a list of shopping items and when you see an item on the shelf, from the list, you will be able to 'pick it up' by clicking on the item with the computer mouse. The computer screen will provide you with feedback so you will know an item has been picked-up. Do you have any questions?

Orient them to the laptop for the 'practice session' and say:

Let's take a look at the task together.

Demonstration: Entering via the map, demonstrate how to navigate left and right, select items, including specials and return to the map.

After the demonstration, say:

This is only a practise, but I would like you to collect the items from this list and if they are on special get that item.

Allow them to orient to the task and answer any questions. Ensure they can navigate the map and collect items. Close the task and move the computer out of view, then say:

There is something else you need to do. Your neighbour is ill, and you need to pick up some items for them. You forgot to add these items to your shopping list before leaving home. Please try to remember to collect these items later when you go shopping. You can click on them just like the other shopping items.

Learning Task

Provide the following instructions to the participant:

I am going to read you a list of the six items for your neighbour. Please listen carefully because when I am finished, I want you to tell me as many items as you can. It can be in any order.

1

Read out the six target items at the rate of approximately one per second. Then write down all the items the participant can remember.

After the first trial is completed, the researcher provides the following instructions: "*I will read the same list again. Like before, tell me as many items as you can, including ones you have already said, if you can".* These instructions are repeated for the third and fourth trials, if needed.

Do not allow any further access to these items or reminders to collect them.

Do you have any questions about this task?

Credit Card Task

Provide these instructions for Credit Card Task:

I have something else for you to remember. Can you ask for your neighbour's credit card before you commence shopping? You can say "I would like my neighbour's credit card". Once you have finished shopping, can you remember to return the credit card to me? Do you have any questions?

Move the laptop out of the way and advise the participant:

"We will return to this task later."

Proceed with another 5-minute task (Trail Making Test; TMT B-A; (Reitan & Wolfson, 1995). Memory tasks should not be administered during this break.

LIST Task

After 5-minute interval, place the laptop in front of the participant and pass them the shopping list (Appendix X).

Now we are going to return to the shopping task we spoke about earlier.

This is the cue for credit card short delay.

a) A spontaneous response

- **If correct, say**: *good thank you. Do you have any questions?* **Proceed to shopping task.**

b) *No spontaneous response*

If participant does not spontaneously ask for their neighbour's credit card within 15 seconds, say: "*You were going to ask me something when we came back to the shopping.*"'

- **If this triggers a spontaneous response i.e., asks for credit card, say,** *"Good, thank you."*

2

- **If they recall the wrong task say,** *"No, not quite, you were going to ask me for your neighbour's credit card".*
- **If the examine doesn't remember that they were supposed to do something, say, "***That's okay, you were just going to ask me for your neighbour's credit card."*

Orient the participant to move onto shopping task. Be seated beside and slightly behind the participant. Record the items the participant collects. **Do not provide feedback.** If the participant asks if they were correct say, *"I can tell you how you've done at the end of todays the assessment,",* or equivalent. Repeat procedure for all remaining shopping targets.

Credit Card Long Delay

When the participant advises they are finished, they should return their neighbour's credit card.

a) A spontaneous response

- **If correct, say**: *good thank you. Do you have any questions?* **Proceed to forced choice.**

b) *No spontaneous response*

If participant does not spontaneously ask for their neighbour's credit card within 15 seconds, say: ""*You were going to do something after you finished shopping."*

- **If this triggers a spontaneous response i.e., returns credit card, say,** *"Good, thank you."*
- **If they recall the wrong task say,** *"No, not quite, you were going to return your neighbour's credit card".*
- **If the examine doesn't remember that they were supposed to do something, say, "***That's okay, you were just going to return your neighbour's credit card."*

Forced Choice Recognition

At conclusion of the shopping task, say:

"I am going to read a list of items, some of them were extra items you needed to get for your ill neighbour. I want you to tell me which one was for your neighbour. Was it…. (Circle response on record form).

Appendix H: LIST Record Form

LaTrobe Itemised Shopping Task (LIST) Record Form

Name: …… ID……

Age: …… (years)

Date of test: ……/……/……..

Comments: e.g., returning to previous aisles, clock checking behaviour, attention fluctuations

……
……

SUMMARY OF SCORES

Record time shopping start: ……/……

Time shopping end :……/……

Length:

Total Shopping list items _____

	PM Score	RM score
Credit Card short delay:	_____	_____
Credit Card long delay	_____	_____
Total Prospective Memory	_____	
Total Retrospective Memory		_____
Credit Card Total: _____		

	Score	Recognition
Target 1 (weetbix)	_____	_____
Target 2 (eggs)	_____	_____
Target 3 (tea)	_____	_____
Target 4 (pasta)	_____	_____
Target 5 (toothpaste)	_____	_____
Target 6 (broccoli)	_____	_____
Total Targets	_____	
Total Recognition		_____

1

The following is a summary to assist the examiner to keep track of the correct procedure, expected reposes, and correct score. It is not intended as a substitute for the detailed instructions provided in the manual, which must be followed at all times.

1. Provide instructions for the LIST
2. Demonstrate how to use the program and then provide them with the practice shopping list. Provide help if needed. If the participant is struggling, repeat the instructions and note this down in the comments section along with any problems they are having.
3. Once they have finished the practice. Provide the instructions for the target items. Then administer list-learning task for a maximum of four trials. If they cannot recall all of the items, note what items they can recall.
4. Provide instructions regarding the neighbour's credit card.
5. Move laptop to the side and administer Trail Making Test (5-minute break)
6. Return to the program. Provide prompt for credit card if necessary.
7. Participant commences shopping.
8. Once they have finished, provide prompt for credit card if required.
9. Administer forced-choice recognition task

Task scoring

List Learning Task

I am going to read you a list of the six shopping items. Please listen carefully to the list because when I am finished, I want you to tell me as many items as you can. It can be in any order.	*I will read the same list again. Like before tell me as many as you can including ones you have already said, if you can.*	*Repeat*	*Repeat*	*This is the last time I will read them.*
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**
1. **Eggs** 2. **Weetbix** 3. **Toothpaste** 4. **Broccoli** 5. **Tea** 6. **Pasta**				

2

Credit card (short delay)
After you have placed the laptop in front of the participant, handed them the shopping list and instructed them to commence shopping the participant should spontaneously ask to have the credit card. If they do not ask after 15 seconds, "*'You were going to ask me something when we came back to the shopping.*"'

a) The participant spontaneously carries out task	PM Score 2 RM Score 2
b) Prompt, asks for the credit card	PM Score 0 RM score 1
c) Prompt, "no"/wrong task	RM Score 0

Targets

(1.1) **Target 1 - weetbix**

a) Pick-up item	Score 2
b) Late item i.e., returned to aisle	Score 1
c) No response/ miss	Score 0

(1.2) **Target 2 – eggs**

a) Pick-up item	Score 2
b) Late item i.e., returned to aisle	Score 1
c) No response/ miss	Score 0

(1.3) **Target 3 - tea**

a) Pick-up item	Score 2
b) Late item i.e., returned to aisle	Score 1
c) No response/ miss	Score 0

(1.4) **Target 4 - pasta**

a) Pick-up item	Score 2
b) Late item i.e., returned to aisle	Score 1
c) No response/ miss	Score 0

(1.5) **Target 5 – toothpaste**

a) Pick-up item	Score 2
b) Late item i.e., returned to aisle	Score 1
c) No response/ miss	Score 0

(1.6) **Target 6 – broccoli**

a) Pick-up item	Score 2
b) Late item i.e., returned to aisle	Score 1
c) No response/ miss	Score 0

Shopping List Item 1: **Special K**

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 2: Vegemite

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 3: Jam

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 4: Milk

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 5: Cheese

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 6: Milo

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 7: Crackers

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 8: Rice

a) Pick-up item — Score 2
b) Late item i.e., returned to aisle — Score 1
c) No response/ miss — Score 0

Shopping List Item 9: Paracetamol

a) Pick-up item Score 2
b) Late item i.e., returned to aisle Score 1
c) No response/ miss Score 0

Shopping List Item 10: Deodorant

a) Pick-up item Score 2
a) Late item i.e., returned to aisle Score 1
b) No response/ miss Score
0**Shopping List Item 1:** Red MeatPick-up item
Score 2

a) Late item i.e., returned to aisle Score 1
b) No response/ miss Score 0

Shopping List Item 11: Red Meat

c) Pick-up item Score 2
d) Late item i.e., returned to aisle Score 1
e) No response/ miss Score 0

Shopping List Item 12: Apples

a) Pick-up item Score 2
b) Late item i.e., returned to aisle Score 1
c) No response/ miss Score 0

Credit card (long delay); when the participant indicates they have completed the shopping, the participant should spontaneously remember to ask to return the credit card. If not, provide prompt *"You were going to do something after you finished shopping."*

a) The participant spontaneously carries out task PM Score 2
RM Score 2

b) Prompt, asks for the credit card PM Score 0
RM score 1

c) Prompt, "no"/wrong task RM Score 0

5

Forced choice recognition: *"Which one of these were items for your ill neighbour? Was it….* (Circle response).

1)	***Weetbix***	***or***	*Sultana bran*
2)	*Bread*	***or***	***eggs***
3)	***Toothpaste***	***or***	*toilet paper*
4)	*Cauliflower*	***or***	***broccoli***
5)	*Coffee*	***or***	***tea***
6)	***Pasta***	***or***	*Oats*

Forced Recognition Score =

6

Appendix I: LIST Shopping lists

Practice Shopping List

Air Freshener

Toilet Paper

Rubbish Bags

Onions

Rockmelon/Cantaloupe

Watermelon

Mangoes

Shopping list

Paracetamol
Vegemite
Special K
Deodorant
Milk
Jam
Rice
Red Meat
Crackers
Apples
Milo
Cheese

Appendix J: Letter of Acceptance for Chapter 5

24-Nov-2020

Dear Ms Gryffydd,

Ref: 'Assessing Prospective Memory in Older Age: The Relationship between Self-report and Performance on Clinic-Based and Naturalistic Tasks'

Our referees have now considered your paper and have recommended publication in Aging, Neuropsychology and Cognition. We are pleased to accept your paper in its current form which will now be forwarded to the publisher for copy editing and typesetting.

You will receive proofs for checking, and instructions for transfer of copyright in due course.

The publisher also requests that proofs are checked and returned within 48 hours of receipt.

Thank you for your contribution to Aging, Neuropsychology and Cognition and we look forward to receiving further submissions from you.

Sincerely,

Dr Nancy Dennis
Editor-in-Chief
Aging, Neuropsychology and Cognition
nad12@psu.edu

Appendix K: Letter of Acceptance for Chapter 7

17-May-2021

RE:

MS Number: CEN-OA 21-49.R2
Title: 'Cognitive Performance in Older Adults at Three Months Following Mild Traumatic Brain Injury'
Authors: Gryffydd, Lei; Mitra, Biswadev; Wright, Bradley; Kinsella, Glynda

Dear Dr. Kinsella,

My thanks again to the expert reviewers for their valuable input that guided the manuscript throughout this process.

I appreciate that you addressed the requested revisions in a timely manner. Having reviewed your response letter and the revised manuscript, I am pleased to accept the manuscript for publication at our journal. We look forward to receiving submissions from you in the future.

I will now pass your manuscript to our editorial assistant who will take it through the production stage.

Sincerely,

Professor Lisa Jane Rapport
co-Editor in Chief
Journal of Clinical and Experimental Neuropsychology
rapport@wayne.edu