PhD Thesis Title:

Investigating Assistive Technology to Support Memory for People with Cognitive Impairments

Thesis Author:

Matthew Jamieson M.A. (Hons), MSc

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Supervisors:

Professor Jonathan Evans (primary), University of Glasgow, Institute of Health and Wellbeing

Professor Stephen Brewster, University of Glasgow, Department of Computing Science

Dr. Marilyn Lennon, University of Strathclyde, Computing and Information Sciences

Institute of Health and Wellbeing

School of Medical and Veterinary Sciences

University of Glasgow

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Abstract

Technologies such as automobiles or mobile phones allow us to perform beyond our physical capabilities and travel faster or communicate over long distances. Technologies such as computers and calculators can also help us perform beyond our mental capabilities by storing and manipulating information that we would be unable to process or remember. In recent years there has been a growing interest in assistive technology for cognition (ATC) which can help people compensate for cognitive impairments. The aim of this thesis was to investigate ATC for memory to help people with memory difficulties which impacts independent functioning during everyday life.

Chapter one argues that using both neuropsychological and human computing interaction theory and approaches is crucial when developing and researching ATC. Chapter two describes a systematic review and meta-analysis of studies which tested technology to aid memory for groups with ABI, stroke or degenerative disease. Good evidence was found supporting the efficacy of prompting devices which remind the user about a future intention at a set time. Chapter three looks at the prevalence of technologies and memory aids in current use by people with ABI and dementia and the factors that predicted this use. Pre-morbid use of technology, current use of non-tech aids and strategies and age (ABI group only) were the best predictors of this use. Based on the results, chapter four focuses on mobile phone based reminders for people with ABI. Focus groups were held with people with memory impairments after ABI and ABI caregivers (N=12) which discussed the barriers to uptake of mobile phone based reminding. Thematic analysis revealed six key themes that impact uptake of reminder apps; *Perceived Need, Social Acceptability, Experience/Expectation, Desired Content and Functions, Cognitive Accessibility* and *Sensory/Motor Accessibility*. The *Perceived need* theme described the difficulties with insight, motivation and memory which can prevent people from initially setting reminders on a smartphone. Chapter five investigates the efficacy and acceptability of unsolicited prompts (UPs) from a smartphone app (ForgetMeNot) to encourage people with ABI to set reminders. A single-case experimental design study evaluated use of the app over four weeks by three people with severe ABI living in a post-acute rehabilitation hospital. When six UPs were presented through the day from ForgetMeNot, daily reminder-setting and daily memory task completion increased compared to when using the app without the UPs. Chapter six investigates another barrier from chapter 4 – cognitive and sensory accessibility. A study is reported which shows that an app with 'decision tree' interface design (ApplTree) leads to more accurate reminder setting performance with no compromise of speed or independence (amount of guidance required) for people with ABI (n=14) compared to a calendar based interface. Chapter seven investigates the efficacy of a wearable reminding device (smartwatch) as a tool for delivering reminders set on a smartphone. Four community dwelling participants with memory difficulties following ABI were included in an ABA single case experimental design study. Three of the participants successfully used the smartwatch throughout the intervention weeks and these participants gave positive usability ratings. Two participants showed improved memory performance when using the smartwatch and all participants had marked decline in memory performance when the technology was removed. Chapter eight is a discussion which highlights the implications of these results for clinicians, researchers and designers.

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Jamieson, M., Cullen, B., McGee-Lennon, M., Brewster, S., & Evans, J. J. (2014). The efficacy of cognitive prosthetic technology for people with memory impairments: A systematic review and meta-analysis. *Neuropsychological rehabilitation*, *24*(3-4), 419-444.

Jamieson, M., Cullen, B., McGee-Lennon, M., Brewster, S., & Evans, J. (2015). Technological memory aid use by people with acquired brain injury. *Neuropsychological rehabilitation*, 1-18.

Conference Proceedings

Jamieson, M., McGee-Lennon, M., Cullen, B., Brewster, S., & Evans, J. (2015, October). Issues influencing the Uptake of Smartphone Reminder apps for People with Acquired Brain Injury. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility*, *Lisbon, Portugal*, (pp. 339-340). New York, USA: ACM.

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Declaration

I declare that this thesis, submitted to the University of Glasgow for the degree of Doctor of Philosophy, is the result of my own research, except where otherwise acknowledged, and that this thesis has not been submitted for a higher degree to any other university or institution.

1 Chapter One – Introduction to Research

1.1 General Introduction

The focus of the work in this thesis is the use of technology to support remembering in people with memory impairment. This chapter will outline the main theories of memory and principles of neuropsychological rehabilitation. It also introduces assistive technology for cognition (ATC), and human computer interaction (HCI), specifically regarding theories of usability and accessibility of technology, and the methodological issues that will be considered in the thesis. It is argued that it is beneficial to use both HCI and neuropsychological approaches and methods when researching ATC.

1.1.1 Introduction

The term acquired brain injury (ABI) refers to trauma to the brain arising from a head injury (e.g. road traffic accidents and falls), cardiovascular events (e.g. stroke), illnesses or diseases (e.g. brain tumour or encephalitis). Dementia is a blanket term for diseases of the brain which cause a gradual deterioration of the brain and leads to impairment in cognitive abilities. Common types of dementias include Alzheimer’s, Fronto-Temporal Dementia and Parkinson’s disease. Individuals who have suffered ABI or who have a degenerative disease have a high prevalence of memory impairments. In particular in ABI, prospective memory is often impaired (Evans, 2003). Depending on the areas of the brain which are initially affected, people with dementia can present with difficulties with remembering events, naming and recognizing objects, and being apathetic or disinhibited (Lancioni, Sigafoos, O’Reilly & Singh, 2013). People with ABI or dementia may also experience disorganized thinking, problems with planning, language impairment, poor self-monitoring and difficulty switching between or initiating tasks (Wilson, Gracey & Evans, 2009). These impairments make it difficult for people to perform everyday tasks such as shopping, personal care or cooking, or healthcare tasks such as remembering appointments, treatment plans and medication. Furthermore, health problems that directly or indirectly result from the ABI or which are associated with ageing, such as physical disabilities, sensory/motor impairments and chronic illnesses can increase the number of health-based memory demands. Some of the main cognitive processes which can become impaired after brain injury or degenerative disease are discussed below.

1.1.2 Memory and Executive functioning

The mechanisms that underlie memory are multi-faceted and theorists have argued that several dissociated component processes are involved in remembering. For example a distinction is made between semantic, episodic and procedural long term memory. Semantic memory is defined as organized knowledge and facts about the world; episodic memory refers to memories of specific events and experiences, and procedural memory refers to learned motor skills (Squire, 2004). These long term memory systems are thought to be distinct from working memory – a limited and temporary store of memories which allows actions to be performed, decisions to be made and learning to take place (Baddeley, 1992). Within working memory theory there are also a number of component processes. For example the phonological loop and visuo-spatial sketch pad hold short term memory traces from auditory and visual sources, the central executive component focuses and switches attention between stimuli in the environment, and the episodic buffer provides a back-up store that communicates with long-term and working memory (Baddeley, 2012). The functioning of this central executive is particularly important to the successful performance of everyday memory tasks and executive functioning is often impaired after injury or degeneration of the brain.

There are many models of executive functions (Norman & Shallice, 1986, Baddeley & Wilson, 1988; Miyake, Friedman, Emerson, Witzki, Howerter & Wagner, 2000) and each describe a number of specific processes that underlie executive functioning. These are reflected in neuropsychological test batteries which are used to assess executive functioning such as the Delis Kaplan Executive Function System (DKEFS; Delis, Kaplan and Kramer, 2001), the Behaviour Rating Inventory of Executive Functioning (BRIEF) (Roth, Isquith, & Gioia, 2014) and Behavioural Assessment of the Dysexecutive Syndrome (BADS; Wilson, Evans, Alderman, Burgess & Emslie, 1997). Processes measured in these tests include planning in an optimal manner while abiding by rules, problem solving in novel circumstances, applying judgement and making decision, task switching, task initiation and inhibition, self-monitoring, adapting to changing circumstances, emotional control, sustained attention & working memory. This list is not exhaustive and there is still debate about whether or not these processes are separable (Miyake & Shah, 1999).

In the neuropsychological rehabilitation literature, memory is often grouped into prospective (memory for future events) and retrospective (memory for past events). This work focuses on the rehabilitation of prospective memory (PM) and executive functioning. Prospective memory refers to the cognitive processes which allow a future intended action to be successfully carried out (e.g. taking medication or going to an appointment). Not being able to remember what you were going to do or successfully carry out future intentions is particularly debilitating and can prevent people from gaining employment, and impact health and social functioning (Wilson et al., 2009). PM involves executive processes including planning, task initiation, inhibition of distracting stimuli and self-monitoring (Shum, Fleming & Neulinger, 2002). PM intentions cannot be carried out at the time they are formed and therefore the intention must be stored in memory and retrieved at a later time. PM can be time-based (e.g. phone the Doctor's office at 2pm), event-based (e.g. remember to ask for a repeat prescription when you see the Doctor) and activity-based (e.g. arrange another appointment at the end of the meeting). Maintenance is required for these delayed intentions while other, unrelated tasks, are carried out.

1.1.3 Neuropsychological Rehabilitation

Many theories of memory and executive functioning were developed by clinicians during their work with neurological patients. Neuropsychology clinicians aim to help rehabilitate cognitive processes after injury, illness, or onset of a degenerative disease. It is beneficial to help those with memory difficulties to live independently at home, rather than in care homes, where possible (Pollack et al., 2005). ABI and the most common form of dementia, Alzheimer's disease

(AD), are estimated to cost the government around £7bn and £23bn per year respectively and a large part of this cost is providing care home services (Quince, 2012; Department of Health, 2005). This is expected to grow to £50bn for AD by 2038. Around two thirds of people with dementia currently live within the community in the UK (Hareven, 2001). The majority of people who live within the community are cared for by family members or friends who help alleviate the strain on care services. However, caring for people with memory difficulties can lead to psychological stress for those providing the support and care (Brodaty & Donkin, 2009; Caprani, Greaney & Porter, 2006). Interventions which improve independence can be beneficial socially and economically, by allowing people to stay in their homes for longer and by relieving carer burden.

Barbara Wilson and colleagues (2009) state that the aim of neuropsychological rehabilitation is to, '…enable people with cognitive, emotional, or behavioural deficits to achieve their maximum potential in the domains of psychological, social, leisure, vocational or everyday functioning.' (Wilson et al., 2009, pp.369) Many different approaches and interventions have been developed which aim to restore, support or compensate for impairment to the cognitive processes outlined above. For example goal management training attempts to focus people with executive and memory impairments on their goals (Robertson, 1996), errorless learning aims to teach new skills and knowledge to people with memory impairment (Wilson, Baddeley, Evans & Shiel, 1994) and memory strategies and aids such as writing on a whiteboard or diary can be taught to help people with prospective impairment (Evans, 2003).

1.1.4 Assistive Technology for Cognition

Assistive technologies for cognition (ATC) can be created, adapted or appropriated to compensating for cognitive impairment, as part of neuropsychological rehabilitation. ATC has great potential to help with the goals of neuropsychological rehabilitation either by prompting to compensate for prospective memory impairment, reminding about forgotten facts and events and supporting people during performance of everyday tasks. The ATC covered in this work does not include technology used in cognitive training (e.g. brain training apps), nor devices used to monitor people's health and wellbeing, nor robotic technologies which do tasks for people.

Assistive technology can be categorised in terms of the technology used, the type of memory impairment they are designed to support, what behaviour they support, which group of people they are designed to help and whether designed to be portable or static. However, people with different aetiologies leading to memory impairment can have similar memory difficulties and different devices can have similar functions. In a review of the ATC literature, Gillespie, Best and O'Neill (2012) used the World Health Organisation International Classification of Functioning (ICF) framework to review the specific domains of cognitive functioning which were compensated for by different technologies. They found that most technologies that were used as interventions targeting ICF domain 'organisation and planning' were micro-prompting systems which support step-by-step completion of tasks with multiple sub-steps, such as cooking a meal. The ATC designed to help with ICF domain 'time management' were reminding systems, supporting PM. Based on this finding, the two types of ATC addressed in the first chapter will be devices that prompt people to carry out intended tasks (prompting devices) and devices which guide or micro-prompt people to complete the steps of a task in order (micro-prompting devices).

1.1.5 Neuro-socio-technical model

The neuro-socio-technical model for ATC developed by O'Neill and Gillespie (2014) makes use of the concept of 'total circuits' when understanding human use of technology. They argue that researchers need to understand the environment, the user and the technology in order to fully understand assistive technology use. The second half of this thesis focuses specifically on prompting software which is presented on smartphone hardware (or mobile reminder apps). Prior to chapter four the neuro-socio-technical model will be used to describe the 'total circuit' of mobile reminder app use. The subsequent three chapters investigate the feasibility and usability of software adaptations and hardware that aim to address three important parts of the reminder app use circuit – a) initiating reminder setting behavior, b) successfully setting a reminder and c) successfully receiving the reminder. Chapter four investigates unsolicited prompting as a way to increase reminder setting; chapter five outlines the development and testing of a decision tree user interface which aims to be more accessible and usable for people with ABI than a calendar based interface; chapter 6 investigates the efficacy and acceptability of wearable smartwatch hardware for receiving reminders set on a smartphone. Using the neuro-socio-technical model to develop a ‘total circuit’ for reminding technology use allows the problem space (or barriers to reminding ATC use) for designers and clinicians to be framed and allow development of future research questions. This future research will be outlined in the thesis discussion.

1.1.6 Human Computer Interaction

Human Computer Interaction (HCI) aims to understand people’s use of computers, including the physiology and psychology of the user, the computer’s design and function and the physical and social environment in which the computer is used (Rogers, 2012). One focus of HCI is technology usability and accessibility for both the general population and those with disabilities (Henry, Abou-Zahra & Brewer, 2014). The concept of architectural universal design (Goldsmith, 1963) - that products and the built environment should be, as far as possible, accessible to all - has been applied by HCI researchers with the aim of designing computing technology which can be accessed and used by everyone regardless of disability (Shneiderman, 2000). In ATC research, using HCI approaches and methods is important when trying to understand issues which influence the interaction between the user and the assistive technology (Dawe, 2006). Universal design and usability research is relevant when investigating ATC because the users have cognitive difficulties which may prevent them from accessing or successfully using technology.

1.1.7 Technology Acceptance Model

In order for designers to develop effective ATC, and for clinicians to confidently introduce ATC to clients, researchers must be able to explain and predict its use and acceptability to prospective users. The Technology Acceptance Model (TAM) (Davis, Bagozzi & Warshaw, 1989) and subsequent adaptation (Venkatesh &

Davis, 2000; Venkatesh, Morris, Davis & Davis, 2003) were developed by HCI researchers to explain and predict use of technology in the workplace. The TAM introduced two key concepts – perceived ease of use and perceived usefulness which were found to influence the uptake of technology. The most recent adaptation of this theory is the Unified Theory of Acceptance and Use of Technology (UTAUT). In the UTAUT, performance expectancy of the technology, social influence and expected effort required to use the technology are constructs that influence the intention to use technology and facilitating conditions determine the use behavior. The UTAUT scale was developed from this research and is a useful tool for assessing user experience. The NASA Task Load Index (TLX) (Hart and Staveland, 1988) is another assessment tool which is widely used to assess the perceived workload of a system. It includes the six subscales, which measure mental, physical and temporal demand, perceived performance level, effort to achieve that performance and frustration during use. These theoretical frameworks are valid when discussing acceptance of ATC by people with cognitive impairments, carers and clinicians. In chapter three the TAM and UTAUT models are used to understand to the findings of a focus group study investigating use of ATC for people with ABI and their carers. In chapters four, five and six an adapted UTAUT scale and the NASA TLX are used to gain insight into the participants experience when using the different technologies under investigation. User experience (UX) trends found in each of these chapters and methodological issues when investigating UX in an ATC context will be reflected on in the thesis discussion.

1.1.8 Aims of thesis

Investigating ATC using approaches and methods from both neuropsychological rehabilitation and HCI allows us to develop, test and evaluate technology which is able to help compensate for the cognitive difficulties which people with neurological damage or decline experience. HCI and neuropsychological rehabilitation approaches such as the neuro-socio-technical model of ATC share a holistic approach in which the technology, the user and the environment are considered. By applying HCI methods when investigating the use of ATC in rehabilitation, the issues influencing the usability and accessibility of the technology can be investigated alongside the efficacy of the technology as a rehabilitation tool.

This work investigates ATC for memory to help people with memory difficulties, specifically focusing on the ability to form intentions and carry out intended actions which are crucial for independent functioning during everyday life. Initial research questions included a) Is ATC effective for compensating for memory? b) What ATC do people with memory impairments use and what predicts this use? c) What are the main barriers to using ATC in this way?

The second part of this work describes the development and testing of software which aims to overcome the barriers to use and support successful use of smartphone reminding apps for people with ABI. Chapters 4, 5 and 6 investigate the feasibility, efficacy and acceptability of three potential solutions to barriers to the use of this type of ATC. Another aim is also to reflect on methodologies used within ATC research and the challenges with doing this kind of research.

2 Chapter Two - A systematic review and meta-analysis of the efficacy of memory aid technology in neuropsychological rehabilitation.

2.1 Introduction

Several previous reviews have investigated various different aspects of cognitive aids. For example, the efficacy and usability of Personal Digital Assistant (PDA) devices (De Joode, van Heugten, Verhey, & van Boxtel, 2010), the efficacy of assistive technology for all cognition (Gillespie, Best & O'Neill, 2012), the efficacy of cognitive rehabilitation interventions in general in a meta-analysis (Rohling, Faust, Beverly, & Demakis, 2009), the potential for the use of technology with older adults (Caprani, Greaney, & Porter, 2006) and the use of technology with people with dementias (Bharucha, Anand, Forlizzi, Dew, Reynolds III, Stevens, & Wactlar, 2009) have been investigated. However, no reviews have specifically examined all compensatory technologies which aimed to improve performance on memory tasks, and which have been tested with memory impaired patients.

2.1.1 Prompting devices and micro-prompting devices

Gillespie and O'Neill (2012) reviewed the literature to find out what types of technologies had been investigated and what kinds of cognitive impairment they had been used to support. They found that technologies for 'organisation and planning' were mostly micro-prompting systems; systems which guided the users through the different stages of a task. The technology designed to help with 'time management' were reminding systems or prompting devices which prompted the user to perform an action at a specific time (Gillespie & O'Neill, 2012). Prompting devices (PDs) include portable or wearable personal digital assistants (PDAs) such as mobile phones (Svoboda, Richards, Leach, & Mertens, 2012), pagers (Wilson, Emslie, Quirk, & Evans, 2001), voice recorders (Yasuda et al., 2002) and watches (van Hulle & Hux, 2006). Some prospective memory aids give reminders from a set location within the home (Lemoncello, Sohlberg, Fickas, & Prideaux, 2011a), care home (Boman, Bartfai, Borell, Tham, & Hemmingsson, 2010) or vehicle (Klarborg, Lahrmann, Tradisauskas, & Harms, 2011). These reminders support the ability to retain future intentions in the medium and long term. However, over a shorter term, prospective memory is also required when performing a task with several sub-tasks, or when interleaving between different activities, as the planned intentions must be retained and then acted upon. Micro-prompting devices (MPDs) are designed to support plan retention and task organisation in everyday tasks with multiple steps such as hand-washing (Mihailidis, Fernie, & Cleghorn, 2000) and donning of prosthetic limbs (O'Neill & Gillespie, 2008). In this chapter, studies which investigate the efficacy of technologies which prompt people about future intentions or guide people through everyday tasks were reviewed and, where possible, analysed in a meta-analysis.

2.1.2 Methodology

Previous reviews unanimously found technology to be useful for aiding performance of memory tasks; however there were methodological limitations which have to be considered. For example De Joode and colleagues (2010) used the criteria outlined by Cicerone and colleagues (Cicerone, Dahlberg, Kalmar, Langenbahn, Malec, Bergquist et al., 2000) to rate their selected papers and found that only one of 25 papers had a top rating and only two received a medium rating. This was due to the lack of randomised controlled trials (RCTs) investigating the efficacy of ATC devices at this time. While RCT design is desirable in most clinical intervention studies, a large number of studies looking at technological memory aid interventions have used single case experimental designs and these vary in their design and quality. Despite this no previous review has attempted to systematically examine the variation in quality of SCED papers using a rating system which is specifically tailored to rate single case experimental design studies.

2.1.3 Single Case Experimental Design

Single case experimental designs (SCEDs) have a long history in evaluating interventions in the behavioural sciences (Evans, Gast, Perdices & Manolov, 2014). In the assistive technology literature, for example, SCEDS have been used to investigate several different assistive technologies prior to larger group studies (Wilson, Emslie, Quirk & Evans, 1999; Lemoncello, Sohlberg, Fickas, Albin & Harn, 2011b). The results from SCEDs investigating similar topics can also be combined to add to the evidence base. A SCED trial is a controlled experiment involving one or more control and intervention phases. Each participant acts as his/her own control and multiple measures of the target behaviour are collected. In recent years, clear criteria for methodologically strong SCED studies have been established, reflected in Single Case Experimental Design (SCED) scale, and subsequently, the Risk of Bias in N-of-1 Trials (RoBiNT) scale, which are comprehensive checklists of requirements for well-conducted SCED studies (Tate, Mcdonald, Perdices, Togher, Schultz & Savage, 2008; Tate, Perdices, Rosenkoetter, Wakim, Godbee, Togher & McDonald, 2013). These include measuring five or more data points for each study phase, using relevant statistical analysis of the results and ensuring that sufficient information is conveyed about the participants and study setting. These methodological standards differentiate well-designed SCED studies from poor ones and help differentiate true SCED studies from weaker methodologies with low sample sizes which do not have a control condition, such as case reports and pre-post studies with n of 1. SCED studies are valuable when an assistive device or technology-based health intervention needs to be trialed with a specific user group who are difficult to recruit in large numbers. This is often the case when a technology has been developed after requirements research such as participatory design sessions with the user group. SCEDs allow the impact of the intervention to be reported with the confidence of having experimental control. SCED studies were included and reviewed in the systematic review reported in this chapter. The SCED approach was used during studies reported in chapters five and seven and in both cases this method enabled detailed measurement and monitoring of participants' memory performance.

2.1.4 Study Aims

The purpose of this chapter was to provide a detailed review of the quality of studies which have investigated memory orthotic technology with people with memory problems and to relate these findings to the different categories of technology. The type of technology and type of disorder leading to memory problems for those using the technology was noted for any study testing a device designed to improve performance on a memory task. The quality of the methodology was rated separately for group and single case studies using established review criteria, namely the PEDro-P scale (Maher, Sherrington, Herbert, Moseley & Elkins, 2003) for group studies and the SCED scale (Tate et al., 2008) for single case experimental design studies (see section 2.2 Methods for details).

For the group studies a meta-analysis was used to determine the overall efficacy of the studies which met the criteria for inclusion. SCED studies do not always report statistics and the statistical techniques vary from study to study. While some studies may compare baseline score with intervention score to prove an effect is significant (e.g. Mihailidis, Carmichael, & Boger, 2004), others may compare the baseline and return to baseline scores to show that there is no significant difference between baselines which may be brought about by learning (e.g. Evans, Emslie, & Wilson, 1998). Other researchers have argued that statistical tests are not required and that an effect should be obvious in visual representation of data in a single case experiment (Tellis, 1997). These methodological differences make the process of combining results of SCED papers in a review challenging. For this review a standard technique, namely Non-overlap of All Pairs (NAP) (Parker & Vannest, 2009) analysis was used to evaluate the efficacy of technology in the first intervention phase vs. the first baseline phase for the single case studies which provided sufficient raw data.

2.2 Methods

2.2.1 Eligibility criteria

Studies testing ATC with adults with any brain injury, trauma or neurological/ degenerative disease which is known to impair processes required for successful performance of intended activities of daily living including attention, organisation and planning, time keeping or retrospective memory were included. Studies which investigated memory aids in people with congenital/developmental intellectual impairment or psychiatric disorders were not included.

2.2.2 Intervention

Papers examining technology which has been designed to be an on-going aid to memory through reminding, alerting, storing and displaying or micro-prompting were included. Technology could be designed for short term reminding (to remind patient of correct order of activities during a task such as cooking or hand-washing) or reminding over a longer time (such as remembering to go to a meeting or take pills at certain times).

2.2.3 Comparators/ context

Studies which investigated task performance with technology compared to pre-treatment performance and/or non-technology control treatment performance were included.

2.2.4 Outcome

Studies with quantitative outcome measures which reflect memory based functioning in activities of daily living that require prospective memory were included. This could be successful performance of one or more artificial intended tasks (set up by the experimenter) or activities of daily living (ADL- the tasks the patient would attempt to perform in their everyday lives), carer report of performance on ADL or a standardised self-report questionnaire measuring perceived independence on ADL. This did not include qualitative feedback in form of quotes and focus groups, usability outcomes, amount of usage outcomes or well-being outcomes. Outcome measure must represent the performance of an intended action. For example recall of therapy goals, task order, previous day's activities or names of family and friends alone was not enough for inclusion. However, if the performance of therapy goals or the actual act of remembering names when meeting a person were measured as outcome variables then the study was included in the review.

2.2.5 Study type/ Design

Single case experimental design (SCED) and group studies were included. Group studies were distinguished from multiple single case designs by a-priori group study design and by the inclusion of combined measures for all the participants which were calculated and statistically analysed at the group level. Single case experimental design studies are distinguished from descriptive case reports by the inclusion of a control condition either through multiple baselines measures or a separate control measure which allows the causal impact of the treatment efficacy to be inferred. Only papers written in English were included.

2.2.6 Sources

Search databases were Medline (Ovid), Embase (Ovid), psycINFO and Web of Science. All the databases were searched via the Glasgow University library online services (http://eleanor.lib.gla.ac.uk/search~S0/y).

Grey data such as conference proceedings and thesis articles were included in the Web of Science and psycINFO searches and additional grey literature was searched for through Open Grey (http://www.opengrey.eu/). The initial search took place from the 5th to the 15th of November 2012. When searching for missed articles after examination of reference sections of selected articles (see flowchart below), all of these databases were used, as was the Association for Computing Machinery (ACM) digital library (http://dl.acm.org/). This secondary search took place between the 3rd and 7th of December 2012. The systematic search was performed again repeatedly during write up and a further two relevant articles which were published in this time were included (De Joode, Van Heugten, Verhey, & Van Boxtel 2012 and O'Neill, Best, Gillespie & O'Neill 2012).

2.2.7 Search

The search within the main four databases (Medline (Ovid), Embase (Ovid), psycINFO and Web of Science) consisted of four groups of search terms separated using the OR function which were combined with the AND function in each of the search databases (see appendix for search terms). The first group attempted to specify the function of a technological intervention. The next group of terms specified that only technology which served this function should be included. Next terms were added which specified the cognitive ability or everyday behaviour which the device(s) aimed to improve. Broad terms such as 'memory' and 'cognition' were left out in order to focus this search towards the types of cognition, memory and behaviours which are within the boundaries of this review. Furthermore, although this review is concerned with prospective memory or executive attention and organisation outcomes, retrospective memory was included in the search as improvement of retrospective memory can lead to better performance on prospective memory tasks. The final search aimed to specify with which cognitively impaired groups the technology should be tested. Grey data was searched via the Open Grey database. This database does not have the capacity for combined searches so only the first set of search terms which specified the function of the intervention was used and the search was specified to ‘psychology’ papers only.

2.2.8 Study selection

After the initial search, duplicate papers were filtered out using EndNote software (http://endnote.com/). Of the remaining articles, titles and, if necessary, abstracts were used to exclude irrelevant papers. Of the articles that remained, abstracts and, if necessary, full text was read while applying the exclusion criteria. The reference lists of the articles selected at this point were then examined in detail and the abstracts and, if necessary, full text of potentially relevant articles were checked (see Figure 2.1 in section 2.3 Results).

2.2.9 Data Extraction

The type of disorder which lead to the study participant’s memory impairment, the type of technology which was tested (prompting device or micro-prompting device)) were extracted along with efficacy and methodological rating for each study. If the type of technology was a prompting device then it was further categorized based on whether it was portable (e.g. a mobile phone or PDA) or static (e.g. a television or personal computer).

2.2.10 Rating of methodological quality

The selected papers were categorised into group studies and single case experimental designs, based on the outlined criteria. The PEDro scale (Maher et al., 2003) was used to rate the group studies and the SCED scale (Tate et al., 2008) was used to rate the single case experimental design studies (SCEDs). The papers were rated independently by two of the authors who then compared ratings and discussed discrepancies in order to agree a final score. Previous studies have established that there is good inter-rater reliability for both scales

(Maher et al., 2003; Tate et al., 2008). The PEDro-P scale was designed for rating randomised controlled trials and includes ten scored items concerning allocation and matching of groups, blinding of participants and experimenters, adherence to therapy and statistical analysis of results (see www.psycbite.com for more detail). The SCED scale also has ten scored items and these concern the repeatability and generalizability of the study, the inclusion of a control condition or return to baseline after intervention, the reliability and independence of assessors and the sufficiency of the sampling, raw data and statistical reporting (see Tate et al., 2008 for more details).

2.2.11 Efficacy rating

The main outcome variable mean and standard deviation or standard error for control and intervention conditions was used to calculate the Cohen's *d* effect size score. A meta-analysis was carried out to combine the results from each study, weighted to the number of participants. The inclusion criteria for the meta-analysis was group studies which included a control condition and which reported means and some form of variance of both conditions. Reasons for papers not being included in the meta-analysis are reported in table 2.1 (in the Results section 2.3). For the SCED papers non-overlap of all pairs (NAP) analysis was performed to give a consistent indication of the impact of the intervention phases on performance compared to the baseline phases. The non-overlap of all pairs (NAP) (Parker et al., 2009) is a simple method for analysing the effectiveness of an intervention between baseline and intervention phases in a trial with a single participant. Each pair (a data point from the baseline phase compared with a data point from the intervention phase) was analysed individually and the NAP score for each participant from which enough raw data was reported was calculated. The NAP score is the proportion of all pairs for which the baseline score is different to the intervention score in the hypothesised direction (non-overlapping). Interventions which are not effective will have a score closer to zero as the proportion of overlapping pairs will be larger. Interventions which are effective will give scores closer to 1 as the proportion of overlapping pairs will be smaller. All data points in baseline and intervention regardless of which phase they were taken were pooled together for the NAP analysis. If a technology stopped working during an intervention stage (in a study in which the control condition was practice as usual) and data was still collected then it was coded as a baseline score. This data was not included in the NAP analysis if the control condition was a non-technological reminder. The NAP score for first baseline vs first intervention only was also calculated. Only SCED papers with at least two data points in both the baseline and intervention phases and which reported participant's raw data could be Included in the NAP analysis.

2.3 RESULTS

2.3.1 Study selection

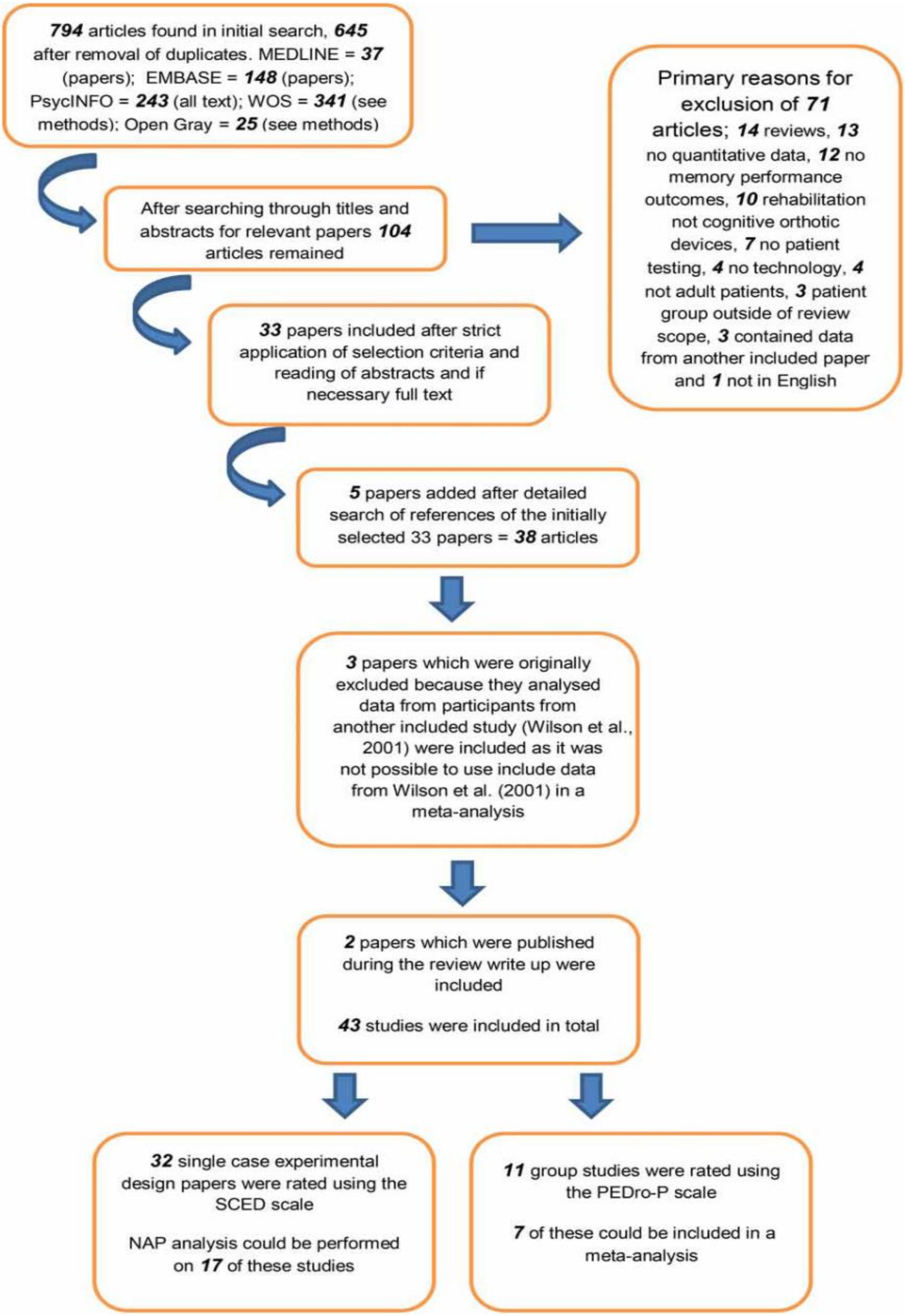


Figure 2-1. Flowchart of study selection processes and results.

2.3.2 Study characteristics

Table 2.1 gives details of the type of technology tested, the type of patient groups, methodological rating and technology efficacy of the studies included in the review

Table 2-1. Details of studies included in the review

Key

Group studies
SCEDs

* = Statistically significant (for meta-analysis this means the 95% confidence intervals did not pass 0, for the SCEDs this means that some statistical test was performed which indicated that the results were unlikely to be a chance finding)

TBI = Traumatic brain injury

ABI = Acquired brain injury

CVA = Cerebrovascular accident

AD = Alzheimer's disease

PD - portable = personal (portable) digital assistant (Prospective prompting device)

PD - static = static prompting device (in-home, care environment or vehicle) (Prospective prompting device)

MPD = micro-prompting device

PEDro-P = reliability of data obtained within the Physiotherapy Evidence Database (PsycBITE adaptation(www.psycbite.com)

SCED = Single Case Experimental Design

MS = Multiple Sclerosis

First author (year)	Diagnosis of participants *[aetiology if specified]* (number)	*Technology type (name)*	*Quality rating (Scale)*	*Effect size(s) (method) [reason for exclusion from meta-analysis or NAP]*
Dowds (2011)	ABI *[TBI]* (36)	PD - portable (Palm Zire 71/72 and Dell Axim X30)	5 (PEDro-P)	n/a [not enough data reported]
De Joode (2012)	ABI (34)	PD - portable (Planning and Execution Assistant and Trainer (PEAT))	6 (PEDro-P)	0.21 (d statistic)
Fish (2007)	ABI *[TBI(14, CVA(4), damage after surgery(2), myocardial infarction(1)]* (20)	PD - portable (Mobile phone)	7(PEDro-P)	0.63 (d statistic)
Fish (2008)	ABI *[CVA]* (36 (subjects from Wilson et al., 2001)	PD - portable (NeuroPage)	5 (PEDro-P)	0.82(d statistic)*
Gentry (2008a)	Degenerative disease *[MS]* (20)	PD - portable (Palm Zire 31)	1 (PEDro-P)	n/a [no control group]

Gentry (2008b)	ABI *[TBI]* (23)	PD - portable (Handspring Visor or Palm Zire 31)	1 (PEDro-P)	n/a [no control group]
Lemoncello (2011a)	ABI *[TBI(15), CVA(5), anoxia(1), brain tumour(1) and unreported(1)]* (23)	PD - static (Television Assisted Prompting (TAP))	5 (PEDro-P)	3.02(d statistic)*
Manly (2002)	ABI *[TBI(9), ischaemic incident(1)]* (10)	PD - static (Goal management cue)	6 (PEDro-P)	1.02(d statistic)
McDonald (2011)	ABI [TBI(4), *haemorrhage(2), haematoma(2), CVA(1), encephalitis(1), anoxic injury(1) and toxic-metabolic encephalopathy(1)]* (12)	PD - portable (Google calendar)	6 (PEDro-P)	2.84(d statistic)*
Thone-Otto (2003)	ABI *[CVA(2), TBI(6), other neurological disease (4)]* (12)	PD - portable Palm m100 and mobile phone with agenda function	3 (PEDro-P)	0.68(d statistic)
Wilson (2001)	ABI *[TBI(63), CVA(36), anoxia, meningitis or encephalitis(21), other conditions (13)]* and degenerative disease *[AD or MS(10)]* (143)	PD - portable (NeuroPage)	4 (PEDro-P)	n/a[not enough data reported]

Boman (2010)	ABI *[haemorrhage(3) and cerebral infarction(s)(2)]* (5)	PD - static ('Home-based electronic memory aid')	8 (SCED)	0.92, 0.69, 0.98, 0.8 and 0.81 (NAP)
Burke (2001)	ABI *[TBI(3) and haemorrhage(2)]* (5)	PD - portable (Patient locator and minder (PLAM))	5 (SCED)	n/a [not enough data reported]
Chang (2011a)	Degenerative disease *[dementia(1)]* and ABI *[brain injury(1)]* (2)	MPD (Kinempt)	8(SCED)	1 and 1 (NAP)*
Chang (2011b)	ABI *[TBI(1) and developmental disabilities(1)]* (2)	MPD (Locompt)	7 (SCED)	1 and 1 (NAP)*
Emslie (2007)	ABI *[encephalitis]* (5)	PD - portable (NeuroPage)	5 (SCED)	n/a [not enough data reported]
Evans (1998)	ABI *[CVA]* (1)	PD - portable (NeuroPage)	6 (SCED)	0.81 (NAP)*
Giles (1989)	ABI *[Haemorrhage]* (1)	PD - portable (The Psion Organiser)	4 (SCED)	n/a [not enough data reported]
Kirsch (1987)	ABI *[damage after surgery to remove hematoma]* (1)	MPD (COGORTH)	5 (SCED)	1 (NAP)

Kirsch (1988)	ABI *[TBI(1), anoxic injury(1)]* (2)	MPD (COGORTH)	5 (SCED)	1 and 0.85 (NAP)
Kirsch (1992)	ABI *[TBI]* (4)	MPD (Interactive guidance system (ITG (COGORTH)))	7 (SCED)	1, 0.99, 0.78 and 0.92 (NAP)
Kirsch (2004a)	ABI *[TBI]* (1)	PD - portable (Generic 'in-house' paging system)	5 (SCED)	0.94 (NAP)
Kirsch (2004b)	ABI *[TBI]* (2)	PD - portable and MPD (Interactive web-based assistive technology for cognition. Compaq iPaq 3850 device and Dell latitude C400)	6 (SCED)	0.67 (NAP) and n/a [not enough data was provided for the participant who was given the MPD intervention]
Klarborg (2011)	ABI *[CVA]* (2)	PD - static (Intelligent speed adaptation (ISA))	9 (SCED)	0.95 and 0.97 (NAP)*
Labelle (2006)	Degenerative disease *[Dementia]* (8)	MPD ('Automated prompting system' updated version of COACH (Mihailidis, 2000))	7 (SCED)	0.91 (NAP)* and n/a [individual results reported for one subject only]

Lemoncello (2011b)	ABI *[TBI]* (3)	PD - static (Television Assisted Prompting (TAP))	9 (SCED)	0.86, 0.89 and 0.49 (NAP)
Mihailidis (2000)	Degenerative disease *[Alcoholic dementia]* (1)	MPD (Computerised cueing device (prototype of COACH))	4 (SCED)	n/a [not enough data reported]
Mihailidis (2004)	Degenerative disease *[Dementia]* (10)	MPD (Cognitive orthosis for assisting activities in the home (COACH))	7 (SCED)	0.97 (NAP)* and n/a [individual results not reported for other participants]
Mihailidis (2008)	Degenerative disease *[Dementia]* (6)	MPD (updated version of COACH)	6 (SCED)	n/a [individual results not reported]
O'Neill (2008)	Degenerative disease *[Vascular Dementia]* (1)	MPD (Guide)	4 (SCED)	n/a [not enough data reported]
O'Neill (2010)	Degenerative disease *[Peripheral vascular disease]* (8)	MPD (Guide)	4 (SCED)	n/a [not enough data reported]
O'Neill (2013)	ABI [*Haemorrhage] (1)*	MPD (Guide)	7(SCED)	0.78 In home phase [0.8 in care setting, not included in review analysis]

				(NAP)
Oriani (2003)	Degenerative disease *[AD]* (5)	PD - portable (Electronic Memory Aid (EMA))	4 (SCED)	n/a [not enough data reported]
Stapleton (2007)	ABI *[TBI]* (5)	PD - portable (Siemens C45 mobile)	7 (SCED)	0.8, 0.52, 0.67, 0.66, 0.69 (NAP)*
Svoboda (2009)	ABI *[complications with cyst removal surgery]* (1)	PD - portable (Treo 680 smartphone)	5 (SCED)	n/a [not enough data reported]
Svoboda (2012)	ABI *[aneurysm(3), anoxia(2), TBI(1), cyst(1), germinoma(1), glioma(1) and CVA(1)]* (10)	PD - portable (Unnamed)	9 (SCED)	n/a [not enough data reported]
Van Den Broek (2000)	ABI *[encephalitis(2), haemorrhage(2) and TBI(1)]* (5)	PD - portable (IQ Voice Organiser Model No. 5300 manufactured by Voice Powered Technology International Inc.)	3 (SCED)	n/a [not enough data reported]

Van Hulle (2006)	ABI *[TBI]* (2)	PD - portable (WatchMinder and Voice Craft)	6 (SCED)	0.54 and 0.45 (NAP)
Wade (2001)	ABI *[TBI(4), haemorrhage(1)]* (5)	PD - portable (Mobile phone reminder system)	4 (SCED)	n/a [not enough data reported]
Waldron (2012)	ABI *[TBI(3), CVA(1), tumour(1)]* (5)	PD - portable (Palm IIIe)	5 (SCED)	1, 1, 0.83, 1 and 0.92 (NAP)
Wilson (1997)	ABI *[TBI(10), haemorrhage(2), cyst(1), CVA(1) and tumour(1)]* (15)	PD - portable (NeuroPage)	6 (SCED)	n/a [not enough data reported]
Wilson (1999)	ABI *[TBI]* (1)	PD - portable (NeuroPage)	5 (SCED)	n/a [not enough data reported]
Yasuda (2002)	ABI *[TBI(4), haemorrhage(s)(3) and tumour(1)]* (8)	PD - portable (Sony IC Recorder (ICD-50))	5 (SCED)	n/a [not enough data reported]

2.3.3 All studies

Of the 43 studies, 30 (69.7%) investigated the efficacy of prompting devices and 13 (30.2%) investigated micro-prompting devices. Nine studies investigated the efficacy of technology as a memory aid with people with degenerative diseases and the rest looked at technology for people with ABI.

2.3.4 Group studies

All of the devices which were tested in the group studies were prompting devices designed to improve prospective memory for either experimental or everyday tasks. Two of the group studies (both included in the meta-analysis) were investigating a prompting device which was located in a set position (a tape recorder (Manly, Hawkins, Evans, Woldt, & Robertson, 2002) and a television (Lemoncello et al., 2011b). The rest of the papers looked at some form of PDA. The studies predominantly tested technology with people with acquired brain injury from traumatic injury or cerebrovascular accident. Many studies also included people with a degenerative disease (e.g. dementia; Mihailidis, Fernie, & Cleghorn, 2000), people who acquired a brain injury from some other illness or disease (e.g. encephalitis; Wilson, Emslie, Quirk, & Evans, 2001) and one study specifically focused on people with multiple sclerosis (Gentry, 2008a). The mean PEDro-P rating for all group studies was 4.45 (median = 5, range = 1 to 7).

A meta-analysis was performed on seven of the group studies. All of the 147 participants included in the meta-analysis had some form of ABI. The mean PEDro-P rating of the studies included in the meta-analysis was slightly higher at 5.43 (range = 3 to 7). The studies included in the meta-analysis all included participants with acquired brain injury and tested prompting devices. The control condition was practice as usual for five of the studies (Fish et al., 2007; Lemoncello et al., 2011; Manly et al., 2002; Thone-Otto et al., 2002; Fish et al., 2008), and a pencil and paper reminder for two of the studies (De Joode et al., 2012; McDonald et al., 2011). The pencil and paper reminders were a paper diary with 90 minute training and a list of diary recommendations (McDonald et al., 2011) and 16 hours of training with a diary (De Joode et al., 2012). After studies were weighted in accordance with sample sizes, a significant, large positive overall effect size (Cohen's d = 1.27, p<0.01) was found. Figure 2.2 is a forest plot showing the relative effect sizes, confidence intervals and weightings of the papers included in the meta-analysis. Visual analysis of a funnel plot indicated a bias towards large positive results which could indicate publication bias. It was calculated that there would have to be 15 hypothetical 'file drawer' group studies which found no difference between control and technology conditions but which had the same average variance and participant number in order for the effect size to fall below 0.4 (Cohens d = 0.398, p<0.05). The value of 0.4 is thought to represent a practically significant effect size for social science papers where negative effect sizes are unlikely (Ferguson, 2009).

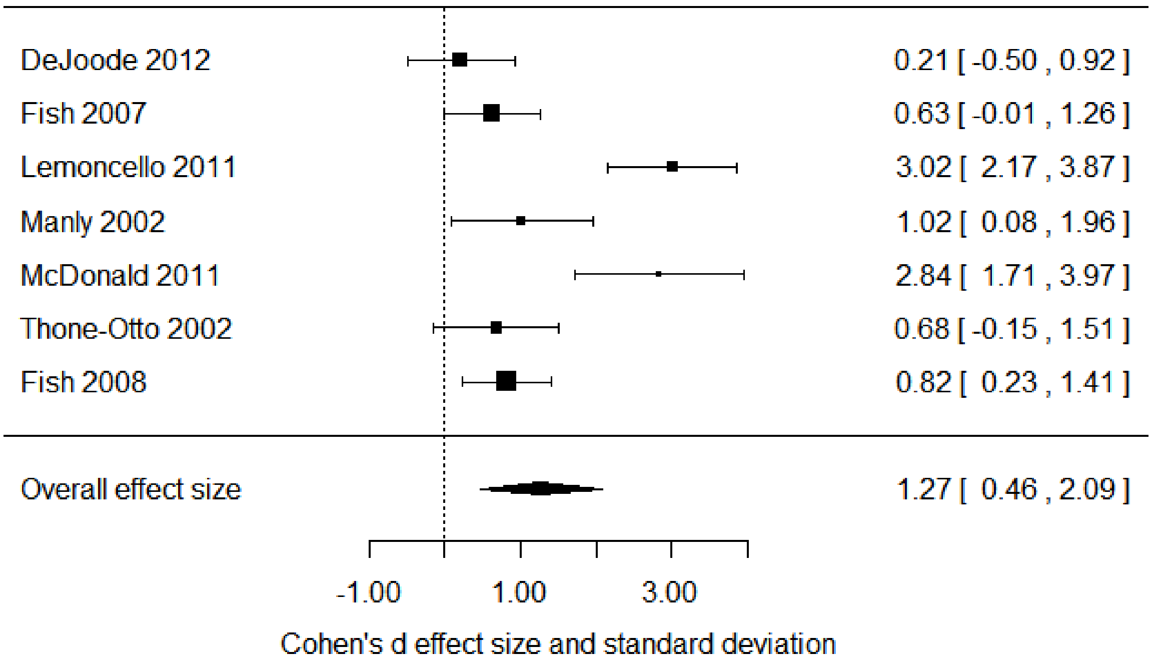


Figure 2-2. Meta-analysis results with effect sizes, confidence intervals and weightings for each individual study.

2.3.5 SCED studies

In the SCED papers the most commonly tested technology was prompting devices (PDs) (20 studies) followed by micro-prompting devices (MPDs) (13 studies). Eight SCED studies investigated the impact of technological reminders on memory performance of people with dementia and the rest involved people with some form of ABI. The mean SCED scale score for all of the SCED studies was 5.9 (range = 3 to 9). The studies investigating MPDs had a slightly higher mean SCED score (5.92) than the studies investigating PPDs (5.8). NAP analysis was performed for 36 participants in 17 of the SCED studies. The mean SCED score for the papers included in the NAP analysis was 6.81. The PPD studies included in the NAP analysis had a slightly higher mean SCED score (6.77) than the MPD studies included in the NAP analysis (6.35).The studies received a mean NAP statistic of 0.85 (minimum = 0, maximum = 1). According to Parker and Vannest (2009) this represents a medium effect as it is between 0.66 and 0.92. Technology was estimated to have a large or strong effect on memory performance (NAP > 0.92) for 51% of participants. Technological intervention had a weak effect on memory performance (NAP > 0.66) with 10.3% participants (Parker et al., 2009). Figure 2.3 shows the mean NAP scores for each participant in each of the studies across the two categories of technology. A medium effect size was observed for the studies investigating the PDs (NAP = 0.79) and a large effect size was observed for the studies investigating MPDs (NAP = 0.94), The NAP score comparing the first baseline phase with the first intervention phase only was also calculated. The mean NAP for this comparison was 0.88 (0.81 for prospective prompting device studies and 0.96 for micro-prompting device studies). Finally, the NAP score comparing the return to baseline with the first intervention condition was calculated. The mean NAP for this comparison was 0.77 (0.58 for prospective prompting device studies and 0.93 for micro-prompting device studies).

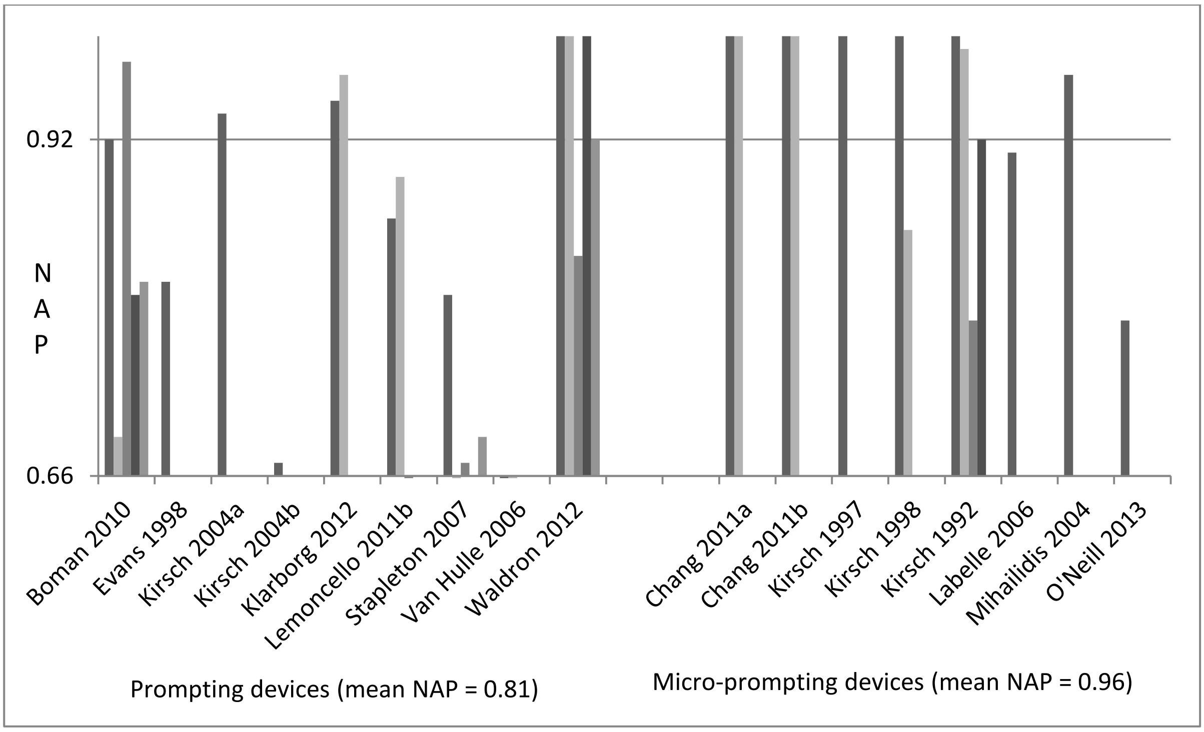


Figure 2-3. NAP score for each participant organised by study and device type. Each bar represents the NAP score for a participant. 0.66 is the NAP cut off score for a medium effect size and 0.92 is the NAP cut off for a large effect size (Parker and Vannest, 2009

2.4 Discussion

2.4.1 Methodology

The apparent effectiveness of technological memory aids must be considered along with the appropriateness of the methodology. In the group studies, methodology could be improved in terms of consistency between studies and good experimental practice. The control conditions were not always comparable (some studies had paper-based reminders as control conditions (De Joode, Van Heugten, Verhey, & Van Boxtel, 2012) and (McDonald et al., 2011) while the others compared technology to no technology or typical practice. The outcome variables also varied from artificial, experimenter set tasks (e.g. the Hotel task (Manly et al., 2002) to participant set everyday tasks (Wilson, Emslie, Quirk & Evans, 2001). There were also issues with experimental practice. Items on the PEDro-P scale which were consistently marked down concerned the blinding of participants and experimenters to the control and experimental conditions. Blinding is extremely difficult in studies testing the impact of a piece of technology. However, studies which used self-report measures reported by participants not blinded to condition which were counted and analysed by experimenters who were not blinded to condition are open to accusations that the results are due to bias to please the experimenter from the participants and confirmation bias from experimenters (McBurney & White, 2009). The consistency of the baseline phase was an issue for the SCED studies. Some studies introduced a paper reminder at baseline and so had no true baseline measure (e.g. Van Hulle et al., 2006), others included a baseline with typical practice (Klarborg et al., 2011) while some studies (for at least a few of their participants) introduced the first intervention phase before they established a baseline (Lemoncello et al., 2011a; Kirsch Shenton, Spirl, Rowan, Simpson, Schreckenghost, & LoPresti 2004b). Around half of the SCED studies did not accumulate or provide enough raw data to perform an NAP analysis between the first baseline and first intervention conditions. A large proportion of the studies were quasi-experimental single case design studies in which participants did not return to baseline after the first intervention phase. In these cases there is no way to show that the technology intervention, rather than spontaneous memory recovery was causing the improvement in performance.

2.4.2 Efficacy

The aim of this review was to investigate the efficacy of technological memory aids by considering both the results and methodology of trials testing the impact of technology on the memory performance of people with memory disorders. This review is the first to perform a meta-analysis with all available group study data from the technological memory aid literature. The studies analysed in the meta-analysis tested different devices, all of which were used to prompt participants to perform an intended task. A *d* statistic which is above 0.8 indicates a large effect size (Cohen, 1988). While the effect size found in the meta-analysis was large, the result should be interpreted cautiously because there were only 147 participants in the seven included studies and because the control condition varied considerably between studies. Nevertheless, the results of the meta-analysis do offer moderate evidence for the efficacy of prospective memory prompting devices which are portable (McDonald, Haslam, Yates, Gurr, Leeder, & Sayers, 2011; Fish, Manly, Emslie, Evans, & Wilson, 2008) or fixed in a home environment (Lemoncello, Sohlberg, Fickas & Prideaux, 2011a; Manly et al., 2002) compared to a non-technological or usual practice control condition.

Single case experimental design studies offer useful information which has not traditionally been pooled together in literature reviews (Busse, Kratochwill, and Elliott, 1995). The NAP analysis of each participant in selected SCED papers indicated that technology can improve both the performance of future intentions and the ability to multitask compared with no aid or a non-technological aid at baseline. A medium NAP effect size was observed for the impact of prospective prompting devices on the performance of future intentions and a large NAP effect size was observed for the impact of micro-prompting devices on the ability to multitask.

The NAP score reported in figure 3 was calculated after pooling together all the baseline and intervention data points and contrasting each baseline data point with each intervention data point. Further calculation of the NAP scores between different phases gave interesting results regarding the performances on return to baseline. Participants in SCEDs investigating micro-prompting technology had very similar NAP scores between first baseline and first intervention and between return to baseline and first intervention phases indicating that the technology was compensatory and performance returned to baseline after removal of the technological intervention. Participants in SCEDs investigating prospective prompting technology had far lower NAP scores between first intervention and return to baseline phases than between the first baseline and first intervention phases indicating that their performance on memory tasks stays at an improved level even after the removal of the technology. This may indicate that these participants would have improved their performance without the technology. However if this does indicate long term improvement brought on by the technology then it may be because prospective prompting technology allows habits to be formed (e.g. association between taking pills and dinner time) or because of the difference in cognitive impairment between participants recruited to PD studies and MPD studies.

2.4.3 Prospective prompting devices

The NeuroPage has been highlighted in previous reviews as being the technology with the most evidence for its efficacy (Caprani et al., 2006; de Joode et al., 2010). The evidence from this review suggests that in recent years evidence is beginning to accumulate in relation to other types of PDA such as smartphone and palm devices (e.g. Dowds, Lee, Sheer, O'Neil-Pirozzi, Xenopoulos-Oddsson, Goldstein et al., 2011; McDonald et al., 2011) and supports the position taken by Gillespie and colleagues (2012) that evidence for the efficacy of NeuroPage should be combined with evidence from other PDA devices to support the use of prompting devices in general (Gillespie et al., 2012). Static prompting devices perform an equivalent reminding function to PDAs but from a set location. The efficacy findings for these devices, albeit still limited, combined with the efficacy of portable PDAs provides substantial evidence that technological devices which prompt the performance of future intentions are useful for people with memory impairment. This evidence is currently far stronger for those with memory impairment resulting from an acquired brain injury than it is for people with other conditions. Future research should attempt to develop and test technology with people with degenerative diseases such as Alzheimer's disease, Parkinson's disease and Multiple Sclerosis.

Given the cost of developing, providing and purchasing a technological prompting device, a crucial consideration when analysing the utility of technological reminders is whether or not technological reminders are better than their non-technological equivalent such as pencil and paper calendars or diaries. Only three of the group studies included in this review used pencil and paper reminders as their control condition (Dowds et al., 2011, De Joode et al., 2012 & McDonald et al., 2011) and two of these were included in the meta-analysis (De Joode et al., 2012 & McDonald et al., 2011). These two studies gave very different results when comparing the efficacy of memory aid technology to a non-technological equivalent, one showed a smaller effect size compared to other studies and one showed a larger effect size relative to the others (see Figure 1). Future research should aim to establish whether or not there is a benefit to using technology even when equivalent training is provided with non-technological reminders. Furthermore, a technological reminder will only be better than a pencil and paper reminder if the advantages of technology are utilized. Therefore, newly developed prompting devices should aim to unlock the potential of technological reminders to provide multi-modal and time specific cues, interactively engage users and automatically schedule everyday tasks.

2.4.4 Micro-prompting devices

All the evidence for the effectiveness of micro-prompting devices came from SCED studies. There is SCED study evidence that MPDs are effective for improving memory for the organisation and ordering of various tasks. These include janitorial tasks (Kirsch, Levine, Lajiness, Mossaro, Schneider, & Donders 1988), food preparation (Chang, Chen & Chuang, 2011a; Chang, Wang & Chen, 2011b) and hand washing (Mihailidis et al., 2000). The NAP analysis shows that within the SCED studies included in this paper, the efficacy of micro-prompting technology in improving multitask and sub-task memory performance was at least equivalent to the evidence for the efficacy of prospective prompting devices in improving memory for the performance of future intentions (Figure 2.3). While prospective prompting devices and micro-prompting devices differ in the type of memory performance they are designed to aid, these findings suggest that if applied correctly both could be useful for memory impaired patients.

There have been considerably more degenerative disease patient studies testing micro-prompting devices than studies testing devices which prompt future intentions. This could be because MPD devices are designed to offer a great deal of support which is useful in the later stages of a degenerative disease when cognitive functioning and memory abilities are becoming increasingly limited. The majority of the MPD research with degenerative disease groups took place during the development of the COACH system (Mihailidis et al., 2000; Labelle & Mihailidis 2006). This system was designed to help people with dementia in a hand washing task. Another research team developed the GUIDE system which has been used to guide participants through a prosthetic limb donning task (O'Neill et al., 2008) and a participant's morning routine (O'Neill, Best, Gillespie

& O'Neill 2013). These systems have been shown to be successful for improving the performance of a specific task in single case studies with multiple participants (Labelle et al., 2006; O'Neill et al., 2010). Future research could attempt to show the efficacy of such devices in a group study design.

2.4.5 SCED studies in systematic reviews

Single case experimental design (SCED) studies accounted for the majority of the studies investigating technological reminders and are very common in neuropsychological rehabilitation. Despite this they are rarely included in effect size calculations in systematic reviews. This is possibly due to studies reporting their findings in different ways. While some studies reported statistical analysis of their findings others offered only descriptive analysis. Furthermore, the collection and reporting of data is inconsistent in a way that prevents further analysis from willing reviewers. Only 17 of the 32 SCEDs in this review collected or reported enough raw data for further NAP analysis to be performed. This review has shown that combining SCED studies can provide convincing evidence about the effectiveness of a cognitive rehabilitation. More consistent methodology and reporting in single case studies would allow SCEDs to be combined more often.

2.4.6 Limitations of the review

The meta-analysis did not include all of the group studies which have been performed in this area. This is because standard deviation or standard error of the intervention and control condition means were not available either because they were not reported (e.g. Wilson et al., 2001) or because there was no control condition (e.g. Gentry, Wallace, Kvarfordt & Lynch, 2008b). While the means and standard deviations for sub-groups of the participants included in the Wilson et al. (2001) study were reported in the study by Fish et al. (2008), many of the participants were selected for re-analysis because they responded well to the technology (NeuroPage). This biased sample could not be included in the current review. The result of the meta-analysis would be more reliable if all the participants from these papers could have been included. The seven studies included in the meta-analysis all reported a positive effect of technology. Even though a search of grey data was performed, it is possible that studies which would have met the criteria for the meta-analysis and which reported no positive effect of technology may have been undertaken and not published. It was calculated that there would need to be 15 such studies to prevent the seven studies included in the meta-analysis from giving a practically significant effect size. This is more than double the number of studies which were included in the meta-analysis suggesting that the finding that technology is a beneficial intervention for people with memory impairments is a robust one.

While the NAP score gives a general picture of the effectiveness, it does not give a very useful estimation of the size of the effect of an intervention. The utility of this technique is also dependent on the amount of data sampled as the larger the number of data points per phase, the more accurate the score will be. The studies varied widely in the number of data points provided. Some studies had over 60 data points per phase (e.g. Evans et al., 1998) while others only provided two or three per stage (e.g. Waldron, Grimson & Carton, 2012). However this variation in NAP score reliability was not reflected in the final score or mean. This score also does not take into account the pattern of responding after the initial intervention which varies among different patients and is an important aspect of cognitive rehabilitation (Yasuda, Misu, Beckman, Watanabe, Ozawa & Nakamura, 2002). As the efficacy of technology in the SCED studies was analysed between the baseline and intervention conditions and the baseline practices were inconsistent between the studies, the results cannot provide evidence that technological reminders are better than pencil and paper alternatives to technological reminders such as diaries or calendars.

The NAP analysis compared all the baseline data points with all the intervention data points. Performing the NAP analysis in this way may confuse spontaneous recovery for which the technology did not have any impact with the continued benefit of the technology after its removal. Analysis of participants who were given the NeuroPage has shown that while some participants returned to baseline performance after removal of technology, some participants retained a high performance as their use of the technology led to the formation of a habit

(Fish, Manly, Emslie, Evans & Wilson, 2008). If the latter was the case for the participants involved in the NAP analysis then their score would be lower than a participant who returned to their baseline performance after removal of the technology even though the technology made a positive contribution in both cases.

Another important limitation of the SCED studies is the selection process of the participants in the study. Many of the studies chose participants they felt would respond best to the intervention (e.g. Mihailidis et al., 2000) or selectively reported the raw data for a subject with typical data (Mihailidis et al., 2004; Labelle & Mihailidis, 2006). This selectivity could bias the NAP results to make the technology seem more useful than it would be for the general population of people with memory impairments. Finally there were no consistent criteria for participant inclusion between the papers. This means that some technology could have been tested with people with mild memory disorders who were well suited to an intervention (e.g. had good insight into their problems or were experienced with technology) while other technology may have been tested with people with more severe problems or with problems which could not be helped by any memory aid technology. This limitation restricts the extent to which the efficacy of different technologies can be compared in this review.

2.4.7 Future Research

The types of technology investigated in papers included in this review are diverse; while some are available off the shelf, others were bespoke technologies designed for the purposes of the study. With some exceptions (e.g. NeuroPage; PEAT), the majority of the latter technologies are currently not available to the general public. Future research could investigate whether available; ‘off the shelf’ technologies are currently being used by people with memory difficulties to support their memory, and to understand the factors that predict this use. Chapter two describes a survey study which aimed to investigate these research questions.

Not all of the participants who took part in the reviewed studies benefitted from the technology. In order to successfully use and further develop assistive technology for memory it is important to understand the reasons for neutral or negative responses to prompting or micro-prompting technologies. In group studies, where the results are pooled together to create intervention and control group means, participants' individual performances are unavailable making it difficult to note reasons why the technology intervention may not have been successful. An advantage of the SCED studies is the detailed descriptions given about individual participants and how they responded to the intervention. For example in van Hulle *et al.* (2006), participant DG showed variable memory performance which did not improve when using assistive technology ('Voice Craft' Dictaphone and 'WatchMinder' watch). The authors suggested that this was due to their motivation because they reported hearing or feeling the alarms and then decided not to do the task. In Stapleton *et al.* (2007) three of the five participants did not benefit from a mobile phone based prompting device intervention. They report that the two differences between the participants who did and did not respond to the intervention were level of cognitive impairment and level of independence. These studies indicate some of the factors which may influence the uptake and continued use of assistive technology. These issues will be the subject of a literature review and survey study in chapter three and a focus group study and co-design session in chapter four.

None of the micro-prompting technologies included in papers in this review are currently available to buy. Much of the prompting technology which was tested such as pagers, personal digital assistants and dictaphones have been rendered obsolete in the last decade by smartphones which can support software with a prompting function. Smartphone devices are becoming increasingly available and low cost. Easily available smartphone devices may be of benefit to people with memory problems as they incorporate touch screen technology which has been shown to be easier for older users than button operated devices (Jin, Plocher and Kiff, 2007) and so may be more intuitive and accessible for people with memory impairment. These devices may also be of benefit to those who wish to be discreet about a reminder system. The use of devices which are ubiquitous in everyday life is likely to be discreet compared with the use of an older technology such as a pager or a voice recorder. These devices, along with recently developed portable tablet computer technology also have the benefit of being highly adaptable to personal preferences. Therefore it is likely that future studies will investigate smartphone based prompting technology as a memory intervention. Smartphones and tablets are also likely to be one of the form factors from which micro-prompting technology is launched (O'Neill, Best, Gillespie & O'Neill, 2013). However, a balance must be struck for any newly developed technology between capitalising on the benefits of recent technological advances and having a simple, usable device. The NeuroPage is successful possibly because its only function is to give reminders and it is wearable. Using a smartphone or tablet device as a reminder may be less effective because of the number of different functions it provides and because they will not always be within the vicinity of the user.

It is not clear from the studies included in this review whether or not the participants liked the technologies or found them acceptable. Similarly, while the technologies must have been accessible and usable enough for them to be used during the studies, it is not clear how easy it was for people to learn to use technologies, and whether certain design characteristics might have helped or hindered people's use. The topics of usability, user experience and acceptability of smartphone technologies are particularly relevant in the field of human computer interaction and mobile usability. These are important issues to understand if clinicians, researchers and designers are to develop and provide technology which can be and is used by clients and service users. Research and principles from the field of human computer interaction are introduced into each of the subsequent chapters in the thesis and later chapters investigate the user experience, usability and acceptability of smartphone technologies designed following co-design with people with memory difficulties.

2.5 Conclusion

Extensive recent reviews of neuropsychological rehabilitation recommend the use of compensatory technology for patients experiencing memory problems (Cicerone et al., 2011; De Joode et al., 2010). However technology is still rarely used in practice and is not typically routinely funded by healthcare systems. Analysis of the studies in this paper showed that the majority of people included in these studies did benefit from technological memory aids. Prospective memory, multi-tasking and task organisation are challenging for everyone but can be especially difficult for those with memory impairments. Technology can give people with memory difficulties confidence and allow them to regain and retain independence after a brain injury or during the onset of a degenerative disease. Clinical trials should continue in order for clinical guidelines to be developed which can in turn influence clinical practice. Technology is currently not widely prescribed or made available for use as a memory aid for people with memory impairments. The evidence from the studies in this review suggests that it should be.

2.6 Appendix

2.6.1 Search terms

memory rehabilitation OR cognitive rehabilitation OR cognitive aid OR memory aid* OR cognitive orthos* OR cognitive prosth* OR assistive technolog* for cognition OR compensat* technolog* OR memory orthos* OR memory prosth**

AND

technolog OR computer OR digital OR robot OR pag* OR text* OR messag* OR telephone OR smartphone OR smart hous*OR camera OR television OR system OR device*

AND

*everyday memory OR prospective memory OR retrospective memory OR attention OR reminding OR micro-prompting OR prompting OR alerting OR organisation OR time keeping OR intention*OR goal manag**

AND

cognitive disorder OR neurolog impair*OR brain disease* OR brain damage OR brain injur* OR memory impair* OR memory disorder OR cognitive impair* OR Alzheimers disease OR dementia OR encephaliti* OR stroke OR anoxi* OR multiple sclerosis OR Parkinsons disease*

3 Chapter Three - Technological memory aid use; prevalence and predictors

3.1 Introduction

Chapter two was a review of memory compensating technologies which aimed to investigate whether or not memory compensation ATC is useful. It is also important to establish what technologies are currently being used to compensate specifically for memory difficulties, how many people with memory difficulties are currently using technology in this way, and what underlying factors might predict and influence use of technology including initial uptake and sustained use over time. This chapter investigates the prevalence of different technologies amongst groups of people with ABI and dementia using a survey (N= 179). Different characteristics of these participants (e.g. education, age, time since injury) were investigated to understand which factors predicted the use of currently available technologies such as mobile phones and computers as reminding devices. This study also provided an opportunity to ask participants about the issues and barriers that may prevent memory aid uptake and use. The results concerning prevalence and factors that predict use are compared throughout to similar surveys completed in 1996 (Wilson and Watson, 1996) and 2003 (Evans, Wilson, Needham and Brentnall, 2003) in order to look at the changing use of memory aids and technology over time. The investigation into the barriers highlighted issues to do with technology usability and acceptance some of which are investigated further in chapter three.

3.1.1 Prevalence of assistive technology use

While the need for memory rehabilitation is great (Wilson, 1999) and technology can improve everyday memory performance, it is less clear whether or not technological memory aids are actually used by people with memory difficulties. Evans *et al*. 2003 found that only 3.2% of people with ABI (n=94) were using a mobile phone to help their memory. The number of people with degenerative diseases using assistive technology is unclear. There has been an increase in interest and investment in health technologies and in-home monitoring systems in recent years (e.g. Multi-modal home and dallas projects (McGee-Lennon, Smeaton & Brewster, 2012; Devlin, McGee-Lennon, Bouamrane, O'Donnell & Mair, 2015). However, at present there is little provision for prompting or micro-prompting memory aid assistive technology within the National Health Service (NHS) in the UK and use is driven by the person with memory difficulties, their family members or suggested by a caregiver. It is likely that the situation is similar in countries with a similar infrastructure to the UK. Use of assistive technology can require support from clinicians and caregivers who may themselves lack confidence with technology. A study by Hart and colleagues (2003) found that clinicians of people with traumatic brain injury believed that technology could help with cognitive difficulties memory, planning, organization and task initiation. However professionals also reported low confidence in their abilities to guide clients in using technology, especially if their experience with technology was limited (Hart, O'Neill-Pirozzi & Morita, 2003). In the last decade, personal technology has become highly advanced and available, in particular with the popularisation of mobile phones and, in particular, smartphones. In 2015 almost 5 billion people were using a mobile phone and 1.75 billion were using smartphones (Statista, 2015). In 2013 it was reported that 7 out of 10 people in Britain used smartphones (Styles, 2013). These devices are now so widespread that they are likely to already be used by many people with ABI, dementia, and their caregivers. Mobiles, smartphones and other widely available and accessible technology such as alarms, timers, tablets, personal computers and cameras have the ability to provide reminders to help with prospective memory, provide pictures and videos to help with retrospective memory, and can provide prompts to guide people through everyday tasks.

3.1.2 Factors which predict use

Wilson *et al.* (1996) and Evans *et al.* (2003) investigated which factors predicted use of memory aids by people with ABI. Based on their experience with clients, the factors which these authors felt might predict use included age, gender, the presence of cognitive and executive deficits, premorbid IQ, length of time since injury, length of coma, number of memory aids used premorbidly, number of memory aids used now, and having received rehabilitation. They found that people who were younger, had a greater amount of time since injury, used more memory aids prior to injury, had a higher level of independence and better attentional functioning used more memory aids (Wilson et al., 1996; Evans et al., 2003). It would be interesting to investigate whether similar or different factors are influencing use of technological memory aids a decade on from the last survey.

Patterson and colleagues (2014) established a feature set, grounded in research, to predict adopters and non-adopters of assistive technology amongst persons with dementia (Patterson, McClean, Langdon, Zhang, Nugent and Cleland, 2014). A feature set of age, gender, mobile reception, Mini Mental State Examination score (Kang, Na and Hang, 1997), living arrangement, physical health, and technical experience was able to accurately predict use 86.24% of the time amongst a sample of 40 persons with dementia. People with degenerative diseases such as dementia are, as a group, older than people with ABI. Therefore they may have had less experience with technology during their working lives. There is evidence that people with dementia and their carers are positive about assistive technology use generally (Rosenberg, Kottorp & Nygård, 2012). However it has also been found that people with mild stage Alzheimer's disease find the management of everyday technology significantly more challenging than those with no cognitive impairment (Malinowsky, Almkvist, Kottorp & Nygård, 2010). A recent study, which investigated the use of assistive technology by people with dementia, found that none of the 16 focus group participants and 42 survey responders (informal carers of people with dementia) had experience of using assistive technology, and neither did the people who they cared for (van den Heuvel Jowitt & McIntyre, 2012). Rosenberg and colleagues found that the perceived difficulty of using technology was higher for those with a diagnosis of dementia or mild cognitive impairment compared with those with no known cognitive impairments (Rosenberg et al., 2009). These studies suggest that cognition and prior experience with technology of the end users are likely to be important factors. Investigating technology use amongst healthy older adults, McGee-Lennon (2008) found that people had to accept technology as their own before they would use it regularly. Within the literature investigating the use of home-based assistive technologies for people with degenerative diseases researchers have highlighted the practical difficulties with introducing technology into people's lives (Cahill, Macijauskiene, Nygård, Faulkner & Hagen, 2007) and the lack of infrastructure around the implementation of assistive technology in care services (Woolham and Frisby, 2002).

3.1.3 Barriers to assistive technology use

The interpersonal and environmental factors discussed above, which may predict memory aid use, are related to the social, personal and environmental barriers that can prevent uptake and continued use of assistive technology. Several recent studies have investigated these barriers to use in qualitative studies by involving people with cognitive impairments, older users and caregivers in focus groups, co-design or participatory design sessions. Eight of the main barriers to use that were consistently mentioned in this literature are outlined below.

Some studies emphasised practical barriers, for example van den Heuvel and colleagues (2012) found that not receiving reminders because the device was not near enough or losing the device was important for people with dementia (van den Heuvel, Jowitt and McIntyre, 2012). In a study by McGee-Lennon and colleagues (2012), older users felt it was important to receive the right reminders at the right time (McGee-Lennon et al., 2012). In other studies it was established that actually having technology (van den Heuvel et al., 2012) and being able to afford technology (Zwijsen, Niemeijer and Hertogh, 2011) were important for people with dementia and carers for people with dementia. Correct provision, installation, instruction and training have also been noted as important factors influencing use (Wessels, Dijcks, Soede, Gelderblom and De Witte, 2003).

Personal preference is also an important factor. For example van den Heuvel *et al.* (2012) found that changing behaviour to get someone to learn or use technology can be difficult if they are uninterested in technology. Some people with ABI reported feeling like 'tech is just not me' (Baldwin, Powell and Lorenc, 2011) or wanted to 'do it my way' using techniques which do not involve technology (Wessels et al., 2003). Conversely, a study involving people with dementia found that keeping up with new technology can be important for people who see themselves as 'tech savvy' and argued that supporting the continued use of technology which was always used by people with dementia is important to allow people to maintain their self-image (Rosenberg and Nygård, 2011). Furthermore integrating technology use with existing habits is crucial for acceptance from people with dementia (Rosenberg et al., 2011) and personalising technology based on preferences is important for acceptance of technology from healthy older users (McGee-Lennon et al., 2012). However it should be noted that older users also felt that personal preference should be over-ruled by care needs if required (McGee-Lennon et al., 2012).

Emotional and social concerns are also highly relevant. For example, people with dementia requested that technology be inconspicuous so people will not see that they need help (Robinson, Brittain, Lindsay, Jackson and Olivier, 2009). People with ABI have also expressed concerns with people thinking they are stupid or thinking less of them if they saw them having to use a memory aid to remember / guide them through tasks (Baldwin et al., 2011). Carers of people with dementia have also raised the issue of stigmatisation arising from use of technology in the outside world (Zwijsen et al., 2011) and older users have voiced a desire to have discrete reminders in shared social spaces (McGee-Lennon et al., 2011). A slightly different social issue was also brought up by older users concerning the fear that human caregivers would be replaced by machines leading to less social interaction (Mitzner et al., 2010).

Researchers have found that aspects of technology can be detrimental to the abilities and everyday functions they are supposed to be supporting, and these have been called reverse effects. This may happen when technology is not flexible to changes in cognition – for example cognitive decline during the progression of dementia – and so is either annoying because it gives too much support (e.g. when a person's cognitive ability is relatively intact) or not useful and even frustrating if it provides too little support if a person's cognitive ability is severely impaired. People with dementia have expressed a desire for technology that is flexible to changes in cognition (Robinson et al., 2009). Carers for people with dementia have expressed concerns about patients becoming over-reliant on technology when they could remember things themselves (Zwijsen et al., 2011) and want technology which will compensate for impaired cognition without making tasks so simple that people stop using their own memory abilities (Rosenberg et al., 2011). Healthy older people have expressed a desire for reminders adjusted for importance so that a reminder for something unimportant is not too annoying and a reminder for something important is not too subtle that it might be missed (McGee-Lennon et al., 2012). Finally, older users have stated a desire for technologies which are user friendly and therefore not annoying (Demiris, Rantz, Aud, Marek, Tyrer, Skubic and Hussam, 2004) and which have useful features but not too many features or annoying features (Mitzner et al., 2010).

People with ABI expressed the view that their beliefs about memory impacted their use of memory aids. For example some had a ‘use it or lose it’ attitude about memory believing that by using a compensatory device / method they would lose their memory ability or that memory ability could improve if they used it often (Baldwin et al., 2011). This attitude has also been expressed by carers for people with dementia who were concerned that over-reliance on technology would lead people to stop using the memory that they did have, and that this was undesirable (Rosenberg et al., 2011). A similar issue is that there must be a belief from the technology user that their memory needs to be supported. People with ABI reported a crucial moment when they realised they needed to use a memory aid (Baldwin et al., 2011) and carers for people with dementia reported that it was necessary for patients to try technology and experience it working or accept that technology would be useful for some tasks before they would use it (Rosenberg et al., 2011).

Safety, privacy and autonomy are ethical issues. Carers of people with dementia were concerned that over-reliance on technology might lead to people being left alone when they require constant supervision (van den Heuvel et al., 2011). Carers were also concerned that technology might negatively impact privacy as people’s whereabouts may be able to be tracked and they may be approached by criminals through a mobile phone or via the internet (Zwijsen et al., 2011). Older users were also concerned about privacy and about technology impacting upon their autonomy and felt that it was important that they were always in control of the device (McGee-Lennon et al., 2012).

Another issue may be cognitive barriers. People with memory impairments and older users may have difficulty with understanding technology especially if there are distracting features (Demiris et al., 2004) or chains of action, choices between several buttons and hidden functions (Rosenberg et al., 2011). Carers of people with dementia reported that they thought about technology in terms of function and so devices with simple basic functions were preferred (Rosenberg et al., 2011). Older users reported a desire to have technology training catered towards their needs (Demiris et al., 2004) and there is literature looking at training specifically for carers of people with ABI to help overcome difficulties with memory, learning and cognition (Powell, Wallace and Wild., 2013).

Finally, people with ABI or dementia and older people may have physical impairments such as vision loss, hearing impairment, loss of tactile senses, loss of balance, difficulty reading fine print, difficulty using small buttons and difficulty using a computer mouse, which may prevent them from being able to use memory aid technology (Demiris et al., 2004; De Joode et al., 2012; Rosenberg et al., 2011).

3.1.4 Chapter objectives

The primary aim of the study reported in this chapter was to investigate the use of memory aids and strategies by people with ABI and dementia. A secondary aim was to investigate if the increase in the availability of mobile and Smartphone devices with memory aid capabilities has been accompanied by an increase in the use of digital memory aids by people with memory impairment, and to quantify and describe that use. Any technologies that can help compensate for various types of memory difficulties during everyday activities were included. If there is an increase in use of memory aid technology then it would be interesting to investigate whether this use is predicted by the same or different factors that predict non-technological memory aid use.

While the survey study aimed to look at the prevalence of assistive technology for cognition (ATC) use, it also provided an opportunity to gain an understanding of the most important reasons why assistive technology might not be used to compensate for memory. Therefore a further aim was to investigate which of the ATC barriers to use that have been consistently highlighted the literature were the most important for people with dementia and ABI when using, or considering using, memory aid technologies. A number of barriers to the use of assistive technology have been identified in studies that investigated the attitudes of ATC end users. However, no study has used quantitative measures to investigate which issues are most important. This is valuable because researchers and designers can use such information to prioritise which barriers they aim to overcome. There are also no studies which investigate how experience of these issues differs according to aetiology of memory impairment. As part of the study reported in this chapter, the relative importance of these barriers for people with acquired brain injury and dementia were compared. Furthermore, these eight barriers which have been described in the literature may not include all of the issues which impact the use of assistive technology for these groups and the survey provided an opportunity to describe any additional barriers which were identified by participants.

3.1.5 Study aims

1) To compare prevalence of memory aid use amongst ABI cohorts in 2003 (results from Evans et al., 2003) and 2014 (current study).

2) To investigate the prevalence of technological and non-technological memory aid use, and memory aid strategy use amongst people with ABI and people with dementia, and to find out which types of technology are most commonly used and in what way.

3) To investigate which factors are associated with use of technological and non-technological memory aids, and memory aid strategies for people with ABI and dementia.

4) To investigate the barriers to uptake of assistive technology for cognition which are most important for people with ABI and dementia, and to describe any further barriers mentioned by participants.

3.2 Method

3.2.1 Participants

Participants were recruited between November 2013 and June 2014. Participants with ABI were identified through NHS services in Scotland: Community Treatment Centre for Brain Injury (CTCBI) within the United Kingdom National Health Service Greater Glasgow and Clyde (NHS GG&C), and NHS Grampian. Recruitment was also undertaken through the UK brain injury charity Headway, via meetings in Scottish localities (Glasgow, Falkirk, Lothian, Dumfries and Aberdeen). Inclusion criteria were a diagnosis of ABI and memory difficulties as reported by self or other. For participants recruited through Headway, memory impairment was self-reported during initial discussion with the researcher. Participants recruited through the NHS were only approached if improving memory had been established as a rehabilitation aim after self-report of memory difficulties and / or a formal assessment from clinicians within the service. Only people aged 18 and over who were able to give informed consent to participate in the study were approached.

Based on the diagnostic criteria for dementia and usual progression of the disease, it was thought to be highly likely that people with dementia would have memory impairment (Singh, Lancioni, Sigafoos, O'Reilly & Winton, 2014). Therefore people with a diagnosis of dementia were included in this study and memory difficulties were assumed. Potential participants were identified through the Scottish Dementia Clinical Research Network (SDCRN). Only participants who were over 18 when they joined the SDCRN and who consented to be approached about research that is approved by the SDCRN were approached.

Glasgow University research ethics approval was granted for this study on 14th October 2013 (project number: 200130011).

3.2.2 Materials

In the following order the survey consisted of:

1) Demographic questions (age, gender, work status and education level)
2) A memory aid use checklist adapted from Evans et al. (2003)
3) A self-reported memory questionnaire (the Prospective and Retrospective Memory Questionnaire - PRMQ (Crawford, Smith, Maylor, Della Sala, & Logie, 2003)).
4) A barriers to ATC use questionnaire created by the thesis author (see Appendix)

Details about how the injury was acquired and time since injury were obtained from the recruiting NHS service where available. Participants who were recruited through Headway were asked to provide information about their injury on the first page of the survey below the demographic information section.

The memory aid checklist was taken from Evans *et al.* (2003). Because this checklist questionnaire was administered during face-to-face interviews in the original study, it was adapted for the present study so that it could be easily understood in a postal survey format. Types of memory aid were split into three categories – non-technological memory aids (such as paper diaries or calendars), technological memory aids (such as mobile phone or alarm based reminders) and strategies (such as leaving objects in noticeable or unusual places) (see sub-section 3.6.1 in section 3.6 appendix for full list of items). In the technological reminders checklist the item 'a mobile phone to remind you' and the item 'asking someone to text you' were both included to separate those using a mobile phone calendar, reminding app or alarm from those simply using a mobile phone to receive texts from a carer or family member to remind them about tasks. For each item participants were asked whether they used it before their brain injury, whether they use it now, how often they use it (daily, weekly or monthly) and how useful it is (helps a lot, helps a little or does not help). After the technology reminders checklist there was a space for people to write what they used tech memory aids for.

The barriers questionnaire was designed to prompt participants about the barriers to technology use discussed in the introduction; practical issues, personal preference, social issues, reverse effects, beliefs about memory, ethical issues, cognitive barriers and physical barriers. Three questions were created for each theme (see figure 3.5 in section 3.6 Appendix for details) and participants were asked to rate their level of agreement with the statement on a five-point likert scale. Some items were positive about technology (e.g. 'I find new technology to be simple to use' (cognitive)) and some were negative about technology (e.g. 'Using technology would make me feel like I had a problem' (reverse effects)) in order to prevent respondents speeding through the questionnaire by putting the same answer to each question. There were 24 questions each with a minimum score of 1 and a maximum score of 5. The full questionnaire would give a score between 24 and 120. Low scores indicated that the included barriers were not perceived as important and high scores indicated that the included barriers were perceived as important to the uptake and continued use of technology based memory aids.

The PRMQ is a validated measure of self-reported everyday memory performance. A normative score for the PRMQ test was calculated in a large sample (n = 551) of healthy people between the ages of 17 and 94 (Crawford et al., 2003). Crawford et al. found that age and gender did not influence PRMQ scores so comparison to an age and gender matched sample is not necessary. The PRMQ showed good reliability between items (internal consistency); Cronbach's alpha was 0.89 (95% confidence interval = 0.88 to 0.90) for the total scale (Crawford et al., 2003).

Given the survey methodology used, it was not possible to use an objective measure of memory for the ABI group. The validity of using the PRMQ as a test of memory logically relies on the accuracy with which people can rate their own memory. This issue is considered in the discussion (Section 3.4 Discussion, sub-section 3.4.2)

3.2.3 Procedure

This was a cross-sectional study and a postal survey was used to recruit participants. People with ABI (n = 308) and people with dementia (n = 299) were sent the survey with the expectation of a 30 to 40% response rate (Bech and Kristensen, 2009). The target sample size of 100 in each group was similar to the number of participants recruited by Evans et al. (2003) (101 people with ABI). The survey was distributed via the Scottish Dementia Clinical Research Network (SDCRN) to people with a diagnosis of dementia who had joined their database in the past 24 months. Although the participants with a diagnosis of dementia had already been approached by the SDCRN to take part in research sponsored by the network, the first time they were approached for the present study was when the survey documents reached them through the post. People with ABI were approached via the Community Treatment Centre for Brain Injury in Glasgow (CTCBI) and brain injury services in NHS Grampian, with questionnaires being passed on to participants either in person or through the post. Participants with ABI recruited through Headway were given the forms by the researcher, Headway care staff or volunteers at support group meetings. All participants returned the survey to the researchers using a freepost envelope provided. The study methods and the survey were approved by Glasgow University ethics committee on 14th October 2013.

3.2.4 Statistical analysis

A returned survey was included in the analysis if the memory aid checklist was judged to be complete by the thesis author. A checklist was judged to be complete if each item was filled out. However, some participants only filled out the checklist items when indicating that they did use that memory aid, missing out the other items. These responses were also included in the analysis provided the demographic information presented before the checklist, and the PRMQ presented after the checklist, were both completed. This pattern of responding was interpreted by the thesis author to indicate that the participant did engage fully with the checklist, and that they simply missed out items when they did not use them. People with dementia returned 102 surveys. Four of these were not used because they were judged to have incomplete checklists leaving 98 completed surveys. Five of the 86 returned surveys in the ABI group had incomplete checklists. These were removed from the analysis leaving 81 fully completed surveys for people with ABI.

Independent t-tests were used to compare the current sample with the 2003 sample on demographic variables. Chi squared tests were used to analyse the difference in proportion of participants indicating they used each piece of technology between the two study samples. Heirarchical regression analyses were used to examine predictors of the number of technological reminders used after injury, and number of all types of memory aids used after injury. The 'technological reminders used' variable was highly skewed – a large number of participants used zero or one technological memory aid only (59%). For this reason negative binomial regression was used to investigate which factors predicted technological reminder use. For negative binomial regression analysis, incidence rate ratio (IRR) was reported, with 95% confidence interval (CI). IRR indicates the estimated relative change in the dependent variable for each unit increase in the independent variable. For example, within a negative binomial regression model predicting technological memory aid use, an IRR for age of 0.97 indicates that for every one-year increase in age, the number of technological memory aids used would reduce by 3%.

A linear regression analysis was used to investigate the factors that predicted the number of aids used (all types) as this variable was normally distributed.

Predictors were added to each hierarchical regression model in a set order based on the findings reported by Evans et al. (2003). For the models predicting technology use, 1) age, 2) pre-morbid technology use and 3) current non-technology use were added to the model first in a hierarchical manner followed by the other factors (4. ACE-R score if available, 5. PRMQ score, 6. education level, 7. work status, 8. gender). For models predicting all memory aid use, 1) age and 2) pre-morbid all memory aid use were added to the model first in a hierarchical manner followed by the other factors (3. ACE-R score if available, 4. PRMQ score, 5. education level, 6. work status, 7. gender). As each factor was added to the model, an ANOVA analysis was performed to test whether the model was significantly improved when the new factor was added.

Pearson's correlations were used to investigate the relationship between memory ability and memory aid use. The technological memory aid use variables (for both before and after injury) were highly positively skewed and the 'all memory aid use before injury' variable was also moderately positively skewed. These variables could not be assumed to be normally distributed. For this reason non-parametric methods (Spearman's rank for correlations) were used when analysing these variables.

Participants' comments about what they used technological memory aids for were grouped according to the kinds of memory being supported. For example if a participant wrote 'for appointments' then this would be coded as using technology to help with prospective memory (future intentions). Three of the authors coded this written feedback independently and then came to a consensus about any disagreement.

The barriers to ATC use questionnaire was analysed descriptively after tallying up responses to each barrier (groups of three thematically related questions) and each individual question. Scores from positive items were reversed so that higher scores for each item meant that issue was more of barrier to ATC use. Seven of the 98 returned surveys in the dementia group did not have completed barriers questionnaires and so 91 were included in the analysis. Seven of the 81 returned surveys in the ABI group did not have completed barriers questionnaires and so 74 were included in the analysis.

3.3 Results

3.3.1 Demographics

Most of the participants with ABI (total n = 81) were recruited through CTCBI NHS GG&C (n=40, 49%) and Headway (n=33, 41%) with a small number from NHS Grampian (n=8, 10%). All participants with dementia were recruited through the SDCRN (total n = 98). The mean age of participants with ABI was 51.2 years (range = 27 – 76, SD = 10.34) and 32 (40%) were female. Mean age of people with dementia was 77.14 (range = 51 to 93, SD = 7.87) and 41 (42% were female). The most common aetiology of injury was traumatic brain injury (n=48, 59%) followed by aneurysm (n=13, 15%), stroke (n=5, 6%), encephalitis (n=4, 5%), infection (n=4, 5%) and other (n=7, 9%). The most common form of dementia amongst the participants who completed surveys, as described in the SDCRN database, was late onset Alzheimer's Disease (AD) (48%) followed by AD with cerebrovascular disease (15%), dementia with unknown aetiology (14%), vascular or multi-infarct dementia (11%), early onset AD (7%) and 'other' dementia (4%). Median time since acquired brain injury was 3.56 years (range = 0.44 to 61, SD = 9.77, median reported due to a participant with a long time since injury) and (n=20, 25%) were employed at the time of the survey. Mean time between onset of dementia (identified as first time that Acetylcholinesterase inhibitors were prescribed) and joining the SDCRN database was 3.76 years (range = 0.83 to 14.3, SD = 3.4). Only participants who had joined the SDCRN database in the 24 months prior to the study were sent a survey. Four people with dementia (4%) were employed. Mean number of years in education was 12.74 (range 10 to 18, SD = 2.47) for the ABI group and 12.69 (range = 10 to 17, SD = 2.06) for the dementia group. Table 3.1 shows all study participants' PRMQ overall and sub-scores, number of all memory aids used, technological aids, strategies and non-technological aids.

For both groups, mean self-reported memory problems score, measured on the PRMQ, was around 1.5 to 2 standard deviations higher than the mean score for the general population (38.88, range = 17 - 67). Around a third of the participants with ABI (33%) and dementia (35%) were within one standard deviation of the mean PRMQ score for the general population. ACE-R data were available for people with dementia and the mean of 72 (SD = 15.76) was well below the dementia diagnosis cut-off score of 82 (Mioshi et al., 2006). For people with dementia for whom these data were available, 22% were above this cut-off and only 10% were above the alternative cut-off of 88.

A Pearson's correlation was performed between the PRMQ and ACE-R scores for people with dementia included in the study who provided scores on both tests. The test found a significant medium negative correlation ($r(81) = -.39$ (p = 0.00035).

Table 3-1. Descriptive statistics for survey responses.

Key: PRMQ = Prospective and Retrospective Memory Questionnaire; ABI = acquired brain injury; SD = standard deviation

Variables	Descriptive statistics (people with ABI, n = 81)	Descriptive statistics (people with dementia, n = 98)
Mean PRMQ score (range, SD)		
Overall	52.98 (17 – 78, 15.87)	56.1 (22 - 80, 14.52)
Prospective	27.53 (8 - 40, 8.38)	28.01 (9 - 40, 7.7)
Retrospective	25.44 (8 - 39, 8)	28.05 (12 - 40, 7.4)
Short term	26.49 (8 - 40, 8.2)	28.05 (12 - 40, 7.4)
Long term	26.48 (9 - 40, 8)	28.01 (10 - 40, 7.5)
Self-cued	28.17 (8 - 40, 8.2)	30.01 (11 – 40, 7.25)
Environmentally cued	24.8 (9 - 38, 8.2)	26.05 (10 - 40, 7.7)
Mean number of all types of memory aids used (range, SD)		
BEFORE injury / diagnosis	6.14 (0 - 18, 4.52)	7.9 (0 – 17, 3.92)
AFTER injury / diagnosis	11.47 (2 – 26, 4.46)	7.4 (0 – 20, 4.4)
Technological memory aid use prevalence (after injury / diagnosis)		
n (%)	61 (75)	37 (38)
One or more used	37 (41)	10 (10)

3 or more used	8 (10)	2 (2)
6 or more used		
Non-technological memory aid use prevalence (after injury / diagnosis) n (%)	78 (96)	88 (90)
One or more used	68 (84)	67 (68)
3 or more used	37 (46)	17 (17)
6 or more used		
Strategy use prevalence (after injury / diagnosis) n (%)		
One or more used	79 (97)	81 (83)
3 or more used	71 (88)	66 (67)
6 or more used	17 (21)	10 (10)

3.3.2 Aim 1

To compare prevalence of memory aid use amongst ABI cohorts between 2003 and 2014.

The participants in the current study were significantly older than the participants in the 2003 study, who had a mean age of 39.53 (SD = 13.38) (t = 6.38, df = 173, p = 0.00001). The mean years since injury in the 2003 sample (5.89, SD = 4.79) was lower than the current sample but this difference was not significant (t = 1.0006, df = 173, p = 0.318). The current sample spent significantly longer in education compared to the 2003 sample (2003 mean = 11.95 years, SD = 2.13) (t = 2.272, df = 173, p = 0.0243).

Table 3.2 compares the proportion of participants in the 2003 and 2014 samples who indicated that they used each memory aid. Only the items that could be directly compared between 2003 and 2014 were included in this analysis. Chi-square analysis was used to examine which aids and strategies were used by significantly different proportions of participants in each study. For the technological memory aids, mobile phones and alarms/ timers were used by a significantly higher proportion of people in the current study. Among the non-technological aids, a significantly higher proportion of participants stated that they asked someone to remind them, used lists on paper and used diaries. Five strategies were used by a significantly greater proportion of participants in the current study compared to the participants in the 2003 study. These strategies were mental retracing, repetitive practice, objects in noticeable places, rhymes or phrases and alphabetic searching.

Table 3-2. Prevalence of memory aid use reported in 2003 and 2014.

The types of aid or strategy are grouped in the following order; technological memory aids, non-technological memory aids and memory strategies.

Memory aid or strategy	Number (%) of whole sample using the aid or strategy (Evans et al., 2003, n = 94)	Number (%) of whole sample using the aid or strategy (this study, n = 81)	Significant on X^2 test? (p value)
Mobile phone	3 (3)	31(38)	YES ($p < 0.001$)
Pager	5(5)	2(2)	NO
Electronic personal organiser	7 (7)	4(5)	NO
Dictaphone	2(2)	2(2)	NO
Alarm / timer	9(10)	31(38)	YES ($p < 0.001$)
Watch with date / timer	17(18)	12(15)	NO
Asking someone to remind	46(49)	63(78)	YES ($p < 0.001$)
you	51(54)	61(77)	YES ($p < 0.01$)
Diary	68(72)	55(69)	NO
Wall calendar	59(63)	62(78)	YES ($p < 0.05$)
Lists on paper	60(64)	49(62)	NO
Notebook	32(34)	32(41)	NO
Post-it notes			
Mental retracing	45(48)	61(77)	YES ($p < 0.001$)
Repetitive practice	28(30)	36(46)	YES ($p < 0.05$)
Objects in noticeable places	33(35)	69(86)	YES ($p < 0.001$)
Rhymes or phrases	2(2)	25(31)	YES ($p < 0.001$)
Writing on your hand	23(25)	25(31)	NO
Alphabetic searching	7(7.4)	28(36)	YES ($p < 0.001$)

3.3.3 Aim 2

To investigate the prevalence of technological and non-technological memory aid use, and memory aid strategy use amongst people with ABI and people with dementia, and to find out which types of technology are most commonly used and in what way.

3.3.4 Technological memory aids

The proportion of people with ABI using each technology-based reminder, with participants' perceived helpfulness ratings, are shown in Figure 3.1. The proportion of people with dementia using each technology-based reminder, with participants' perceived helpfulness ratings, are shown in Figure 3.2.

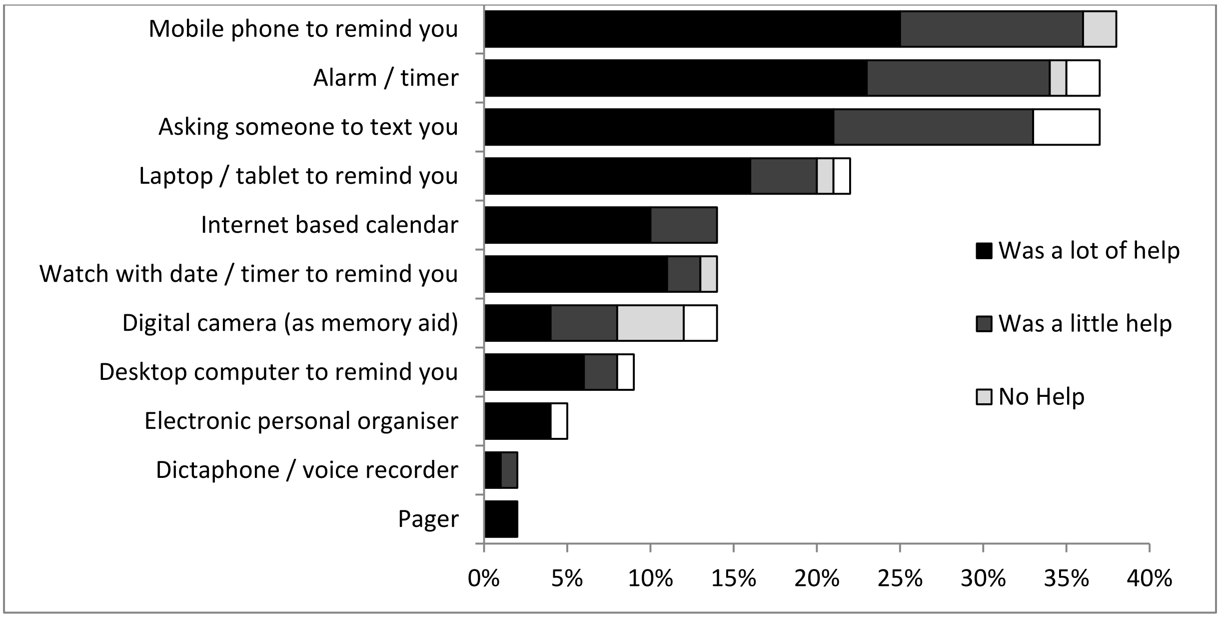


Figure 3-1. ABI survey respondents' use of assistive technology, with usefulness evaluation.

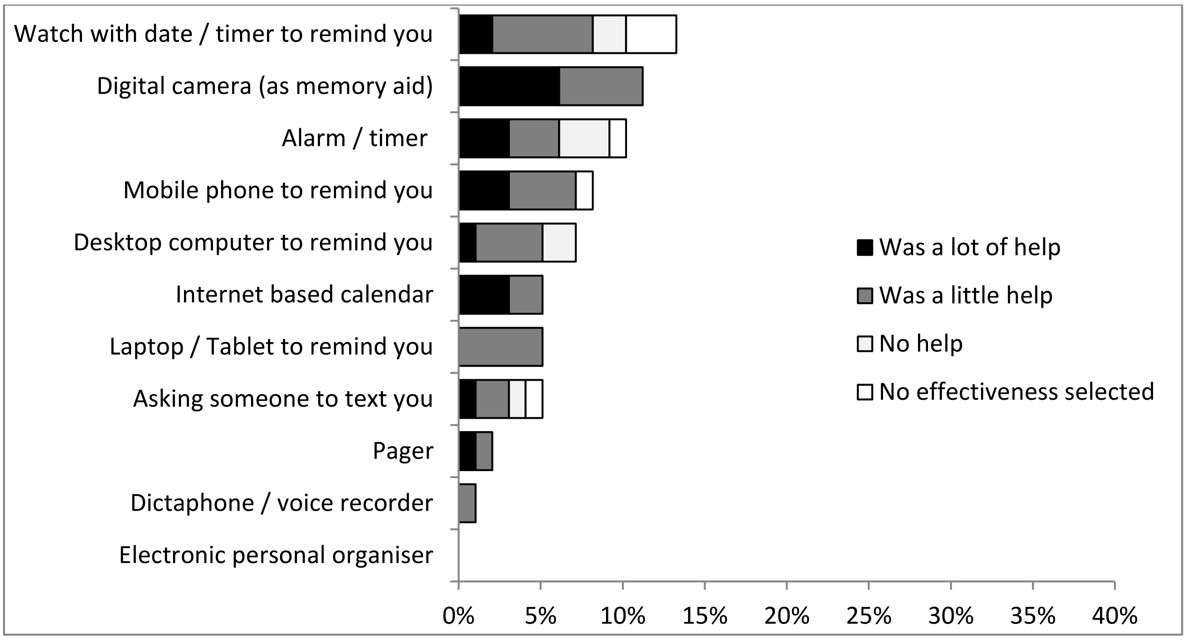


Figure 3-2. Dementia survey respondents' use of assistive technology, with usefulness evaluation.

3.3.5 Non-technological memory aid and strategy use

The prevalence of use of each non-technological strategy or aid for the ABI respondees, with participants' perceived helpfulness ratings, are shown in Figure 3.3. The same results for the dementia group are shown in figure 3.4.

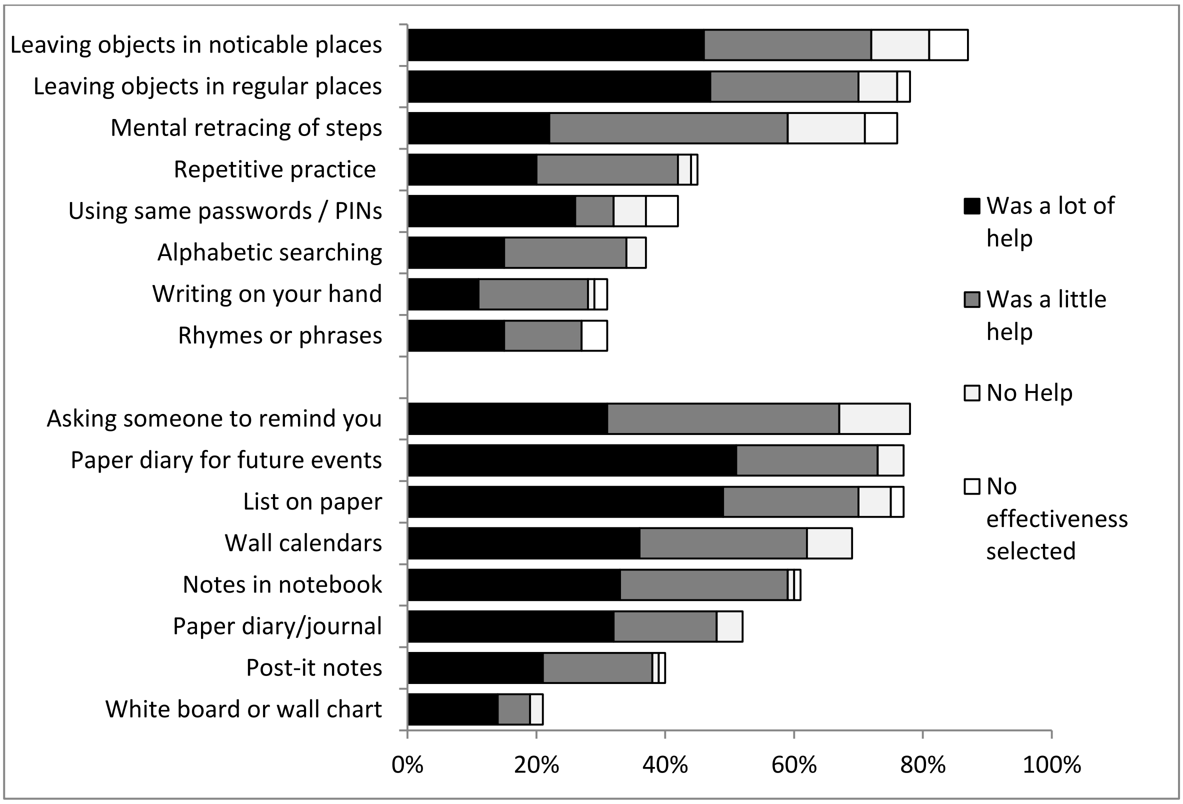


Figure 3-3. ABI survey respondents' use of strategies and non-technological memory aids, with usefulness evaluation.

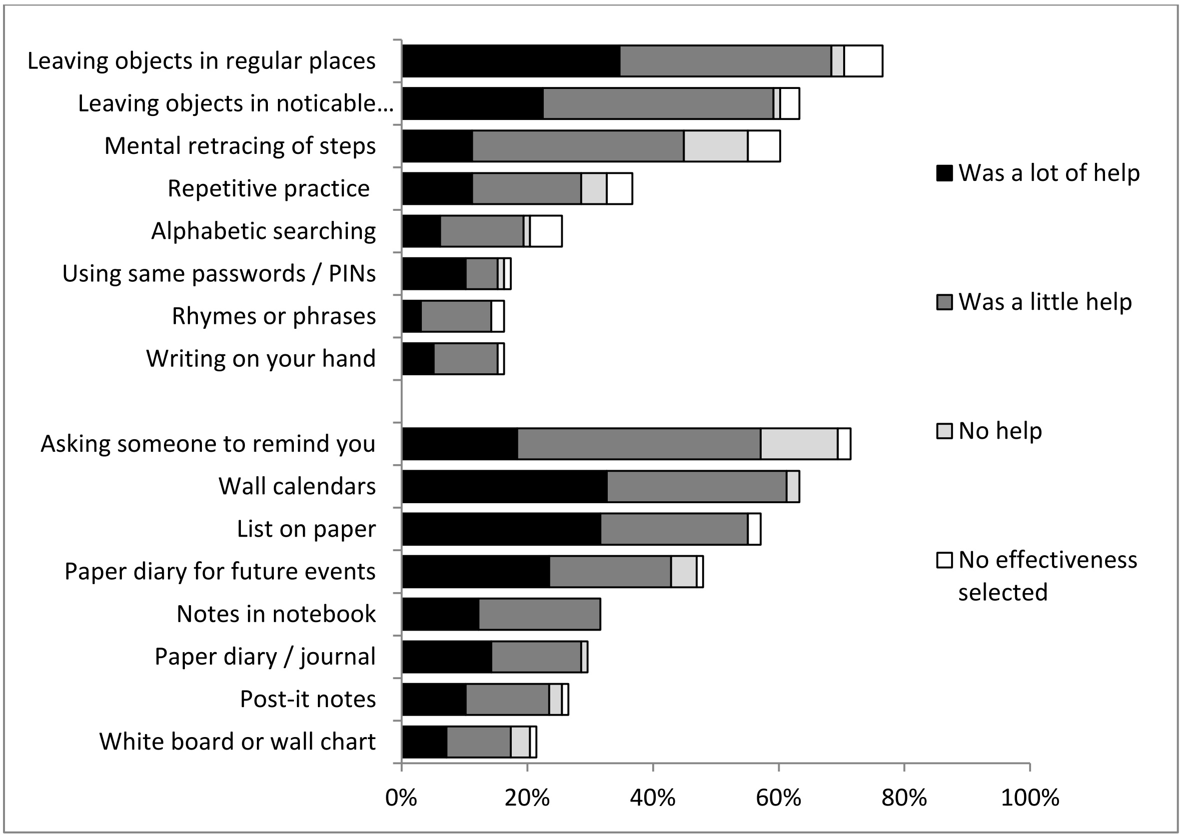


Figure 3-4. Dementia survey respondents' use of strategies and non-technological memory aids, with usefulness evaluation.

3.3.6 How memory aids were used

When coding the answers to the open ended comment box question, 'If you use any of these technological memory aids, what do you use them to remind you about?', there was reasonable level of agreement between the three raters with 80% of the comments coded in the same category by each rater. Thirty five participants (43.2%) answered this question in the space provided. Some of the participants' comments contained information about more than one different use of technology and so there were 46 separate comments analysed. The majority (n=30, 65%) of answers referred to reminders about future intentions. These included using phone calendars, text messaging and alarms to alert about appointments, household tasks, social events and medications. The second most common use of technology was to wake up in the morning or after a nap (n=11, 24% of comments mentioned using technology in this way). Three comments (6.5%) mentioned using technology to help orient to time and date. One comment talked about using a mobile phone to store information (e.g. who they had called) to prevent them doing the same thing twice. There was also a single comment about using technology to help with emotional regulation. Mobile phone use or texting was mentioned in 34.3% (n=16) of the comments and all of these comments mentioned it in reference to setting and receiving reminders for future intentions.

3.3.7 Aim 3

To investigate which factors are associated with use of technological and non-technological memory aids, and memory aid strategies.

The factors which predicted the use of memory aid technology and all memory aids and strategies were investigated for both groups using negative binomial regression analyses.

3.3.8 Memory aid technology

Greater use of technological reminders post-ABI was associated with younger age (IRR = 0.97, CI = 0.956 to 0.987, $p < 0.001$), higher premorbid technological memory aid use (IRR = 1.23, CI = 1.15 to 1.32, $p < 0.001$), and higher current use of non-technological memory aids/strategies (IRR = 1.09, CI = 1.04 to 1.15, $p < 0.001$). These variables explained 75.8% (Nagelkerke $R^2 = 0.758$) of variance in technological memory aid use.

Greater use of technological reminders after diagnosis of dementia was associated with higher premorbid technological memory aid use (IRR = 1.49, CI = 1.33 to 1.66, $p < 0.001$), and higher current use of non-technological memory aids/strategies (IRR = 1.15, CI = 1.07 to 1.24, $p < 0.001$). These variables explained 70.7% (Nagelkerke $R^2 = 0.707$) of variance in technological memory aid use.

3.3.9 All memory aids

Greater use of all reminders and strategies post-ABI was associated with younger age (estimate = -0.11, CI = -0.19 to -0.04, $p < 0.01$), higher use of all memory aids before injury (estimate = 0.53, CI = 0.34 to 0.71, $p < 0.001$) and higher PRMQ scores (estimate = 0.2, CI = 0.097 to 0.304, $p < 0.001$). These variables explained 38.5% ($R^2 = 0.38$) of the variance in memory aid use.

Greater use of all reminders and strategies after diagnosis of dementia was associated with higher use of all memory aids before injury (estimate = 0.6, CI = 0.43 to 0.76, $p < 0.001$), lower PRMQ scores (estimate = -0.17, CI = -0.27 to -

0.08, $p < 0.001$) and higher ACE-r score (estimate = 0.08, CI = 0.037 to 0.128, $p < 0.001$). These variables explained 57.2% ($R^2 = 0.572$) of the variance in memory aid use.

3.3.10 Aim 4

To investigate the barriers to uptake of assistive technology for cognition for people with ABI and dementia.

People in the ABI group had a mean barriers score of 63.56 out of 120 (SD = 17.44) and the dementia group had a mean score of 72.8 out of 120 (SD = 13.56). For both groups there was a significant negative correlation between technology use and total barriers score. For the dementia group this negative correlation was small ($r = -0.25$, $p = 0.016$) and for the ABI group this correlation was moderate ($r = -0.56$, $p < 0.01$). Figures 3.5 and 3.6 shows the scores for each theme for people with ABI and dementia.

3.3.11 ABI group

The top three barriers which were endorsed most often by the participants with ABI were; ‘beliefs about memory’ (the belief that memory will decline if you rely on technology and that it is beneficial to remember things without help; that you need to ‘use it or lose it’) (mean = 9.93, SD = 2.76), ‘cognitive’ (the feeling that you will be, or the experience of being, unable to figure out how to use the technology) (mean = 9.6, SD = 3.81) and, ‘personal preferences’ (unwillingness to use technology because it is disliked, or due to a preference for pencil and paper methods (technology use not being in your nature)) (mean = 9.53, SD = 3.54).

The top three highest scoring barrier items within the questionnaire were; agreement with, ‘It feels like a step forward if I remember things myself without relying on technology to remind me (beliefs about memory item) (mean = 3.81, SD = 1.32), disagreement with, ‘I find technology easy to use’ (cognitive item) (mean = 3.57, SD = 1.37), and agreement with, ‘I prefer to write things down’ (personal preferences item) (mean = 3.55, SD = 1.4).

3.3.12 Dementia group

The top three barriers which were endorsed most often by people with dementia were; 'cognitive' (the feeling that you will be, or the experience of being, unable to figure out how to use the technology) (mean = 11.74, SD = 3.43), 'personal preferences' (unwillingness to use technology because it is disliked, or due to a preference for pencil and paper methods (technology use not being in your nature) (mean = 11.25, SD = 3.3) and, 'beliefs about memory' (the belief that memory will decline if you rely on technology and that it is beneficial to remember things without help; that you need to 'use it or lose it') (mean = 10.24, SD = 2.11).

The top three highest scoring barrier items within the questionnaire for the dementia group were; disagreement with, 'I find technology easy to use' (cognitive item) (mean = 4.12, SD = 1.16), which was equal to disagreement with, 'I always feel in control of technology' (ethical item) (mean = 4.12, SD = 1.16), and disagreement with, 'I have always kept up to date with new technology' (personal preferences item) (mean = 3.98, SD = 1.41).

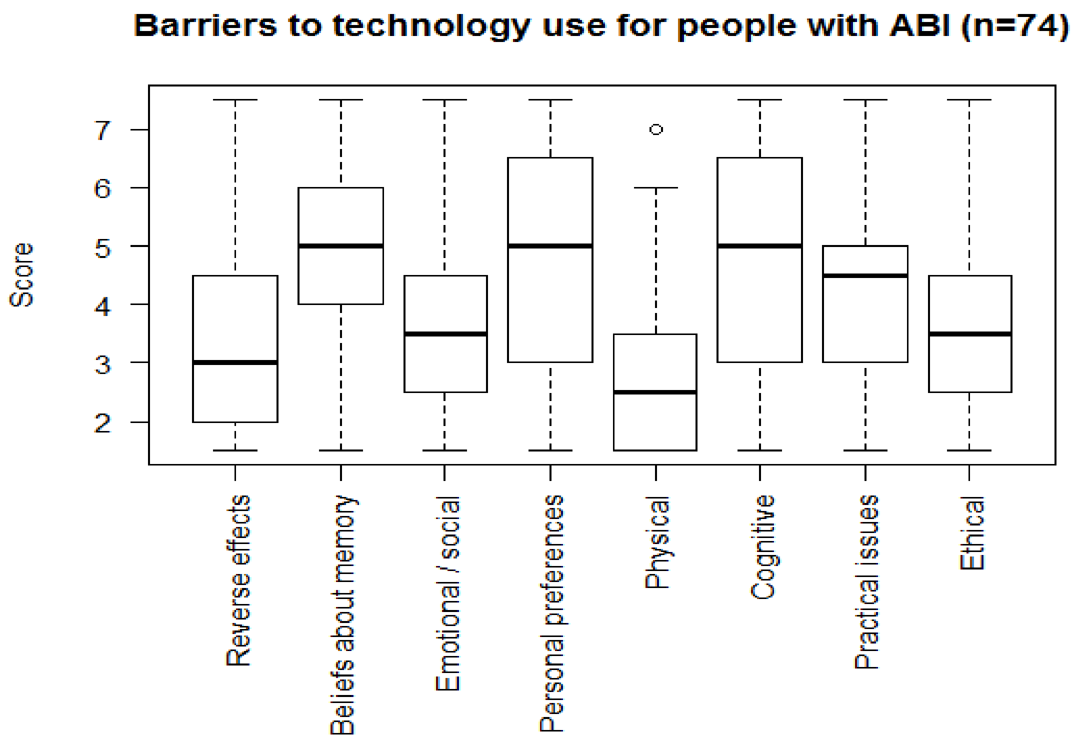


Figure 3-5 Box-plot for responses to different barrier themes for people with ABI

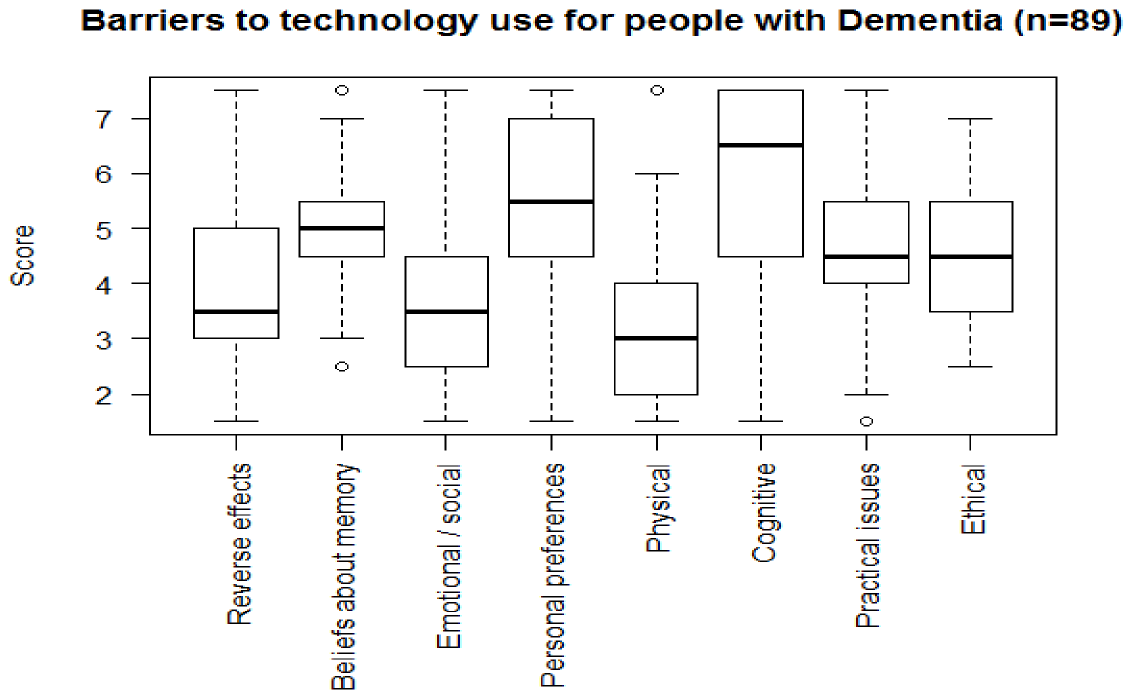


Figure 3-6 **Box-plot for responses to different barrier themes for people with dementia.**

3.4 Discussion

A postal survey was used to examine the types of memory aids currently used by people with acquired brain injury and dementia living in the community. The proportions of different memory aids used were compared to the proportions reported in a 2003 ABI survey, and the factors which influence memory aid uptake and continued use were examined.

3.4.1 Memory Aid Prevalence

Ten of the 18 memory aids compared were used by a significantly greater proportion of people in the current study compared to the participants in Evans et al. (2003). These included many different types of aids including technological aids such as mobile phones and alarms/ timers, and non-technological aids and strategies such as asking others to remind, lists on paper diaries, mental retracing, repetitive practice, objects in noticeable places, rhymes or phrases and alphabetic searching. It is possible this increase represents a general increase in memory aid and strategy use for people with ABI. The increase could also be explained by other differences between the two study samples. The studies were carried out in Cambridgeshire (2003) and Scotland (current) and so participant overlap is unlikely. The current study participants were, on average, older by around ten years. It seems unlikely that this would account for the difference in memory aid use, as both studies found that younger age predicted use of all types of memory aids. The participants in the current study reported significantly more years in education than the 2003 participants. Education level was not a significant predictor of memory aid use in the current study. However, higher education level could indicate higher socio-economic status (SES) and factors related to higher SES such as better social/family support may contribute to greater use of memory aids. While Evans and colleagues (2003) did not test the impact of level of education on memory aid use, they did investigate pre-morbid intelligence using the National Adult Reading Test – revised (NART; Nelson and Willison, 1991). They found that the NART was not significantly associated with memory aid use.

3.4.2 Predictors of memory aid use

Greater time since injury was found to be related to increased memory aid use in Evans et al. (2003). The current sample had, on average, just over one year more since their injury, although this difference was not significant. Differences in recruitment method mean that severity of injury could be different for the two groups. Eighty-one of the 94 participants in Evans et al. (2003) had a history consistent with a period of coma and posttraumatic amnesia (PTA). Mean coma time was 7 days and mean PTA time was longer than 4 weeks. Therefore many of the participants in the study fell into the PTA category of 'very severe'. Methodological limitations prevented such detailed information about participants' injuries being collected in the current study, but it is possible that the Evans et al. (2003) study included participants who had more severe difficulties compared with the current study sample and this may have impacted on their ability to use memory aids effectively.

People with ABI who were younger, used more memory aids prior to injury and who had poorer self-rated memory were found to use more of all types of memory aid in the present study. Age and pre-morbid memory aid use were also found to be influential in Evans et al. (2003). They did not find objective memory ability (Rivermead Behavioural memory test – RBMT (Wilson, Cockburn & Baddeley, 1999)) to be a significant predictor of memory aid use in a regression analysis (self-reported memory ability data were not gathered). However, Wilson and colleagues (1996) did find that RBMT score influenced memory aid use and, using a bi-variate analysis, Evans et al. (2003) found that a RBMT screening score above 3 was related to use of six or more memory aids. Therefore it does seem that previous studies have found that better objective memory ability is associated with higher use of aids. These findings contrast the current findings that poorer self-reported memory leads to greater use of strategies in this group. An explanation for this could be that better objective memory is related to higher cognitive functioning, which may lead to greater insight into memory difficulties. This could lead to low memory self-evaluation and to increased use of memory aid strategies. Alternatively somebody with very poor memory might lack insight into their difficulties and be unaware of their need for memory aids. In the absence of objective memory data in the present study sample, it is difficult to clarify the relationship between objective memory ability, self-reported memory ability and memory aid use.

For people with dementia the PRMQ and ACE-R scores were significantly correlated, but this was a medium sized correlation. This indicated some overlap between the two measures but it is clear that PRMQ cannot be used as a valid measure of objective memory ability. In contrast with the ACE-R, which is an objective test of memory performed by an examiner, the PRMQ is a subjective test which requires insight from the test taker about their memory performance. All memory aid use was more prevalent amongst people with dementia who used more memory compensation prior to onset, who had better objective (ACE-R scores) and better subjective memory ability (PRMQ scores). One interpretation of these results is that better memory leads to better insight into problems and therefore more use of memory aids to compensate for relatively mild cognitive impairment. It is surprising that age was not a significant predictor in either of the regression analyses given that age has been found to be such an important predictor in the use of technology by older users (Rosenberg et al., 2012). This may be due to the limited range of age for the group included in the present study. It is also possible that, because the participants in this study were mostly over 70 (86%), very few of the participants would have experience with current easily available modern technology during their working lives. It is possible that age would have been a more important factor if there had been a wider range of ages in the sample.

3.4.3 Technological aid prevalence

Comparing the results of this study to those of Evans et al. 2003, use of some technological memory aids does appear to have increased. Use of mobile phones as memory aids has increased from around 3% to 38% amongst people with ABI in the last 10 years. Alarm/timer use has also seen a large increase from 9% to 38%. This could reflect the general trend of greater memory aid use in the current sample compared to the 2003 sample. It could also be due to the advancement in and greater availability of mobile phone technology for personal use. Two of the most commonly used technological memory aids were mobile phones, and asking someone to text them. Use of other technologies studied in both papers has not increased and this is likely because pagers, dictaphones and electronic organisers have become obsolete in the last 10 years and their functions are now performed on smartphones.

The proportion of people with dementia using technology is similar to the proportion of people with ABI who used technology 10 years ago. It would be interesting to observe if use of technology increases amongst this group in the next few years as younger generations who are more experienced with technology begin to face the memory challenges brought about by dementia. The most commonly used technological memory aids amongst people with ABI were mobile phones, alarm / timer and asking someone to text them. Although there is no way to know exactly what kind of reminding task these devices are being used for, the most common reminding utility of these technologies is prospective memory prompting.

3.4.4 Technological memory aid predictors

In this study, people with ABI who were younger, used more technological memory aids prior to their injury and who used more non-technological aids and strategies after their injury tended to use a higher number of technological memory aids. When investigating which factors predicted all memory aid use, Evans et al. (2003) found that age, time since injury, previous use of memory aids, level of independence and attentional functioning were the most important predictors. Therefore there is a similarity between the factors which predicted all memory aid use in 2003 and the factors which predict technological memory aid use in 2014. It is interesting to note that the most commonly reported use for memory aid technology was to remind about future intentions, with a small number of references to waking up and orienting to time and date. There is growing interest in technologies that can support autobiographical memory (Hodges et al., 2005) and working memory during performance of tasks with several sub-steps (Mihailidis Carmichael & Boger, 2004). However the current results suggest that prompting technologies which help organisation and prospective memory and, to a lesser extent, alerting technologies which support orientation are the types of assistive technologies currently being used by people with ABI to support memory.

The findings for people with dementia were similar to those with ABI, in that people who use more non-technological memory aids currently and those who used technological memory compensation strategies prior to the onset of their memory impairment were more likely use technology after the onset of dementia. The findings do support previous research which highlights the role of previous experience with technology in assistive technology use (e.g. Patterson et al., 2014). Since this is such an important factor, it is a concern that many people with dementia and caregivers do have experience using assistive technology (van den Heuvel et al., 2012). These findings also emphasise the importance of equipping rehabilitation and support services with the means to supply and train people with appropriate memory aids and assistive technologies, in order to reach end users as early as possible. In contrast to the findings of Patterson *et al.* (2014), age, gender and memory ability (PRMQ and ACE-R scores) were not found to influence assistive technology use. Again age may not influence technology use because the participants were all similar ages.

It is difficult to put these results into context through comparison with the general population as few statistics on the general use of memory aid technologies are available. A comparison can be made by using smartphone use as a proxy for being familiar and comfortable with technology. Although statistics vary, it has been reported that around 50% of people between the ages of 45 and 55 (the average age of the participants in the study) use a smartphone in countries where smartphone penetration is high such as the UK and USA (Nerea, 2013). This is higher than 41% of people who, in our survey, used 3 or more pieces of technology and higher than 38% of people who commonly used mobile phone reminders. These statistics allow the tentative suggestion that while technology use has increased markedly over the last decade for people with ABI, this group is behind the general population in terms of the uptake and use of smart technologies and mobile phone reminding technologies.

The most commonly used memory aids or strategies for both groups were leaving items in noticeable or regular places, developing habits after repetitive practice, making lists on paper, using wall calendars and asking other people to remind them about things. Diaries and notebooks were quite popular amongst people with ABI. These findings are useful when thinking about how technology could be designed around people's existing habits. Many reminding technologies have been developed from non-technological strategies which people commonly use. For example calendar and notes applications come as standard on modern smartphones. Turning these memory aids into memory aid technology is useful because it allows active prompting from the device at relevant times. However technological versions of some of the most popular strategies have not become so widespread. For example, a technological version of the strategy ‘placing items in regular places’ could be a system displaying reminders which is placed in a highly visible regular place in the home. A tablet based system which performed this function was developed by McGee-Lennon and colleagues after several co-design sessions with older users (McGee-Lennon, Smeaton & Brewster, 2012). These results offer more evidence that this type of technology may be useful for people with memory impairment after ABI.

This study highlights factors which are associated with memory aid use and which explain quite a large proportion of the variance in all memory aid use for people with ABI and dementia. These factors are fairly easy to establish within a few minutes in a clinical setting and have potential to be a good indication of the likelihood that somebody will make use of memory aids or not. This information is useful when developing individual rehabilitation plans for patients and when considering the use of technological and non-technological memory aids, and whether additional training may be required to support use of technology.

3.4.5 Barriers to memory aid use

Participants with acquired brain injury gave lower scores on the barrier items in general indicating that these issues are perceived as less important overall by this group. The same barriers were perceived as most important for both groups. Participants felt technology was too complicated to use, or learn to use, and felt out of touch with, and not in control of, technology. They also reported that they would be unlikely to turn to, and would be unwilling to rely on, technology if they felt they needed help with their memory. The most important reasons for not using memory aid technology were that people did not feel able to use them, that using technology was not in their nature and that relying on technology might cause further memory decline. Cognitive difficulties, for example, not believing that you can work out how to use technology, was the most important barrier for people with dementia. Beliefs about memory, for example, the idea that relying on technology will be detrimental to any recovery of their memory, was the most important barrier for people with ABI.

More research is required to understand how these barriers might be overcome. For example if technology is designed to be more accessible then people may feel more confident with it and be able to use it. If it is designed and introduced in collaboration with rehabilitation clinicians, caregivers and end users then it may be that people will not be worried about over reliance on technology negatively impacting on their rehabilitation. If people experiencing cognitive decline do not believe they will be able to learn how to use new technology, then perhaps it should be introduced earlier. For example, technology could be introduced as part of post-diagnostic support or in the context of getting a diagnosis of mild cognitive impairment. It is possible that attitudes, preferences and beliefs about technology might be different for younger generations and so some of these issues may disappear or change over time.

3.4.6 Methodological Considerations

Although there was a wide range of self-reported memory ability, the PRMQ results show that most participants reported some level of memory impairment and all participants in this study self-reported impaired memory and/or had memory functioning as a rehabilitation goal. However, objective assessment of memory performance was not carried out. The PRMQ does correlate with global measures of memory in the general population (Rönnlund, Mäntylä and Nilsson, 2008) and it has been found that prospective memory performance is predicted by prospective memory complaints in older adults (Zeintl, Kliegel, Rast and Zimprich (2006). However, people often have difficulty with insight and self-awareness after ABI (Fleming and Strong, 1995). A number of participants were within one standard deviation of the mean PRMQ score for the general population and it is difficult to tell whether this reflects a weakness in the recruitment method or a lack of awareness from participants about their memory difficulties. Acquired brain injury can often lead to memory impairment, apathy and cognitive, sensory and motor difficulties. It could be claimed that a self-reported survey administered without researcher supervision might fail to elicit many responses (due to the difficulty of the task). Additionally, any responses that are obtained may not be accurate (due to the difficulty of remembering or processing answers, or perseveration in responses). Various steps were carried out when designing the survey in order to overcome these potential hurdles. It was made clear on the instructions on the front of the survey that while the survey was addressed to the person with ABI, it was recommended that a family member or caregiver help with the completion of the survey. For the memory aid items it was made clear, both in the description of the task and the individual items, that the participants should only select the technologies, aids or strategies which they used for reminding. The aim of this was to prevent participants from selecting items that they use for other purposes (e.g. a mobile phone to stay in contact with people or a computer to play games). Other steps such as making the questionnaire as short as possible so that it only took 30 minutes to complete and splitting the questionnaire into two parts with the suggestion that people take a break between the sections were designed to improve the likelihood of accurate completion. A draft questionnaire was also altered after consultation with an acquired brain injury expert at the charity Headway and a group of dementia caregivers. Several changes were made including the layout of the checklist (making the font larger and easier to read and grouping each checklist item in its own box to hold people's attention) and the wording of the introduction to the different sections (making it as clear as possible and giving examples to illustrate the points).

The comparison between this study and Evans et al., 2003 is limited by their differing methodologies. Variables such as independence, everyday attention and severity of head injury cannot be compared as they were not possible to ascertain in a postal survey. The methodology also meant it was not possible to distinguish how much help each participant received from caregivers to complete the survey. Recruiting through Headway, which a voluntary rehabilitation and support service run in the community, may have meant that many of the individuals who responded to the 2014 survey were keenly motivated in their rehabilitation.

In general, the postal survey method of this study may have led to a selection bias. It is possible that the 169 people who returned the survey were different from the 428 people who did not respond. For example, successfully responding to a postal survey may reflect a high level of functioning, organisation and insight into memory problems. The invitation in the survey for caregivers to help participants to respond may have tempered selection bias by allowing carers to scaffold the cognition required for survey completion for participants who may otherwise have failed to complete and return the survey. Furthermore, although the PRMQ data are difficult to interpret because of the issues with insight described above, it does provide some evidence that this sample is representative of people with increased memory difficulty after mild to moderate ABI or dementia.

3.4.7 Future research

Future studies might benefit from asking about extra technologies that were not included in this survey, for example day/date clocks for orientation or smartwatches as an orientation or memory support. It might also be interesting to survey caregivers separately to investigate whether there is a difference between carer and self-report of memory aid use. Mobile phones were one of the most commonly used memory aid technologies and they have many potential uses for cognition. While the survey responses indicated that phones (and all technology) were mostly used to aid prospective memory, future work could investigate in greater detail how people are using mobile phones to support memory.

Future work could continue to explore the barriers which prevent the use of currently available assistive technology. The barriers to use questionnaire used in this study needed to be brief in order to fit into a postal survey. It was created with close reference to the recent literature investigating attitudes towards assistive technology. However, other barriers to assistive technology were only briefly touched upon or were not included in the survey. For example Wessels *et al.* (2003) provided a number of factors related to non-use of provided assistive technology including the user's social circle of support, provided instruction and training, follow-up services, acceptance of disability and the expectations of oneself and others during rehabilitation. The Universal Theory of Acceptance and Use of Technology (Venkatesh, Morris, Davis and Davis, 2003) includes items which predict the use of technology such as user perceptions of the performance of the technology, and the amount of effort it will take to use it successfully. These are difficult issues to explore using a survey study which investigated use of all types of assistive technology for memory. Chapter three aims to focus on these kinds of issues by using a qualitative approach to focus on one type of technology, namely reminding using a smartphone.

3.4.8 Rehabilitation

One potentially important predictor of memory aid use that was not investigated in this study was level of neuropsychological rehabilitation each participant received. Evans *et al.* (2003) looked at the influence that acute inpatient and post-acute specialist rehabilitation had on memory aid use. No association was found between memory aid use and rehabilitation received. It was concluded that rehabilitation was either ineffective in teaching people to use aids or it was not encouraging the use of aids. While the recruitment method of the present study guaranteed that all participants had received some rehabilitation or input either through the NHS or Headway, further details about rehabilitation were not investigated in this study because of the limitations of the survey design. It was decided that questions about rehabilitation services would be difficult for people with ABI to accurately report. There were also concerns that the survey should not be too long as this would lower the response rate. Future studies could investigate the impact that rehabilitation currently has on use of technological and non-technological memory aids.

3.4.9 Design

This study found a large increase in use of technological memory aids amongst people with ABI compared to previous research. However, in the sample as a whole, 23.5% did not report using any technological memory aid and 59% used two or fewer pieces of technology. Few people with dementia used technology for memory, although the majority used non-technological memory aids and strategies. Therefore there is great potential to increase the use of technology amongst people with both ABI and dementia. While we accept the possibility that more technological memory aid use may not equate to better functioning in everyday life (and that using one or two memory aids effectively and often may be better for some people), the evidence suggests that use of memory aid technology in general can be an effective intervention for compensating for memory difficulties (Chapter two; Gillespie, Best and O'Neill, 2012). Designing technology that is appropriate for people with cognitive impairment is one way in which to improve uptake and effectiveness of memory aid technology, and future research could investigate how different designs influence people's perception and use of technology. The participants in the current study were using more non-tech aids and strategies than technology. More appropriate design and improved accessibility of technology may be necessary for it to become as prevalent as pencil and paper methods. Chapter five goes into detail investigating the design of reminding software to improve its accessibility for people with acquired brain injury.

3.5 Conclusion

This study has highlighted a significant increase in use of reminding technology by people with ABI in the last ten years, showing that alarms, texting and mobile phone reminding are the most commonly used technologies. It was also clear that participants with ABI who completed this study used more of all types of memory aids than the Evans et al. (2003) study. This may have been because of a general increase over time in memory aid uptake for people with ABI, although it could also reflect differences between the two cohorts. People with dementia in the current study used a similar amount of technology to that of people with ABI in the Evans *et al.* (2003) paper. Technological memory aid use was best predicted by age (ABI group only), pre-morbid technological memory aid use (both groups) and amount of non-technological strategies and aids used (both groups). These factors explained a large amount of the variance in technological memory aid use. The results of the barriers to use questionnaire highlighted that cognition, beliefs about memory and personal preferences are particularly important issues that prevent the uptake and continued use of technology for both groups. While methodological limitations must be considered, the results of this study give some important insights into which memory aids and strategies people with ABI are using, who is making good use of them, and what factors help and hinder use.

3.6 Appendix

3.6.1 Non-technological reminders - instructions

Below is a list of memory aids, devices and strategies that are sometimes used for remembering things such as birthdays, doctor's appointments, names or everyday tasks such as shopping.

For each one, please indicate;

1. Tick a box to indicate if you used the memory aid before your brain injury.
2. Tick a box to indicate if you use the memory aid now.
3. Tick one box to indicate how often you use it (monthly, weekly or daily).
4. Tick one box to indicate how useful the aid or strategy is for you.

First we want to know about simple pencil and paper or verbal reminders which you use:

items

Asking others to remind you in person

A diary to help you remember things coming up in future (e.g. appointments or things to do)

A diary/journal to help you remember what you have done

Wall calendars

Whiteboard or wall chart

Making a list of things to do on a piece of paper (e.g. a things to do list or a shopping list)

Making notes of what you need to remember in a notebook.

Post-it notes

Technological reminders - instructions

Next, tell us about any technology (e.g. a mobile phone or computer) which you use to

remind yourself about things. For example, do you use technology to help you

remember to go to appointments, to remember social events such as birthdays, or to

help you perform everyday tasks such as shopping, cooking or cleaning?

Please only tick the boxes if you have used or currently use this technology to help

you remember things – many people will use a mobile phone as a phone but only tick

the box if you use it to help you remember things.

Items

Mobile phone to remind you

Laptop computer or tablet computer (e.g. iPad) to remind you

Desktop computer to remind you

Television (e.g. automatic prompting about or recording of favourite shows)

Using a camera to take pictures of a holiday or special occasion to help you remember it afterwards.*

Using a digital camera to take pictures of everyday events to remind you of what you have done.

A pager to remind you

Electronic personal organiser

Dictaphone/ voice recorder to remind you

Alarm clock to wake up*

Alarm clock/ timer to remind you to do something

An internet based calendar to remind you (such as Google calendar)

Asking someone to send you a text message you to remind you about something

A watch with a date/timer to remind you

If you use any of these technological memory aids, what do you use them to remind you about?

*These items were not included in analysis as the function of reminding was not prompted. These items were added to prevent people from reporting that they used camera or alarm to remind them, when they really only used them to take pictures on holiday or wake up.

3.6.2 Strategies – instructions

Finally, tell us about other tricks, habits or strategies do you use to remind yourself of things

Items:

Mental retracing of your steps - to find misplaced items (e.g. 'where did I last see the keys?'…)

Repetitive practice- repeating tasks until they become a habit

Leaving objects in places you will notice them to remind you to use them or take them with you.

Leaving objects in the same place so you know where to find them

Rhymes or phrases to remember important information (e.g. 'remember remember the 5th of November')

Changing passwords or PIN numbers to combinations you use regularly

Writing on your hand (or elsewhere)

Alphabetic searching- Considering if a name or object begins with the letter A, B , C.....etc.

Please give details here of any other memory aids or strategies which you use that were not in the checklist and tell us what you use them to help you remember.

3.6.3 Barriers to ATC use questionnaire

STATEMENTS	DO YOU AGREE?
I can easily access new technology (practical)	strongly disagree 1 2 3 4 5 ←→ strongly agree
I would be able to learn how to use a new piece of technology (cognitive)	strongly disagree 1 2 3 4 5 ←→ strongly agree
Technology just isn't for me (personal preference)	strongly disagree 1 2 3 4 5 ←→ strongly agree
I find it difficult to see so it would be hard for me to see a computer screen unless it was very clear (physical)	strongly disagree 1 2 3 4 5 ←→ strongly agree
Technology is unsafe (ethical)	strongly disagree 1 2 3 4 5 ←→ strongly agree

If people saw me using technology they would know I had a memory problem and think less of me (emotional)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I would enjoy being able to show off a new piece of technology which I could use (emotional)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I don’t think I could understand new technology (cognitive)	1 2 3 4 5 strongly disagree ⟷ strongly agree
If I had trouble using technology then people might think I was stupid (emotional)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I prefer writing things down (personal preferences)	1 2 3 4 5 strongly disagree ⟷ strongly agree

After I forgot something important, I felt like I should use technology to help me remember (beliefs about memory)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I find it difficult to use technology because my hands shake (physical)	1 2 3 4 5 strongly disagree ⟷ strongly agree
Using technology would make me feel like I had a problem (reverse effects)	1 2 3 4 5 strongly disagree ⟷ strongly agree
Having a phone which send me reminders all the time would invade my privacy (ethical)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I have always kept up to date with new technology (personal preferences)	1 2 3 4 5 strongly disagree ⟷ strongly agree
It feels like a step forward if I remember things myself without relying on technology to remind me (beliefs about memory)	1 2 3 4 5

	strongly disagree ⟷ strongly agree
I have difficulty hearing, so it would be difficult for me to be reminded by an alarm sound (physical)	1 2 3 4 5 strongly disagree ⟷ strongly agree

If I tried to use technology and failed I would feel like I couldn't do anything (reverse effects)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I always feel in control of technology (ethical)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I know someone who would show me how to use technology (practical)	1 2 3 4 5 strongly disagree ⟷ strongly agree
My memory would fade if I just relied on technology (beliefs about memory)	1 2 3 4 5 strongly disagree ⟷ strongly agree

I didn't know technology could be used in this way (practical)	1 2 3 4 5 strongly disagree ⟷ strongly agree
I find new technology to be easy to use (cognitive)	1 2 3 4 5 strongly disagree ⟷ strongly agree
The technology would annoy me (reverse effects)	1 2 3 4 5 strongly disagree ⟷ strongly agree

Figure 3-7. Barriers to ATC use questionnaire

4 Chapter Four - Investigating the Barriers to Successful Use of Assistive Technology

4.1 Introduction

In chapter two, evidence of the efficacy of prompting and micro-prompting technology was synthesised from the existing literature. Good evidence was found for the efficacy of prompting technology compared to practice as usual or the use of pencil and paper memory aids. In chapter three, a survey was conducted with people with ABI (N=81) and dementia (N=98) and showed that prompting technology is currently used less than non-technological memory aids such as wall-calendars, lists and diaries in these populations and that use of technology was predicted by being younger (ABI group only), frequent use of non-technological aids currently and frequent use of technological aids prior to injury or onset of dementia. This suggests that an increase in the use of prompting technology could potentially benefit people with memory impairment and that, as of yet, technology use is not as prevalent as it could be amongst these groups of people. It is important therefore to understand more fully the factors that directly or indirectly predict and influence use, and non-use, of assistive technologies. Both the ABI and dementia cohorts from the study in chapter two indicated that the most important issues included in the 'barriers to use' questionnaire were beliefs about memory, difficulties with cognition and personal preferences. Chapter three further investigates these perceived and actual barriers to the uptake and successful use of memory aid technology.

At this point the thesis focuses on smartphone prompting technology used by people with memory impairments after an acquired brain injury. A focus group study was conducted involving people with ABI and their carers. The methods and results are reported in this chapter. This provides a thematic analysis of the barriers to use of prompting software on a smartphone. The aim was to gain a better understanding of the issues that prevent the uptake and continued use of smartphone reminding ATC with this population and use this knowledge to develop and trial prototype reminder software that would be perceived and rated as more usable and useful for people with cognitive and memory difficulties after ABI (see Chapters 4, 5 and 6).

4.1.1 ABI User Group

The majority of studies reported in the systematic review (chapter 2) used prompting technology with ABI populations and this may reflect the fact that prompting technology is particularly suited to helping compensate for the difficulties which often occur after ABI. This is because prospective memory or the memory processes required to perform an intention at a particular time or after a particular event, are often impaired after ABI (Evans, 2003). People may also experience disorganized thinking, problems with planning, difficulties with attention, poor self-monitoring and difficulty switching between or initiating tasks (Gillespie, Best & O'Neill, 2012). These impairments can make it difficult for people with ABI to perform everyday tasks such as shopping, personal care or cooking, or healthcare tasks such as remembering appointments, treatment plans and medication. Furthermore, health problems that directly or indirectly result from the ABI such as physical disabilities, sensory/motor impairments and chronic illnesses can increase the number of health-based prospective memory demands. For people living with these difficulties, relevant time based alerts or prompts are likely to be particularly effective.

The encouraging findings in chapter two, the systematic review of studies testing memory aid technologies as rehabilitation tools, are an indication of the potential for memory aid technology. However if people do not feel willing or able to use this technology then this potential will not be reached. The Human Computer Interaction literature is concerned with the usability of computing technology and user experiences as well as the accessibility of technology for everybody in society (Shneiderman, 2000). However, in contrast with the neuropsychology literature, there is a paucity of research from human computer interaction (HCI) literature investigating assistive technology use by people with ABI. For example, in a systematic review by Coursaris and Kim (2011) investigating the literature on mobile phone usability, no studies were reported with people with ABI. Therefore there is a disparity between the potential for memory aid technology as a clinical rehabilitation intervention, and the research developing the usability and accessibility of the design of the technology. These are the issues which motivated the focus of the rest of the work in this thesis which investigates the use of assistive technology by people with ABI in clinical and community settings from a usability and user experience perspective.

4.1.2 Smartphone Based Prompting Technology

One of the overarching aims of this thesis was to develop and test memory aid technologies designed after gaining feedback from those who would use them. To do this it was necessary to choose which function this technology would have and which form factor it would take. The systematic review investigated two functions of memory aid technology; prompting devices which remind the user about a future intention and micro-prompting devices which guide the user through everyday tasks. Technology with a prompting function was chosen as the focus of the rest of this thesis for the following reasons:

- In the systematic review in chapter two there was convincing evidence for the efficacy of prompting technologies
- In contrast to bespoke micro-prompting devices, many prompting technologies are off-the-shelf or are currently in production and available to buy (e.g. the NeuroPage service, PC calendar software and reminders on mobile feature phones and smartphones).
- Chapter three showed that participants with ABI and dementia were mostly using memory aid technology to prompt about a future intention.

Smartphones were chosen as the devices upon which prompting would be investigated for the following reasons:

- In the survey study in chapter three, mobile phones were the most commonly used technology by people with ABI
- There are several relevant prompting applications (apps) freely available on smartphones.
- The use of smartphone apps as an assistive technology intervention is appealing because of the ubiquity of smartphones, which may prevent users feeling conspicuous or stigmatised when using technology. This was a concern highlighted in the social / emotional barrier which was

described by studies investigating barriers to assistive technology reviewed in chapter three.

- Apps can be developed quickly and easily for smartphones and this allows for the development of app design to help overcome some of the barriers to uptake and successful use.

Smartphone reminder apps

Reminding apps are often designed as digital calendars or diaries into which reminders or alerts can be entered when adding events. Smartphone reminding software has been shown to be effective in helping people to compensate for prospective memory difficulties (Svoboda, Richards, Leach & Mertens, 2012; de Joode, van Heugten, Verhey & van Boxtel, 2013). The barriers which prevent the use of assistive technology reported in chapter three are likely to be relevant for smartphone reminders. Additionally, it is of interest to investigate any issues specific to smartphone technology that could prevent its successful use in rehabilitation. While there has been growing interest generally in end-user's attitudes towards assistive technology (Dawe, 2006; Razak, Razak, Wan Adnan & Ahmad, 2013; Robinson, Brittain, Lindsay, Jackson & Olivier, 2009), issues impacting usability of smartphone software have rarely been investigated by the HCI community with populations with cognitive impairments (Coursaris et al., 2011). Understanding both user perceptions and attitudes towards this technology as well as the actual usability issues that impact initial use is crucial in order to investigate uptake in a way that can inform the design of reminder software for people with ABI.

The studies that do exist have tended to focus on the efficacy of apps as a memory compensation device for this group, for example, asking whether or not the use of smartphone-based reminders after a training period is more effective for improving performance on everyday memory tasks than a non-technological reminder or practice as usual. Svoboda *et al.* (2012) gave people with ABI 6 weeks training for a smartphone calendar application. De Joode and colleagues (2013) tested the efficacy of a smartphone app created for people with ABI after up to 16 hours of training. These studies both demonstrated an improvement in memory performance with the mobile app compared to a pencil and paper equivalent. Reminding software that is commonly available on the smartphone platform has also been investigated. McDonald *et al.* (2011) tested the efficacy of Google Calendar software in compensating for memory impairments resulting from acquired brain injury. The system tested included using a personal computer to plan tasks and create reminders that linked to a mobile phone on which reminders were received. It was found that using the software significantly improved memory performance for activities of daily living for people with acquired brain injury compared to baseline and paper diary use.

Despite the evidence for its efficacy, the actual uptake of assistive technology by people with ABI is generally very low (Evans, Wilson, Needham & Brentnall, 2003; Gillespie et al., 2012; de Joode, Proot, Slegers, van Heugten, Verhey & van Boxtel, 2012; Svoboda et al., 2012). One reason for this could be poor perceived utility, usability and acceptability. However, in the studies described above, subjective usability was rated highly. For example, in the Google Calendar study by McDonald and colleagues, the majority of participants (9 out of 12) preferred it to the paper diary. Continued use of the technology was also generally high. Svoboda and colleagues (2015) found that the participants continued to use the mobile phone as a reminder up to a year after the study was completed (Svoboda, Richards, Yao & Leach, 2015). These findings suggest that people did find smartphones and reminding software useable after they had engaged with it in the first place, and in some cases after training. People's perception of reminding technology prior to use was not investigated in these studies. The positive usability findings in these studies may have been influenced by the amount and quality of training and the encouragement from experimenters throughout the study and there may have also been a selection bias towards recruiting participants who were keen to use technology for memory compensation. Unless the issues that impact perceived usability and acceptance of technology prior to use are investigated further, it will be difficult to tell if smartphone reminding software would be used spontaneously by people with ABI, if they would find it acceptable, or continue to use it without substantial training.

4.1.3 ABI in HCI

Smartphone reminders have been investigated for people with ABI in efficacy studies which have not investigated usability (de Joode et al., 2013; Svoboda et al., 2012). Issues impacting usability for people with ABI have been investigated for non-smartphone technologies (McDonald et al., 2011; Sutcliffe, Fickas, Ehlhardt & Laurie, 2003) and smartphone reminder usability has been investigated in user groups with neurological difficulties from aetiologies different from ABI (Dawe, 2006; Robinson et al., 2009). However, no study has investigated the issues that impact usability of smartphone reminders for people with ABI. Furthermore people with ABI have rarely been included in mobile usability research. Out of 100 studies reviewed by Coursaris *et al.* (2011) in their meta-analysis of mobile phone usability studies between 2000 and 2010, only two investigated usability for people with a disability and only one investigated the effect of memory loss. This was a study investigating personal digital assistant use by seniors with mild cognitive impairment, but it did not investigate reminding software (Dahlberg & Oorni, 2007). People with ABI often have cognitive impairments which are likely to make it difficult for them to use mobile apps which were designed for the general population. Due to the lack of research investigating mobile usability for this group, it is difficult to know which aspects of mobile design should be investigated. A thematic analysis of the issues which impact smartphone reminder app usability for this group is a contribution to the literature which can provide the building blocks for future mobile usability studies for people with ABI.

4.1.4 'Total Circuits' in Assistive Technology

The issues that could influence the uptake of assistive technologies such as smartphone apps for memory compensation are diverse because they include both issues of *perceived* usability and attitudes about technology prior to uptake and *actual* usability and attitudes during initial use. These issues often interact as perceptions prior to using technology can influence actual use, and experiences with technology create attitudes towards technology.

Understanding the full experience of a person using technology is important and this is highlighted in the 'total circuits' model described by Bateson (1972). He said, 'if you want to explain or understand anything in human behaviour, you are always dealing with total circuits.' (Bateson 1972, pp. 465). The example given is a blind man using a stick to navigate. If you wish to understand his navigation then you need to understand the role of the street, the man and the stick in a circuit. You have to consider all of these factors at each moment, their interaction and the way they change over time. For example, if the environment changes to a street the man is less familiar with then he may use the stick more often, or in a different way, to sense obstacles. O'Neill and Gillespie (2014) suggested that this applies to assistive technology for cognition and to prompting technology; you need to investigate all aspects of the 'use circuit' of a device. For example, if you only look at a prompting technology's effectiveness after a relevant and timely notification then you only understand a small part of the circuit. It is important to examine other aspects, for example, how that notification was set in the first place?, who set it?, what the users experience of setting the notification was like?, what social factors influence the setting of a reminder?, what influences when and how people want to receive reminders?

4.1.5 Study Aim

This chapter aims to develop an understanding of the barriers to smartphone reminder app use. This was done by investigating uptake and usability within the context of the feedback loop between the user, their social and physical environment, and the technology. Focus group and co-design sessions were conducted to explore the key issues that impact the uptake and perceived usability of smartphone reminder apps for people with ABI. This includes qualitatively capturing and mapping both *expectations and perceptions* that people have about the technology as well as *actual usability difficulties* experienced when introduced to a currently available app (Google Calendar).

4.2 Method

4.2.1 Participants

This study involved three focus groups (N=12, 4 males) with people with ABI and caregivers or clinical psychologists working with people with ABI. Two focus groups involved people with a mild or moderate ABI (diagnosis was either self-reported or communicated by a senior charity worker from Headway, who was involved in participant recruitment) and self-reported memory difficulties and one focus group involved two family caregivers of people with mild or moderate ABI with self-reported memory difficulties and a clinical psychologist who works in a community treatment centre for brain injury (see Table 4.1 for details). Participants were all over 18 (mean age = 47, range 36 – 68) and were able to speak fluent English. Only people able to provide informed consent without severe physical or sensory disability were included. People with ABI can suffer from a wide spectrum of difficulties. This is a group who may lack insight into their own memory difficulties and for whom reminder technology may need to be pre-programmed by a third party. Therefore it is also important to get the views of people who care for or who provide rehabilitation for people with ABI. While ages of participants did vary, the only participant over 65 (a regularly used cut-off for defining 'older user' in HCI studies (McGee-Lennon, Wolters & Brewster, 2011) was in the carer group and was talking about her nephew's experience using technology (in his 30's). All participants with ABI were adults between 38 and 60 and none described themselves as experts with technology. Therefore this group is relatively homogenous in age, tech ability and ABI severity.

This study received NHS research ethics committee approval on 14.02.14 (REC reference: 14/WS/0038).

Table 4-1. Details about participant's aetiology (or caregiver's background) and tech literacy.

Focus group	Participant Details (initials)	Self-reported Tech Literacy (initials)
1) 5 participants with ABI **(2 female)**	All mild / moderate ABI - illness (NS, SW, LK), unspecified (RW, PD)	Novice (LK, RW, PD), Tech literate (NS, SW) (own and use smartphones and tablets)
2) 3 Carers of people with ABI **(3 female)**	All carers of people with ABI - family caregivers (CT, NM), professional clinician (NG)	Novice (NM), Tech literate (CT, NG) (own and use smartphones, PCs and familiar with apps and reminding software)
3) 4 people with ABI **(3 female)**	All mild / moderate ABI - tumour (DB), fall (AB), cardiovascular accident (CH), unspecified (BS).	Novice (CH, BS), Novice but some experience (DB, AB) with non-smartphone mobile reminders.

4.2.2 Focus group and 'keep lose change' session structure

Focus group methodology was used because we wanted to build up a rich qualitative dataset. The structure of the study session was the same for all three focus groups. The sessions lasted from two to three hours and were audio recorded. Two experimenters were present during the first focus group in order to establish a sound approach and methodology (the second researcher noted timings etc that could be used in further sessions) and one was present (the author) during the others. The focus group comprised of: 1) A focus group discussion covering; A) A discussion of experiences of memory impairments, B) A discussion of perceptions of mobile phone based memory aids, and C) A demonstration of, and chance to try out, a smartphone reminder app (Google Calendar app) followed by a discussion about this app; and 2) An interactive user-centred design session ('*keep lose change*') using screenshots of Google Calendar.

1. A) The first topic of the focus groups was experiences with memory impairment. This 15 minute discussion was designed to set the context of

the session to be about memory difficulties so that people did not talk about technology use for things other than reminding during the remainder of the session. The carers group was asked to talk about the difficulties experienced by those for whom they care.

1. B) The discussion then moved on to mobile technology participants had used to help their memory and any issues they had that would prevent initial or prolonged use. This discussion lasted 30 minutes and focused on the psychological, practical, emotional and social barriers that prevent uptake of mobile phone memory aid.
1. C) Finally the discussion turned to the issues that impact the perceived usefulness and usability of a smartphone reminder app. This involved an introduction to Google Calendar and the Samsung Galaxy S3 smartphone followed by a walk-through demonstration of Google Calendar on a large screen (via a digital projector). The researcher demonstrated the app, paused regularly to ask questions and encouraged feedback and discussion. Three Samsung Galaxy S3s with Google Calendar installed were also available for participants to try out during this session. Observations by the experimenters during participants' use of the app were added to the transcripts for this session. It was hoped that introducing an existing standard reminding app to participants during the focus group sessions would initiate general conversation about app and mobile phone usability and design. Having an example app also made the discussion more concrete, as abstract thinking (for example, imagining what an ideal reminding app should look like or what you could use it for) can be difficult for people with ABI (Evans, 2003; Baldwin, Powell & Lorenc, 2011). Google Calendar was chosen because it is a common app designed for the general population.
2. Following the demonstration and discussion about Google Calendar there was a user-centred design session called *keep, lose, change* (KLC) (McGee-Lennon et al., 2011; Mcgee-Lennon, Smeaton & Brewster, 2012). This took approximately 30 minutes. A4 print-outs of each screenshot of Google Calendar were presented (Figure 1) and participants were asked 'what design features, functions and content would you keep, which would you

lose and which would you change if you were redesigning this app?' They were provided with marker pens and green (for *keep* comments), red (for *lose* comments) and orange (for *change* comments) sticky notes on which they were asked to write feedback (attitudes, observations and opinions) and attach them to the relevant screenshot printouts. The purpose of this session was to 'live' code feedback in a way that could lead us closer to specific design recommendations for reminding apps for this user group. Having the screenshots facilitated discussion and made concrete some of the app features that might otherwise have been difficult for people to mentally picture. It also served as a useful way to include people who were not able to contribute much during the discussions due to communication difficulties.

While only people with adequate communication abilities were asked to participate in the study, there were people with comprehension difficulties, problems with speech, difficulty hearing or cognitive difficulties as a consequence of their head injury that made communication in a group setting difficult. These participants were able to give extra feedback during the KLC session as the experimenter could talk to them individually as the other participants completed the task. The materials included in the KLC sessions are shown in Figure 4.1.

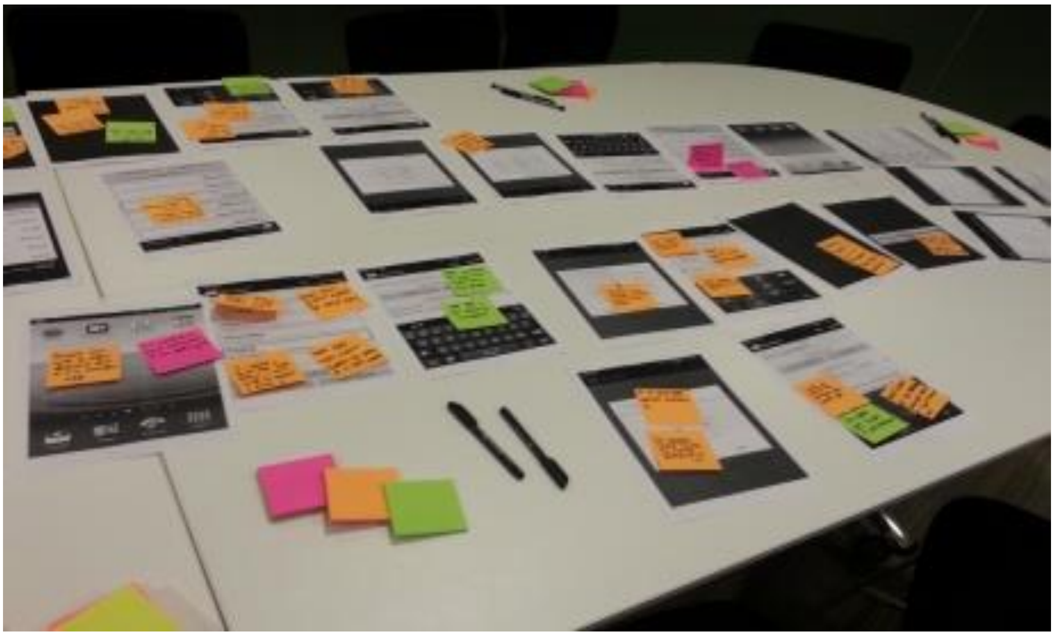


Figure 4-1. Materials given to participants for the keep lose change session.

4.2.3 Data Collection and Analysis

Figure 4.2 shows a flowchart of the processes involved in data collection and analysis.

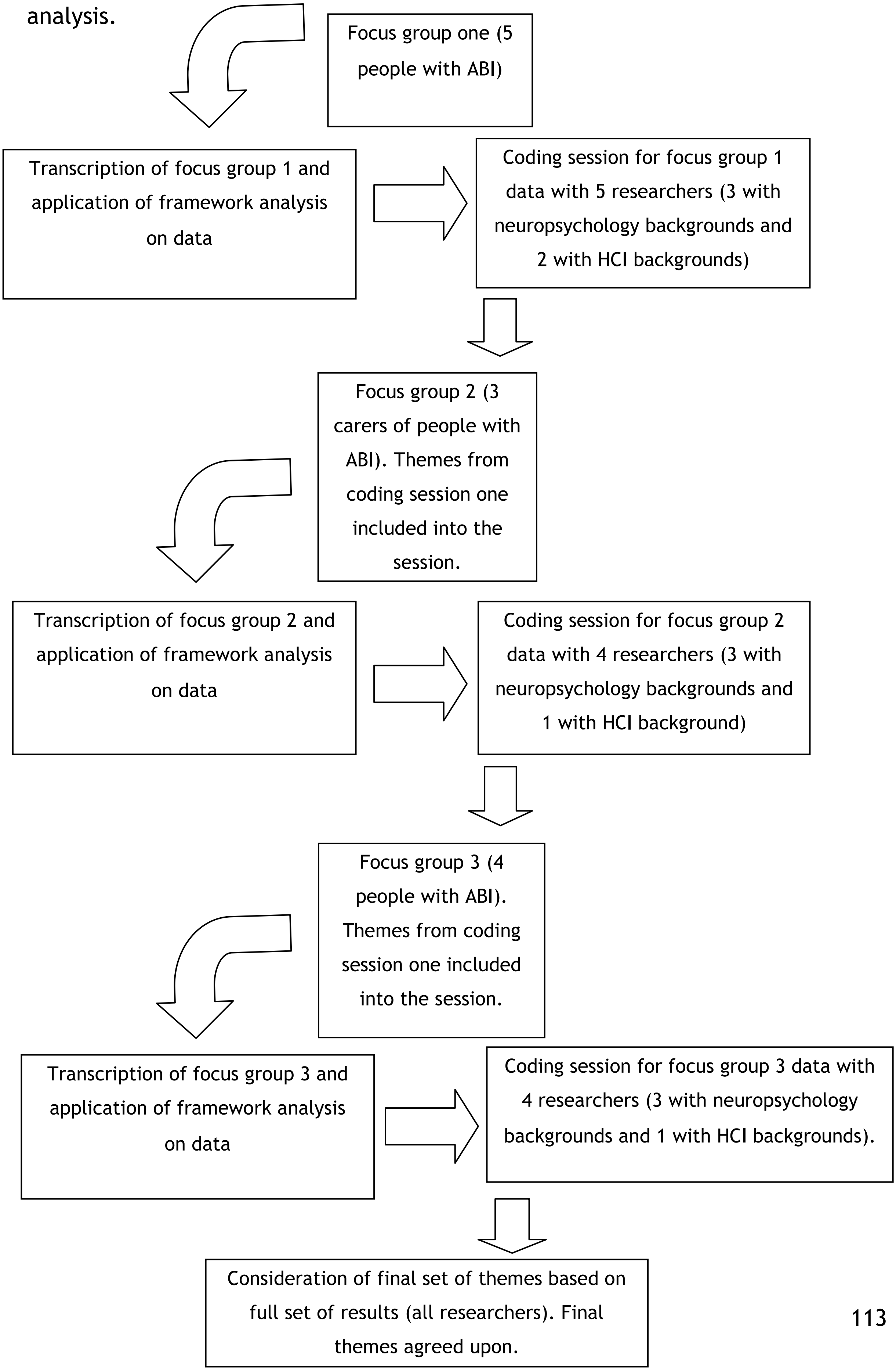


Figure 4-2. A flowchart of the processes involved in data collection and analysisFive experimenters who had experience with working with people with ABI and / or experience in the field of assistive technology and HCI took part in the qualitative analysis of all of the focus group and KLC data. Each focus group was transcribed verbatim and the main author organized the data into comments, quotes, interactions, observations or written feedback. The KLC feedback was analysed along with the discussion transcripts and observations. The data were coded using thematic analysis following a framework approach (Ritchie, Lewis, Nicholls & Ormston, 2013).

4.2.4 Framework Approach

The framework approach was followed because it allowed the large quantity of transcript and KLC data to be reduced and organised prior to thematic analysis. The framework approach used was outlined by Rabiee (2004), and recommends eight key steps during data interpretation (words, context, internal consistency, frequency, intensity of comments, specificity of responses, extensiveness and big picture), was followed as closely as possible. This framework approach was ideal because it was developed to be used in health based focus group analyses. Data were then printed out onto sticky notes and colour coordinated according to the focus group topic or question the participants were addressing during their comments (e.g. blue for during an initial discussion about memory difficulties or orange for during the discussion of the Google Calendar app). This allowed the experimenters to keep the context of the comments in mind while organizing the data into themes.

4.2.5 Thematic Analysis

In the thematic analysis, the data were coded with close reference to the verbatim transcript of the focus group in order to give due consideration to the intended meanings of the words used (e.g. where there might be double meanings or local expressions) and the intensity of the comments made (e.g. emotional weight of comments or positive and negative terms used). The frequency and level of depth of the comments were noted and participant’s internal consistency was kept in mind (especially when talking about attitudes towards technology before and after being shown Google Calendar). It is recommended that coding be performed while data collection is taking place, with the thematic analysis feeding back into future focus groups. Finally it is recommended that time is taken between coding sessions for experimenters to reflect on the larger issues which emerge from an accumulation of evidence (the big picture). These two recommendations were followed by having three separate focus groups over several weeks with four group coding sessions (one coding session between focus groups 1 and 2, one between focus groups 2 and 3 and two final coding sessions after all the data had been collected). Coding sessions involved five contributors, including the thesis author, collaboratively interpreting the data. At least four of the coders were involved in each coding session. Two had expertise in human computer interaction research including assistive technology and two had expertise in neuropsychological rehabilitation including technology based interventions. Where the discrepancy of opinion could not be resolved after a debate a consensus was reached to decide which theme the data should be coded to. Themes were named by the experimenters to define and summarize the ideas expressed by participants as accurately as possible. Theme and sub-theme names were based on common terms in the HCI (e.g. ‘accessibility’ & ‘acceptability’) and neuropsychological rehabilitation (e.g. ‘insight’ & ‘executive attention’) literatures. During this coding process the six overarching themes outlined in figure 4.2 emerged.

4.3 Results

4.3.1 Themes

Figure 4.2 shows a visual representation of the themes that were established by coding the focus group data. Two of the themes, *Social Acceptability* and *Perceived Need,* relate to perceived usability that would influence whether or not someone would decide to use a smartphone reminder. Two themes, *Cognitive Accessibility* and *Sensory / Motor Accessibility*, relate to actual usability of the software once the device is in use. Finally, two of the themes, *Desired Content and Functions* and *Experience and Expectation*, could influence both perceived and actual usability. For example, a lack of experience with technology may put people off using it and may also hinder their use of technology if they do decide to try it out. Similarly, while having desired functionality and content will clearly influence the usefulness of an application, the perception that technology has functionality that will be useful is also likely to encourage uptake in the first place. The six themes are discussed in more detail below.

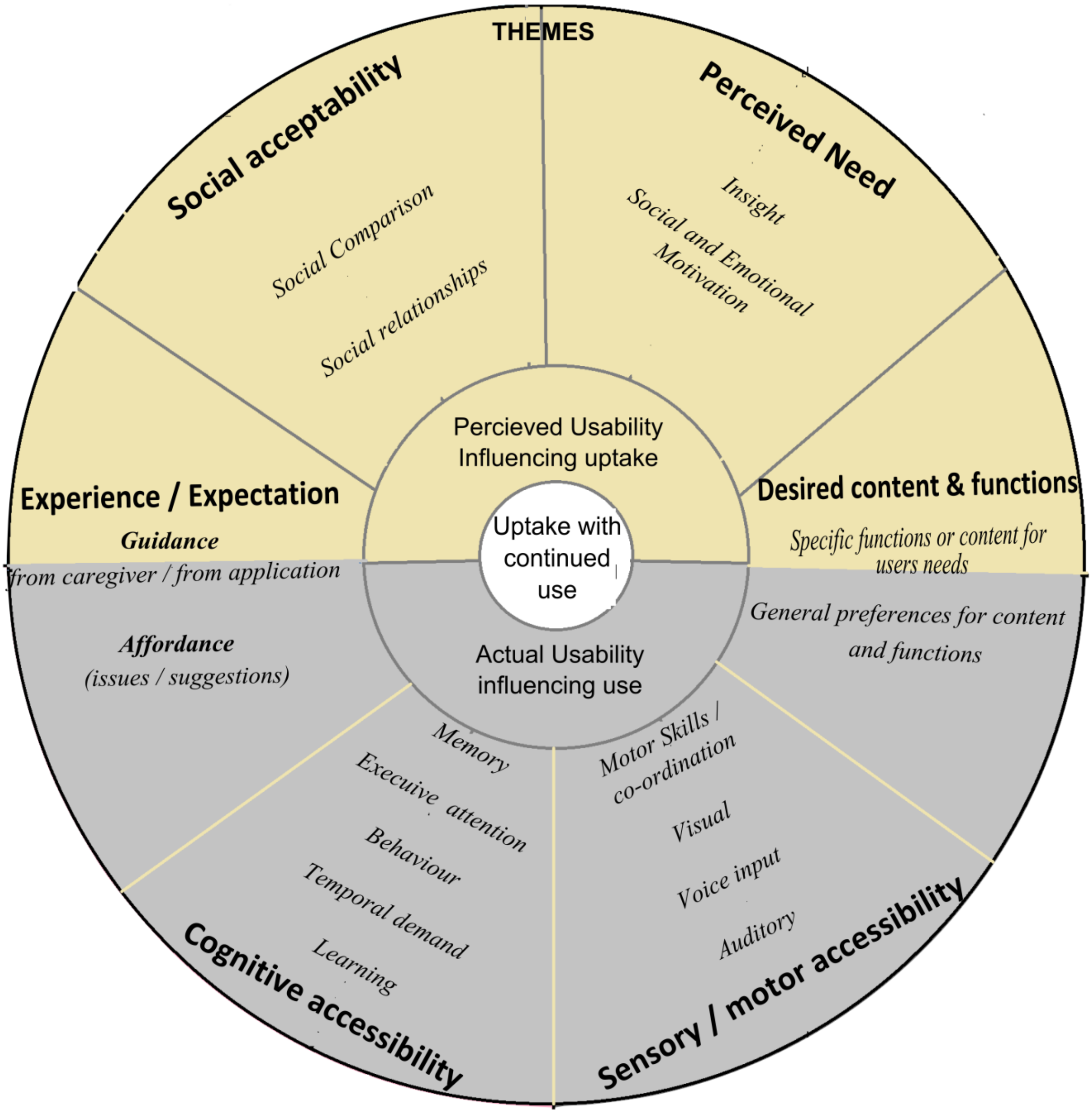


Figure 4-3. Themes established from participants' feedback with number of comments split into participant group.

4.3.2 Perceived Need

Before they will use Smartphone reminders or any other type of assistive technology for memory, people with ABI have to understand the need for them and be motivated to use them. Sub-themes for this theme were *insight into memory difficulties* and *motivation to use technology*.

4.3.2.1 Insight

Participant AB expressed how her difficulties with insight prevent her from using appropriate memory compensation when she said, "I also forget I don't remember. And then I remember that I forget. It's a really complicated thing to deal with". This lady loses insight into her difficulties from time to time, and so forgets to set reminders that she will need. Participant NS mentioned a similar issue when he said, "It's when these things happen that you realise hang on I've got to do something else and I forget I don't remember." This issue was also mentioned by NM when discussing her family member with ABI, "It's just sometimes though he doesn't want to use it because he thinks he'll remember". A related difficulty reported by some participants with ABI is overestimating their ability to remember the content of a reminder even when they do enter a reminder. If this happens then they may not remember to to add all of the necessary detail to allow them to comprehend the reminder effectively at a later time. For example DB said, "I put things into my diary with just initials and I'm like, I know at time what I'm doing and I know what it's all about…" Later in the focus group she explained that her parents help with this, "My parents are good with that they say write you are meeting so and so at such a time and they say it as if they're writing it with me. Otherwise I won't know who it is I'm meeting – to get all the details right." These comments highlight the important issue of insight when people with ABI are setting reminders and this is an issue related to the memory and cognitive difficulties which reminding interventions are designed to compensate for.

4.3.2.2 Motivation - emotional

A separate but related theme that arose only from the carer's focus group was the motivation to use technology. The impact of negative and positive emotions associated with using reminder technology was mentioned by family caregiver NM, "Sometimes it depends on what mood they're in. You have to pick your time". Different negative emotional terms mentioned included frustration and anger about memory difficulties and fear of technology. It was also stated that people were more likely to remind themselves of events they were looking forward to than everyday tasks that were more tedious.

4.3.2.3 Motivation - social

Another motivation issue, separate from emotion, was social motivation. It was stated that social comparison can make people feel like they should not have to use reminder technology when their peers are not using it. However, becoming aware of the positive impact that using a reminder can have on their social lives, and seeing other people without a brain injury using reminders effectively, can encourage uptake of technology. This highlights the importance of family caregivers setting an example by using reminders – CT stated when asked about using the Google Calendar reminder, “I think initially we’d be quite happy to use that. I think it would introduce again that curiosity you see where he’d eventually ask – how did you do that? I’d like to do that myself”.

4.3.3 Social Acceptability

4.3.3.1 Social comparison

The *motivation – social* sub-theme of Perceived Need highlights the importance of social influences in the uptake of Smartphone memory compensation and a separate theme arose from the data called Social Acceptability. A sub-theme of this was *social comparison*. While this social comparison can have a negative effect - putting people off using technology because none of their peer group are using it - the majority of the participants’ comments for this sub-theme were positive. As well as mentioning that seeing family members or peers using technology would encourage use, there was also the feeling that technology would be more acceptable for people to use in public than pencil and paper reminders. NG said, “what it may look like in the public domain, which is obviously where technology becomes so discreet – everybody’s banging into everybody because they are flicking through their phones – but I guess that’s quite different from taking out a big bit of paper in the supermarket”.

4.3.3.2 Social relationships

Another sub-theme of Social Acceptability was Smartphone’s impact on social relationships. The majority of the comments were negative, talking about experiences with annoying beeping, loud phone calls or friends being unsociable in public because they were always on their phones. NS summarised that "technology is helpful as long as it doesn't take over and you never have any contact with people" echoing the concerns of many of the participants. On the other hand LK expressed positive views about Smartphone technology's impact on social relationships stating that she thought it could lessen the burden placed on caregivers. She also stated that mobile phones could improve her social communication, "I feel intimidated and uncomfortable when I'm talking to other people. I'd probably find it easier playing about with a phone".

4.3.4 Cognitive and Sensory / Motor Accessibility

Many of the participants' comments were about the accessibility of reminder technology. This could be split into the cognitive and sensory / motor difficulties that impact the use of a smartphone reminder app. Figure 4.3 is a visual representation of the cognitive and sensory motor accessibility themes. The themes were separated into their sub-themes and each quote is represented by a dot. Orange dots are comments from the two ABI focus groups and blue dots are feedback from the carers. Representative and particularly relevant quotes are shown to highlight sub-themes. The diagram shows that some of the participant's quotes could be interpreted as being cognitive or sensory issues.

4.3.5 Desired Content and Functions

As well as suggestions about the design and layout of the app, the focus group participants talked about the content and functionality that they would like from smartphone reminder software. This feedback could be categorized into general preferences for content and functions and specific functions or content for user's needs.

4.3.5.1 General preferences

Some general preferences for reminding technology were expressed. For example AB suggested picking one device to 'focus on' would be better than having many devices as too much technology for different functions could cause 'stress.' CT was unimpressed by the limited nature of currently available apps that she had seen, saying that only, "two… impressed me, the rest were too basic". A few participants discussed events in their lives that would require different types of reminding, for example medication such as antibiotics which need to be taken outside mealtimes and sending cards to relatives living abroad for their birthdays. There was also discussion about the removal of functions which were not deemed necessary, for example SW did not like the Google Calendar function which allows you to add guests to an event and said, “guests – what’s the guests for? I don’t even understand what that is”. However, NS expressed the alternative view and asked for this functionality to be retained as, “it could be useful sometimes”.

4.3.5.2 Specifically requested functions and content

The ability to merge a reminder with notes was a desire that many participants expressed. Having notes to refer to before a Doctor’s appointment or a shopping list after a reminder to go shopping were two examples given by participants. SW summed up the importance of this information storing function when she said, “That memory (holding) thing is important too – it’s the content”. Another desired function was the inclusion of different output modalities. These comments were mostly requests for different reminder modalities, depending on the social environment, task or activity, or personal preferences. For example DB wanted different colours in her calendar and said, “the Doctor would be pink, birthdays green”. In social situations, SW, CH and PD wanted texts or vibration feedback instead of a beep and even a way of communicating with technology which would not require eye contact with the device so that, ‘the information is relayed to you in some other way.’ There was also some discussion of different input modalities, for example voice activated technology, “not even involving physical touch at all”.

Two participants in different focus groups (LK and DB) expressed the importance of involving carers in the process of setting reminders: ‘a double check’ from carers is often vital in helping people organise their day. This sub-theme only comprised of two comments and there were several interesting desired functions that only comprised of one comment. While it is difficult to know if these sub-themes are representative of the group as a whole, they are interesting suggestions which could be incorporated into a reminder app. NS suggested a “diary that… could categorize your appointments in one section and then it would categorize the people who you met during that day”. Another participant asked for more encouraging output or feedback from the device which, “gives you confidence (so) you'll be more confident of doing something the next day". NM suggested a directions or travel advice function to tell people "how are you getting" to an appointment. During the KLC session BS suggested that the, "phone could send reminders automatically" perhaps meaning that the app would suggest events or tasks or send content free reminders without requiring input from the users. Finally SW called for the app to prompt her about a task in a way that did not give her all of the details straight away, so that she could try to remember them herself saying, "you might have something which reminds you initially and then you have to remember all the details (yourself)". An example of this would be an appointment reminder which prompts you about the appointment but gives you a chance to remember where and when it was to take place before giving the rest of the details.

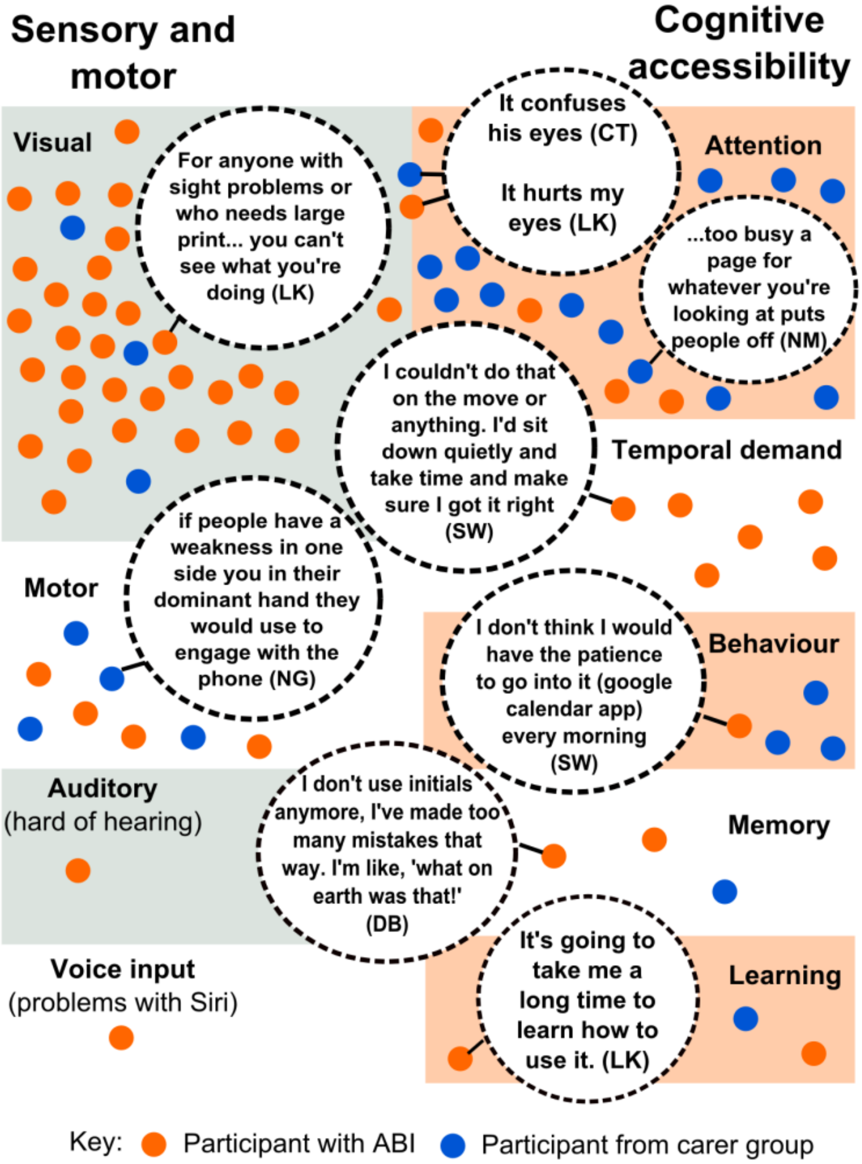


Figure 4-4. Visual representation of all comment organized into cognitive & sensory/motor themes/sub-themes.

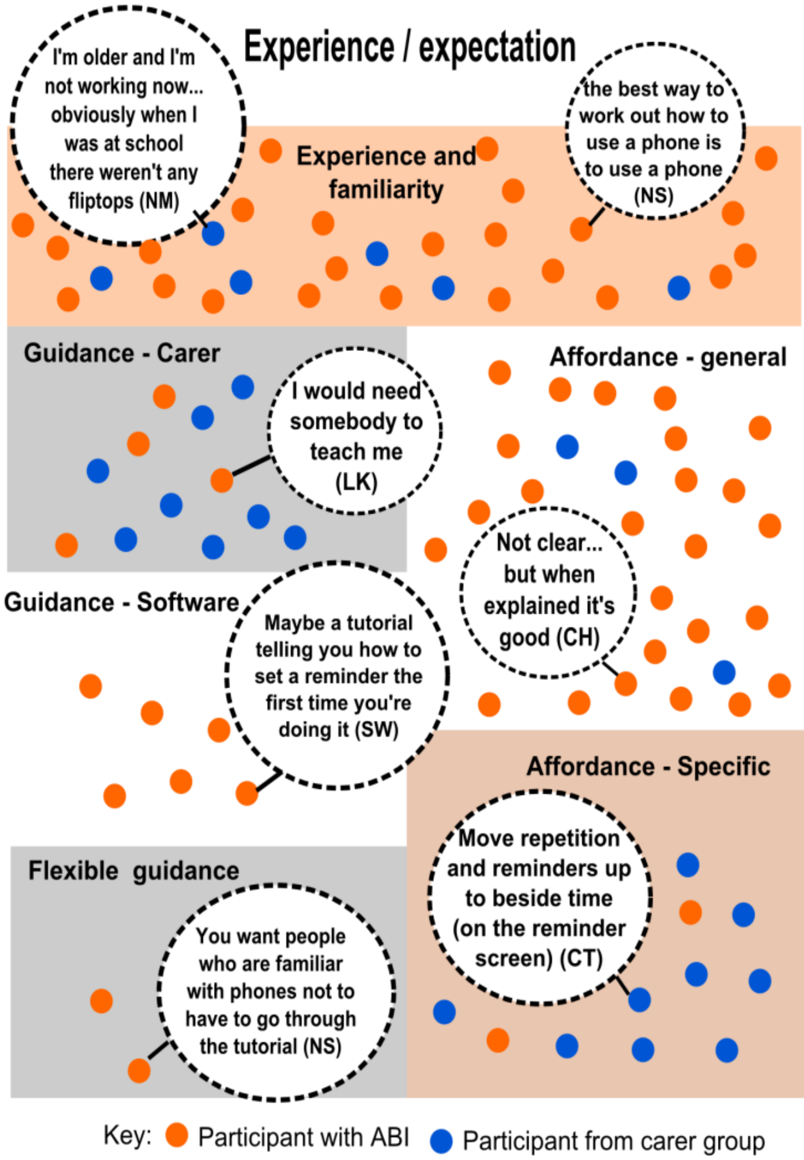


Figure 4-5. Visual representation of the experience / expectation theme.

4.3.6 Experience / Expectation

Experience / expectation was the largest theme comprising the following sub-themes: experience and familiarity, guidance and affordance / learnability. Figure 4.4 is a diagram of the theme and sub-themes showing relevant quotes, the number of quotes for each sub-theme and which user-group the comments came from. The sub-themes of the Experience / Expectation theme which particularly focus on the design of the smartphone reminder are: software guidance, general issues with affordance / learnability and specific suggestions to improve affordance and learnability. These themes are described in more detail below.

4.3.6.1 Software guidance

Two different types of software guidance were discussed by the participants. Firstly the possibility of, “a tutorial telling you how to set the reminder the first time you’re doing it so it’s a bit clearer?” was mentioned by participants in all three focus groups (quote from LK). The second possibility would be more reactive guidance. For example, NS said “If you make a mistake and press the wrong thing there should be something there – up there on the bar – that will, if you press, take you right back to where you were”.

4.3.6.2 Issues with affordance / learnability

For this sub-theme affordance is defined as the extent to which the apps features, interactions and commands are likely to lead the user to the correct action and learnability is defined as the extent to which the operations and features can be easily figured out by novice users.

These issues were mentioned in each of the focus groups. For example CH wrote a comment on the monthly calendar view screen during the KLC session which read, “not clear… but when explained its good!” and there were several observations of people finding it difficult to work the app because of their lack of experience combined with a lack of affordance from the software – it was not clear what they needed to do to set a reminder until they were told how to do it. This impacted the use of the app through several screens including the calendar screen for viewing event entries, the reminder screen for inputting events and reminders at certain times and the clock screen for time setting.

A lack of affordance and learnability from the software also affected people’s understanding of interactions. For example, participants were unfamiliar with the touch gesture when attempting to select the right date / time on the calendar and had difficulty typing in text because they were not used to the text input interface. Many participants were also not aware of where the back button was going to take them and at times ended up on the wrong screen or outside the app onto the smartphone’s home screen. Finally some participants had difficulty understanding the command ‘scroll up’ when they believed they should be scrolling down. The issues of affordance and learnability are key with this population due to cognitive, behavioural and memory difficulties that may impact learning. SW tellingly commented, “If you didn’t guess right (when inputting a reminder) you’d get fed up with it. It would be difficult to finish it”.

4.3.6.3 Specific suggestions to improve affordance / learnability

While there was a limitation to the detail in which design issues could be investigated in the focus group setting, the Google Calendar demonstration and KLC session did allow for some more specific design and layout suggestions to be made. These suggestions were mostly made by the carers group. On the calendar (monthly view) screen it was suggested that a time-independent “add reminder” option could be added to the top right of the screen which is standard in many reminding apps and would reflect more experienced user’s expectations. On the reminder screen it was suggested that the reminder and repetition options should be moved closer to the top of the screen. This was because they were seen as important functions of a reminding app and making them more prominent would increase the likelihood of them being used correctly and prevent the need for scrolling. Finally both the carers and ABI groups recommended changing the symbols on the screen (e.g. Google Calendar has a pencil for edit and a wastepaper basket for delete) to be altered to make them easier to recognise or to be made more obvious by replacing the symbols with words or having both symbols and words.

4.4 Discussion

4.4.1 Implications / design considerations

Assistive technology uptake is a complex issue and this is reflected by the diverse themes that were described by participants. This is an exploratory study, designed to gain an understanding of the issues that impact whether people can, and want to, use smartphone reminder apps. The issues described above are those that arise when people with ABI and their carers consider using reminding software and when they are introduced to a new app software or hardware for the first time. These results allow us to highlight areas which computing scientists and app designers should consider when developing software for people with ABI.

4.4.2 Limitations

Focus groups were chosen to develop a set of rich qualitative data about technology uptake and to encourage discussion of the issues. It was not possible to investigate long term usability issues by giving people smartphones and detailing use over time, although many of the issues brought up by participants would impact use over time. Future studies could use different methods to add to the current findings such as longer term usability evaluations with reminder apps. The themes that arose from these focus groups may not be a final set of themes and more research is needed to fully understand the issues for this group. For example, future studies could investigate the differences between novice and experienced smartphone users with and without ABI in order to separate issues that are down to a lack of experience from issues due to ABI. It must also be noted that no two people with ABI will experience the same symptoms and while it is easier to do research with groups of people in similar neurological groups (e.g. ABI, dementia, stroke), future HCI research into assistive technology for cognition should try to develop technologies specific to cognitive difficulties such as memory failure, difficulties with visual perception or problems with attention (Sutcliffe et al., 2003; de Joode et al., 2012).

4.4.3 Design Considerations

4.4.3.1 Perceived Need:

The *Perceived Need* theme indicates that a lack of insight into memory difficulties may prevent people from wanting to use apps (because they do not realize they need a memory aid) or using apps appropriately (because they over-estimate their future memory and so do not input enough information at the time). A visual overview of the frequency of comments shows that, in contrast to the groups of people with ABI, the carers group had a detailed discussion about how a lack of insight from patients could impact uptake of technology. The issue of insight was also found to be a barrier to assistive technology use in a study by Baldwin and colleagues (2011). Participants with ABI reported that they needed the experience of forgetting something important before they would accept that a memory aid was necessary. Future studies could look into designing for people with poor insight, for example by investigating if prompting to enter reminders in the first place, or prompting users to include enough information (to ensure they remember it later) is an acceptable and effective addition to a smartphone reminding app (see Future Research section).

4.4.3.2 Social Acceptability:

The *Social Acceptability* of using reminders in public is an issue that has been mentioned in previous studies. In studies that have not focused on smartphone technology, participants with memory difficulties have reported that the social stigma of using technology would be a barrier to uptake (Baldwin et al., 2011; Robinson et al., 2009). However in the study reported in this chapter, participants suggested that using a mobile phone as a reminder in public is actually more acceptable than using a pencil and paper. This may reflect the ubiquity of smartphones and reminder apps and adds to the evidence supporting the use of smartphones as prospective memory aids for people with ABI. One interesting finding which came from the carers group was that use of assistive technology is influenced by social comparison and part of this may involve comparison to 'healthy' carers. Future app design could take advantage of this knowledge by linking people with ABI's reminders to carer's reminders in order to normalize mobile reminding. For example users could receive a notification every time a carer or family member received a reminder.

4.4.3.3 Experience and desired content and functions:

The issues which came up most often were *experience / expectation* and *desired content and function*s with 89 and 60 comments respectively. This may be because these issues are relevant when thinking about using technology prior to actual use, and during actual use of and discussion about Google Calendar. The Desired Content and Functions for smartphone reminders is a novel theme as no previous study has gathered details on which functions people with ABI would like from a smartphone reminder application. Desired functions have been suggested by different user groups in previous studies. For example older adults asked for reminders to have different output modalities based on the task or their preferences (McGee-Lennon et al., 2012) and in a study looking at assistive technologies for young adults with cognitive impairments, participants called for technology that was initially easy to use but which would also develop complexity as the user became more experienced (Dawe, 2006). It is interesting that so many participants called for a notes function to link up to their reminders. This memory holding function is available on most smartphone calendar systems, however the evidence from this study suggests it should be a more prominent feature in an app for people with ABI. Future research could formally evaluate the efficacy and usability of this and other functions and content suggested by the participants in this study.

As well as carer guidance and tutorials, training is one solution to the experience issue and this was not mentioned in the focus groups. Several recent efficacy studies investigating the use of smartphone based reminder systems have included a lengthy training session prior to the start of the trial (de Joode et al., 2013; Svoboda et al., 2012). However this type of training is not always practical or feasible and better design could reduce the need for training, particularly if it can increase the app's affordance and learnability. User Interface design heuristics such as Shneiderman's "eight golden rules of interface design" (Sneiderman & Plaisant, 2005) were created to guide the design of apps with good affordance and learnability. Some of these heuristics fit with ideas participants in the focus groups alluded to such as positive feedback, system guidance and affordance and reduced complexity to help attention. However, as they were developed for the general population they may need to be adapted for people with ABI. For example people may become impatient, frustrated or disinterested with the device if they are not able to learn how to use it quickly. Furthermore people may have learning difficulties that would prevent or delay their development from novice to expert users. This means that, for this user group, app designers should focus more on making their software easy to use the first time to encourage and preserve future use rather than creating highly functional software that is good for experienced users but that has a steep learning curve.

4.4.3.4 Sensory Accessibility & Cognitive Accessibility:

The ABI groups had a proportionally larger amount to say about sensory and cognitive accessibility compared to the other themes. Visual accessibility was the most consistently mentioned *Sensory Accessibility* issue and difficulties with attention - feeling overwhelmed by the amount of information - was the most consistently mentioned *Cognitive Accessibility* issue. While these issues have been described in personal computer usability studies (Sutcliffe et al., 2003; McDonald et al., 2011), they may both be more prominent with smartphone apps compared to PCs because they display a large quantity of information on a small screen. This issue has also been reported by older users in mobile usability (Razak et al., 2013) and reminder technology [McGee-Lennon et al., 2011; McGee-Lennon et al., 2012] studies. Such information overload may be a difficult barrier to overcome without increasing hardware screen size, though changes to software design could improve sensory and cognitive accessibility.

4.4.4 Future Research

The purpose of this chapter was to understand the issues that impact the use of prompting technology for people with ABI. The themes offered insights into potential design solutions which could be tested in further studies within this thesis. For example, participants highlighted the issue of failing to initiate reminding behaviour especially when lacking insight into memory difficulties (*perceived need*) or because of low motivation (*perceived need* and *social acceptability*), and because setting a reminder is a prospective memory task which may be forgotten (*cognitive accessibility*). In this case the use of technology could be particularly advantageous compared to pencil and paper memory aids because it can prompt the user to initiate reminding behaviour, prior to any input from the user. Chapter four investigated the efficacy and acceptability of a smartphone reminder app intervention (ForgetMeNot) which automatically prompts the user to set reminders around five times a day (named Unsolicited Prompts or UPs).

A recurring theme through the focus group and co-design session was the accessibility of the user interface of Google Calendar. For example participants stated that it was difficult to see large amounts of information on a small screen (*sensory and motor accessibility*), that they had trouble making sense of the information because of cognitive difficulties (*cognitive accessibility*) or prior experience (*experience / expectation*) and that the app did not do what they wanted it to do (*desired content and functions*). As a consequence people felt that they would be unlikely to have the patience, inclination or ability to use, or learn how to use, the technology especially in the context of potential social stigma and negative social comparison, negative experiences with technology, poor insight into difficulties and behavioural difficulties (*social acceptability*, *perceived need* and *cognitive acceptability*). Therefore the accessibility of technology was a relevant issue within a constellation of themes which appeared during discussions with users and caregivers. Chapter five investigated the literature surrounding accessible technology for those with cognitive impairment with the aim of developing accessible smartphone reminding software. A reminding app (ApplTree) designed based on recommendations and insights from the focus group and the wider literature was used by people with acquired brain injury and performance with this app was compared to Google Calendar.

4.5 Conclusion

People with acquired brain injury could benefit greatly from smartphone reminding software. However, there is little research investigating the perceived and actual usability of reminder apps for this user group. This study is novel in its focus on issues that impact smartphone reminding app usability for people with ABI – particularly the issues that impact initial uptake and use. In this chapter we studied participants' comments and feedback during a focus group discussion, a demonstration of the Google Calendar app on a mobile phone accompanied by a *keep lose change* session. Important issues were highlighted that impact actual and perceived usability of Smartphone reminding applications for people with memory impairment following ABI. The main themes reported here; *perceived need, social acceptability, experience / expectation, desired content and functions, cognitive accessibility* and *motor / sensory accessibility*, can be used as a building block for future mobile usability studies and development with and for this user group. The rest of this thesis describes studies which have developed and tested software designed to overcome some of the barriers described in this chapter.

5 Chapter Five - Don’t Forget to Remember: Exploring Active Reminder Entry Support for Adults with Acquired Brain Injury

5.1 Introduction

To successfully use mobile reminding technology you need to be able and willing to input relevant reminders and be capable of receiving and interpreting the output (e.g. alarm and message) at the correct time. In the meta-analysis reported in chapter two, only 5 of the 9 group studies which tested the efficacy of prospective prompting devices had participants entering their own reminders. In the other studies reminders were set by a third party such as a caregiver or the experimenters. This means that a large proportion of the evidence that prompting technology is useful for people with ABI has only investigated the output stage of reminding. However, the input stage is of crucial importance because if people fail to enter reminders in the first place then they will not receive the prompt. Furthermore, it may not be possible or desirable for a third party such as a caregiver or a clinician (or experimenter during a study) to enter reminders on behalf of the person with ABI. For example, there could be issues with privacy or simply because events come up which caregivers do not know about (e.g. a spontaneous change of plan). Setting and abiding by one’s own schedule is an important part of independent living and is one of the goals of neuropsychological rehabilitation (Wilson, Gracey & Evans, 2003).

5.1.1 Unsolicited Prompting

One of the main themes from the focus group study described in chapter four was *insight and motivation*. People reported that apathy (failing to initiate the use of memory aids and strategies in the first place), and poor insight and memory (not realising that they are or were likely to forget) were important barriers to the use of smartphone prompting devices. These issues present a particularly challenging problem for clinicians hoping to encourage a client to use a pencil and paper or technological memory aid. Even if the client has received substantial training and is capable of using the memory aid, they may still forget to use it, or not realise or believe that they need to use it.

An advantage of technologies such as smartphone reminding apps over pencil and paper memory aids is that they can actively alert attention and aid memory with well timed and relevant prompts. After reminders have been entered into the device (e.g. a weekly schedule), the technology will alert the user's attention (at a relevant time) to the events or tasks which they intended to attend or perform. It is also possible to create software which will prompt the user prior to any input. This kind of alerting is unsolicited by the user and so these types of prompts are referred to as Unsolicited Prompts (UPs). It would be difficult for the content of the UPs to give any specific reminders before any information was provided about the user's schedule. However UPs could be used to periodically prompt participants to enter reminders into a smartphone reminder app and this could overcome some of the insight and motivation issues described in chapter four. For example if someone with memory difficulties after an ABI took a note of a Doctor's appointment while on the phone, but became distracted and forgot to enter it into their reminder app, a prompt from the app asking if they needed to enter any reminder could remind them to do this. If later they made mental note of a task they needed to do that evening, but did not believe they would forget it, the same UP from a reminder app might convince them to set the reminder (especially if the prompt gave them the option to enter the reminder app).

In this chapter, the design, development and evaluation of bespoke reminding software (ForgetMeNot) is described. ForgetMeNot was developed as a platform to enable the investigation of unsolicited prompts (UPs). A single case experimental design (SCED) study with three participants with severe ABI is presented. This study investigated the efficacy and perceived acceptability of ForgetMeNot for improving memory performance with and without Unsolicited Prompts (UPs). It is important to determine whether there is a benefit of this feature (increasing reminding behaviour) and if this benefit outweighs the potential negative aspects (decreased social acceptability and increased annoyance). UPs could easily be added as a feature in reminding apps for people with ABI.

5.1.2 Interruptions

One problem with a smartphone app providing UPs is that they may become annoying which may lead people to stop using software which utilizes UPs. Prompts and 'push' notifications from mobile devices have become ubiquitous. Pielot *et al*. reported that 15 healthy smartphone users received on average 63.5 notifications per day and rated this as 'normal' (Pielot, Church & de Oliveira, 2014). However, the majority of these notifications were social messages which may be responded to in a different way to a prompt from a reminder app to actually do something. Shirazi and colleagues (2014) reported a large scale study of mobile users' responses to different notifications (Shirazi, Henze, Dingler, Pielot, Weber & Schmidt, 2014). They found that social notifications were generally responded to within 30 seconds and these social apps were unlikely to be 'blacklisted' (so that notifications were prevented from appearing on the device). Prompts from Calendar apps, which are the closest equivalent to the prompting app used in this study, were responded to after around 5 minutes and were blacklisted more often. This may be because non-social prompts were considered less important and therefore more irritating than social prompts. Paul and colleagues (2011) used a one-word-response method to investigate the emotional experiences of receiving notifications (Paul, Komlodi & Lutters, 2011). They found that while people described receiving a social notification (e.g. an email or text from another person or a social media notification) with more positive words than negative, notifications which were not social were described with a similar number of positive and negative words. Of the negative words used, the most common was 'annoying'. These findings suggest that users may not necessarily attend to or positively react to UPs in all cases.

The perceived usefulness of the content of the notification is also important; Felt and colleagues (2012) found that if apps which are not perceived as useful keep sending messages then users become annoyed and more likely to delete those apps (Felt, Egelman & Wagner, 2012). This may be a bigger issue for people with ABI as they often lack insight into their memory difficulties and so may not find a UP useful even when they do have something to remember. These issues may hinder the effectiveness and acceptability of UPs. However, these studies looking at mobile phone interruptions have been carried out with high functioning, healthy people who use a mobile phone regularly. Little is known about how interruptions are perceived by people with ABI. Rehabilitation researchers highlight the low employment rates (Wilson, 1991) and social isolation of people with ABI (Douglas, 2013) so they may not be a group who receive high volumes of notifications from technology.

5.1.3 Study Aims

The main aim of this chapter was to investigate the impact of Unsolicited Prompts (Ups) on reminder setting frequency and memory performance. The method chosen was a SCED trial in a real-world setting with three participants testing the efficacy and acceptability of an app with UPs to address a problem with reminder application use by people with ABI: remembering to enter a reminder. SCED methodology was chosen because it allows a controlled trial to be performed to test efficacy when large scale recruitment is not possible (see *Single Case Experimental Design* section in chapter two). Secondary aims were to explore the user's experience of receiving the UPs while using the ForgetMeNot app. It was also of interest to use participant feedback about ForgetMeNot and observations of participant's behaviour during the study to provide further insights into the results.

5.2 Method

5.2.1 Participants and setting

The study involved adults with self-reported memory difficulties after ABI. It took place within a post-acute rehabilitation hospital in the UK for people with severe ABI. This is a living environment with 24 hour support, staffed by nurses, support workers, psychologists, occupational therapists and physiotherapists. Each service user has his/her own room, there are two communal lounge areas, two dining room areas, a laundry room, exercise studio and a kitchen. Difficulties in carrying out future intentions (prospective memory difficulties) are extremely common amongst the group. This study setting was ideal because it allowed close observation of service users living in an environment where they have to remember several everyday tasks (e.g. medication, laundry, their daily rehabilitation schedule).

University of Glasgow college of Medical, Veterinary and Life Sciences college ethics committee (MVLS CEC) and Disabilities Trust Research Ethics Committee (DTREC) approval was granted for this study on 02.03.15 (MVLS CEC) and 03.03.15 (DTREC) (reference numbers 200140069 and 07.2014 respectively).

Four adults with prospective memory difficulties were approached by the thesis author to participate in this trial. Participants were only approached if they were physically able to use a smartphone, able to comprehend written instructions and had adequate verbal communication skills. These judgements were made based on clinical notes and feedback from psychology staff at the service. One service user declined to take part, leaving three participants (LE, KT and CD). Their cognitive profiles are reported below to provide context. All participants were given the Cambridge Prospective Memory Test (CAMPROMPT) (Wilson, Shiel, Foley, Emslie, Groot, Hawkins & Watson, 2005). The CAMPROMPT tests participants' ability to form and maintain intentions over a 25 minute period. For example, participants are asked to remember where a number of objects are hidden and to point these out at to the experimenter at the end of the test. All participants were impaired compared to general population norms on the CAMPROMPT. Two participants owned mobile phones (KT an iPhone and CD owned a feature phone). Before the study, KT reported previously using a calendar app to set reminders. He was not observed to use his own phone to set reminders for any of the memory tasks during the trial apart from doing the laundry (see Table 5.1). His use of a mobile phone reminder on his own phone was consistent throughout the trial and this memory aid was part of his practice as usual.

5.2.2 LE

LE is a 45 year old man who sustained a subdural haematoma after a fall in 2013. He has a history of previous injuries including a haemorrhagic cardiovascular accident in 2007, a traumatic brain injury (TBI) in 2010 and recurrent seizures in 2012, with inpatient rehabilitation in 2012 and 2013. LE has had difficulties with communication which have improved due to a cochlear implant. He also has difficulties with controlling his behaviour and with functional abilities such as self-care, cooking and cleaning. These have improved since admission to the unit. He has recently begun a vocational placement and has independent access outside the unit. He finds it difficult to initiate new behaviours which are not established habits. He also has difficulty maintaining his intentions and goals over more than a few minutes and so he is strongly driven by his environment. He has little insight into his difficulties and often does not understand the need for safety procedures or cognitive interventions. Staff reported that a reminder app could be helpful because he requires frequent prompting about activities.

5.2.3 KT

KT is 37 and sustained a severe TBI in a road traffic accident when he was 17. He has social skill deficits, disinhibition and psychiatric symptoms. Initial difficulties with inappropriate behaviour have improved since he was admitted to the rehabilitation unit. More recent rehabilitation efforts have focused on his initiation of activities (morning routine and time keeping) and memory difficulties. He requires prompting to get out of bed in the morning and to ensure he is ready for his rehabilitation sessions and vocational placements. Staff noted that KT sometimes requires prompting about everyday tasks such as doing the laundry. KT's memory difficulties, lack of motivation and apathy are issues that may benefit from prompting from technology. He expressed that he dislikes being asked by staff members to do everyday tasks and so it was hoped that he might find prompts from technology more acceptable.

5.2.4 CD

CD is a 55 year old man who sustained a skull fracture in late 2014 which led to left lateral ventricular dilation and a left subarachnoid haemorrhage. His medical history includes alcohol and substance misuse and a traumatic brain injury with subdural haematoma in 2008. CD was admitted to the unit in early 2015 and has severe memory difficulties, poor working memory and anxiety about his memory difficulties. He writes many notes because he is anxious about missing activities. However, he is also disorganized and has impaired short-term memory, so his notes often get lost or covered up leading to him forgetting the reminder. A memory app could help because it would allow him to store his reminders in a phone which could alert him at the correct time. During the study period, CD had a rehabilitation goal of reminding the nurse about his medication, with the aim of moving to self-medicating safely.

5.2.5 Procedure

An A-B1-A-B2-A single case experimental design was used. The A phases were the baseline conditions where no technology was provided and participants used their usual reminding techniques such as writing in diaries, notes and asking staff to try to remember each activity. The B phases were the intervention phases during which a Samsung Galaxy S3 smartphone with the preloaded ForgetMeNot app was provided. UPs were included in one B phase and not the other. Each A phase lasted one week and each B phase lasted two weeks, giving a total study duration of seven weeks. Memory tasks that participants found difficult were identified at the beginning of the study through talking to staff, asking the participants or referring to neuropsychological reports. Table 1 gives details of the activities which required prompting from staff, or which were often not completed because of memory problems. Specific experimental tasks were also given at the beginning of each day. Once a day, each participant was asked to pass on a brief message (written on a piece of paper) to the researcher or staff. Sometimes this was a time based task (e.g. ‘pass on the message at 2.20pm’) and sometimes it was event based (e.g. ‘pass on the message after dinner’). Participants were also asked to send the researcher a text message at two specified times each day. The text times were given on a piece of paper at the beginning of each week. The purpose of these additional tasks was to ensure that there were enough memory tasks each day to have a reliable measure of daily memory performance. However, the number of memory tasks which could be given to participants was constrained by the schedule within the rehabilitation centre and the desire not to overburden the participants. The participants had four, hour long, rehabilitation sessions per day and meals at breakfast lunch and dinner, giving them five half hour breaks between breakfast and dinner and free time in the evening after dinner. After communication with the staff and participants it was decided that the optimal total number of memory tasks which could be carried out in this time was between three and seven. The exact number varied because of the participants’ everyday circumstances.

Table 5-1. Participants' daily tasks.

Initials	Daily tasks
LE	• Apply creams after shower • Ask to use the computer • Remember laundry • Remind the nurse about medication
KT	• Check schedule for vocational appointment • Have breakfast before leaving for a vocational appointment • Go to a rehabilitation session • Remind the nurse about medication
CD	• Ask to play a board game • Ask to use the computer • Remember laundry • Remind the nurse about medication

When participants were in a B phase, UPs were set by the experimenter to go off six times per day. UP times were randomly selected within certain constraints: it was not possible to prompt during rehabilitation sessions (between 10am-11am, 11.30am-12.30pm, 1.30pm-2.30pm and 3pm-4pm) because it would have been unethical to interfere with the rehabilitation programme. Therefore UP times were selected from the remaining possible times.

At the beginning of each B phase, participants were given a demonstration of how to use the app, during an hour long study session. This covered how to enter the app from the home screen, set a reminder task and time, check today's reminders, respond to prompts and how to respond to a UP. The researcher attended the rehabilitation centre every day during the study to collect the data. They helped with any other issues to do with phone use such as keyboard use for text messaging, phone charging and screen navigation, throughout the study. Participants were also free to use the phones for purposes separate from memory prompting (e.g. access internet and make phone calls) and £10 of credit was given with each phone to cover text costs.

The experimenter met with participants in nine hour long study sessions: one prior to the beginning of the study to gather information about which memory tasks to set prompts for and to administer the CAMPROMPT; two at the beginning of each B phase to give participants the phone and a demonstration of use; four on different days during the B phase to take measurements of UTAUT and TLX ratings and to interview participants about their use of ForgetMeNot; and sessions during the second and third A phases to administer further neuropsychological tests when necessary. The experimenter was granted access to neuropsychological test scores which were completed as part of practice as usual in the rehabilitation unit. Test scores were used to build a cognitive profile for each participant. Neuropsychological tests performed with service users were the Weschler Adult Intelligence scale version 4 (WAIS-IV) (Wechsler, 2008), the Behavioural Assessment of the Dysexecutive Syndrome (BADS) (Wilson, Evans, Alderman, Burgess & Emslie, 1997), the Cambridge Test of Prospective Memory CAMPROMPT (Wilson, Shiel, Foley, Emslie, Groot, Hawkins & Watson, 2005), and the Rivermead Behavioural Memory Test (RBMT) (Wilson, Cockburn & Baddeley, 1991).

Task Load Index (TLX) (Hart & Staveland, 1988) and Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, Morris, Davis & Davis, 2003) questionnaires were completed by participants to measure perceived task load and different aspects of perceived usability and acceptability of the system, at the end of each week within the B phases. TLX asks about mental demand, physical demand, temporal demand, evaluation of performance, evaluation of effort needed to achieve that performance and level of frustration. These scores (each on a scale of 1 to 21) were reported separately and aggregated together to create an overall task load score. The UTAUT includes groups of items concerning the following: performance expectancy (expectancy that the tech will be useful for its purpose), effort expectancy (perceived effort needed to use it), attitude towards the technology, social influence (the influence of others on the use of the technology), facilitating conditions (the extent to which their environment facilitates use of the tech), self-efficacy (estimations of their own ability to use the technology), anxiety (levels of anxiety felt when using the tech) and behavioural intention (an indication of whether the participant is intending to use the tech in the next 6 months). Scores for each item (on a scale of 1 to 6) within each domain were aggregated to give overall scores for each domain at each time point.

5.2.6 Procedures to Improve Internal and External Validity

The RoBiNT scale (Tate et al., 2013) details 15 recommendations which researchers should adhere to when conducting high quality SCED studies. Internal validity items include ensuring the design demonstrates experimental control, that phase sequence or commencement is randomised, and that there is sufficient sampling of data points for each participant in each condition or study phase. The design of this study was A-B1-A-B2-A which is a withdrawal / reversal design and is defined as a SCED because it does demonstrate experimental control. The order of B phases was randomly counterbalanced by using an online research randomiser (www.randomizer.org) to select between numbers 1 and 2 for each of the three participants (1 = UP condition first and 2 = UP condition second). The randomisation was controlled so that at least one participant would receive the UPs in the first B phase, and at least one participant would receive the UPs in the second B phase. Participants KT and LE received UPs in the first B phase, and CD received UPs in the second B phase. The study was designed so that at least five data points (the minimum recommended) would be collected for each phase of the study. Occasionally participant absence prevented all five data points from being collected for each phase, although at least four data points were collected and reported in these cases.

The RoBiNT scale also recommends blinding of participants, experimenter and assessors, the use of independent assessors to enable inter-rater reliability analysis to be conducted for at least 20% of the data, and an evaluation of treatment adherence. In the study reported in this chapter the experimenter was not blind to the study phase and it was not possible for participants to be blinded because the phones had to be provided with some instructions about use. To reduce the possibility of confirmatory bias from the experimenter (who knew the study phase of each participant and the study hypotheses), staff members were asked to be independent assessors of whether or not the participants performed some of the memory tasks. For example, the nurses would be asked if any participants had approached them for their medications at the correct time. While these staff members may have witnessed the participants using the devices, they were blind to the study phase and were not aware of the purpose of the study or study hypotheses. Other data was collected automatically and so could not be subject to experimenter bias, for example when participants were asked to send a text at a set time. Performance of each memory task was assessed either by the experimenter, an independent assessor, or were automatically collected. Either an independent assessor or automatic measure was responsible for scoring 79.05% of the data from each condition, far above the recommended 20% from the RoBiNT scale (Tate et al., 2013). This reduced the potential impact of confirmatory bias from the experimenter during the trial. The use of different methods of gathering memory performance data made it possible to measure a large number of memory tasks each day which would not have been possible using only one method (e.g. using independent assessors only). It was not possible to calculate inter-rater reliability between different types of assessment because they were used to assess different memory tasks. There was no external assessor of treatment adherence, to assess how the intervention was delivered by the experimenter (e.g. training with the smartphones). However, the training and study session times were regulated by an independent staff member within the rehabilitation centre, who organised hour-long study sessions which were part of the participant's rehabilitation schedule. This meant that the experimenter kept to the pre-determined study schedule with nine, hour-long study sessions.

External validity recommendations from the RoBiNT scale relevant to the study procedure include systematic or inter-subject replication and the inclusion of generalisation measures throughout each stage of the trial. The study reported in this chapter included three participants and so did provide inter-subject replication. There were no generalisation measures taken during the study reported in this chapter. While standardised measures of memory functioning such as the CAMPROMPT (Wilson et al., 2005) were reported in order to form a clinical description of the cognitive profiles of the participants, these measures were not expected to, nor used to, demonstrate any generalisation of the intervention's impact on memory performance.

5.2.7 Materials

5.2.7.1 ForgetMeNot app

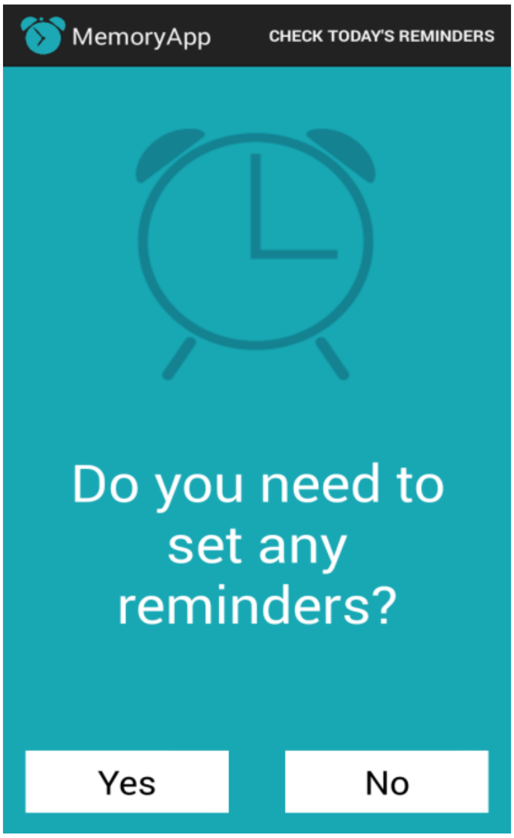
ForgetMeNot is a simple reminder application designed and developed specifically for this study (Figure 5.1) and the requirements for this design were developed by the thesis author and PhD supervisors after consideration of the research questions and study aims and methodology. The design requirements were a) that the app allows the user to set reminders for a specific time, b) that the app alerts the user at this time with an audio and visual prompt, c) that the app could be altered by the experimenter to include unsolicited prompts (UPs), d) that the app automatically logs the reminders set by participants and the participants' responses to the unsolicited prompts.

The interface of the app was designed to be easy to read with large, high contrast text. The home screen of the app gives a list of 6 reminders to set and no keyboard entry is required. Once the reminder has been chosen, a time can be selected for the alert to go off. A standard Samsung time selector widget was chosen for the time selection screen. When the alert goes off, the text flashes continuously and the beep sounds every 30 seconds until the 'Done it! button is pressed and the reminder is acknowledged. The reminders set for the day are logged automatically by the app (event selected and time) and can be seen by the user by selecting 'view today's reminders' at the top right of the reminder selection screen. There is also the (hidden) option to set prompts throughout the day. These are the unsolicited prompts (UPs) and the researcher set these at the beginning of the appropriate B phase. When the UP prompt fires it asks, 'Do you need to remember anything?' and flashes and beeps every 30 seconds until an option is selected; 'YES' to this question allows a reminder to be set, and 'NO' closes the app. The participants' responses to this YES / NO question were logged automatically by the app and could be viewed by the experimenter.

The design of the ForgetMeNot app was not intended to be a solution to all smartphone reminder usability difficulties for this group. Rather, it was intended to be a usable and learnable platform upon which to test the impact of UPs on reminder entry, and the impact of reminders on memory task performance with this user group. If UPs were found to be useful, then this function could be added to other reminding software.

5.2.7.2 *Daily reminders – study and app design*

Only the six different daily tasks could be set using the app and reminders could only be set for the current day. We recognize that setting reminders for longer-term events (e.g. ‘meeting tomorrow’ or ‘appointment next week’) is a useful function of most reminder apps. However, participants in this study received their rehabilitation plans daily and had few longer-term activities to remember. The ForgetMeNot app and experiment were designed to allow accurate measurement of the effectiveness of UPs in an everyday setting. Whether the memory task is to be performed later in the day or in a month’s time, the user still needs to remember to enter it into the calendar application. Furthermore, unexpected events that were not planned at the beginning of the week may occur daily and require revision of the initial plan and extra reminders to be added. This app and study allowed us to investigate whether or not UPs are an effective and acceptable way to increase this reminder setting behaviour. The app also allowed us to collect data on what reminders were set by logging all of the reminders set during the study.



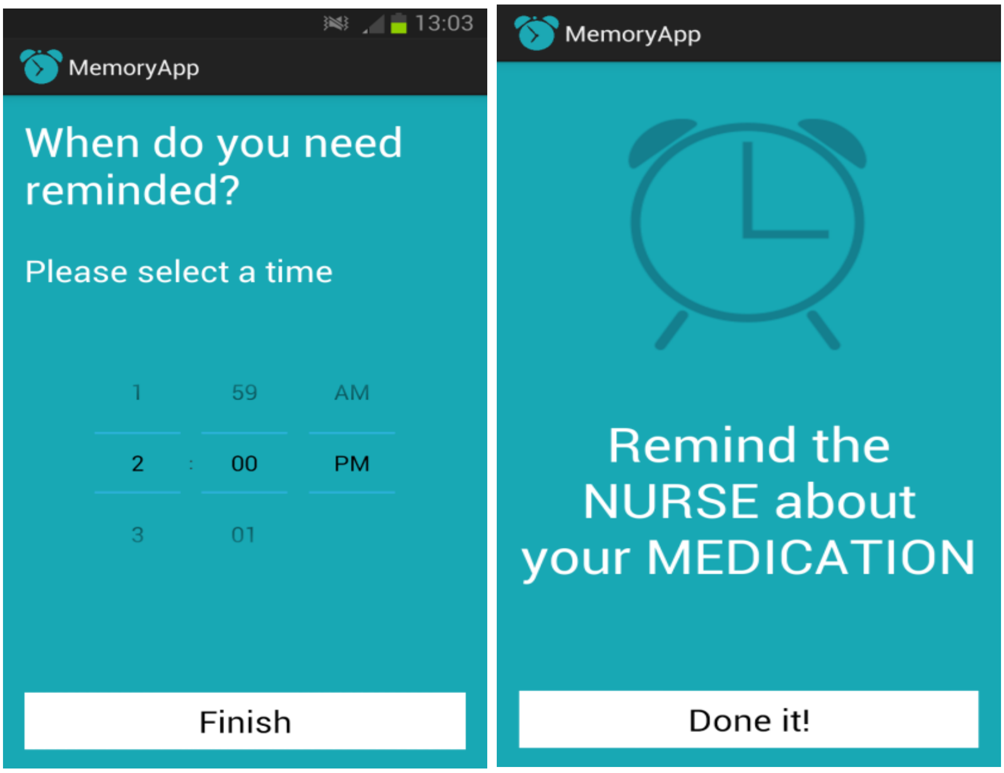


Figure 5-1. ForgetMeNot app.

Top left: Unsolicited Prompt (UP) Top right: Task selection screen. Bottom left: Time selection screen. Bottom right: Specific reminder prompt. The task selections shown were the ones created for LE. KT and CD had slightly different tasks (see Table 5.1).

5.2.8 Outcome Measures

The outcome variables were:

(i) Number of times reminders were entered into the phone (B phases only)

(ii) Number of relevant reminders entered into the phone (B phases only)

(iii) Everyday memory performance (all phases)

(iv) Efficacy of the relevant prompts on memory performance (all phases)

(v) TLX and UTAUT scores

The reminders data were logged by the software electronically and were used to calculate how many reminders were set by each participant on each day. The logged data also allowed the investigation of reminder quality as well as quantity. A measure of reminder relevance was developed: a ‘relevant’ reminder was defined as a reminder set for a task which was to be performed during that day and which was set for the correct time. The number of 'relevant' reminders set each day, for each participant, was calculated and these data were analyzed in the same way as the total numbers of reminders set measure. For everyday memory performance, the percentage of the memory tasks given during each day which were successfully performed was calculated. A measure of the efficacy of receiving a relevant reminder was also developed. For this, the overall percentage of tasks successfully completed when a relevant reminder was set was compared to the percentage of tasks successfully completed when no relevant reminder was set. Percentages in B1 and B2 phases were compared for each participant.

5.2.9 Field Notes

During the study phases in which the phone was in use the experimenter asked the participants to comment on their attitudes towards the phone and (if they were receiving them) the unsolicited prompts. They were also asked to comment on their thoughts about the study, and their use of memory aids. These interviews were transcribed and added to the experimenter's observations during the study. These data were then used to help interpret the findings in the study, for example to understand how the participants reacted to the unsolicited prompts over time. The further insights section in this chapter brings some of the participant quotes and observations together to gain a further understanding of the factors which influenced the use of the ForgetMeNot and unsolicited prompting intervention.

5.2.10 Data Analysis

The data was analysed using the non-overlap of all pairs (NAP) method (Parker & Vannest, 2009). NAP analysis takes each data point in one phase of a study and compares it to each data point in another phase to calculate how much overlap there is between two phases. This calculation gives a score out of 1. A score below 0.5 occurs if there is a lot of overlap between the phases and suggests no effect of the intervention; between 0.5 and 0.65 suggests a small effect; 0.66 and 0.91 is a medium effect; and 0.92 to 1 represents little overlap and therefore a large effect. An online NAP calculator was used to compute NAP score found at; http://www.singlecaseresearch.org/calculators/nap (Vannest, Parker & Gonen, 2011). NAP analysis was chosen because it is good for establishing whether or not there is an effect of phase change, especially when there is a lot of variation in the data. It was found to favourably compare to other SCED analysis techniques in its ability to discriminate between typical results in SCED data and its correlation with established effect size indices (Parker et al., 2009). The NAP technique has been used in similar trials of assistive technology for memory within a rehabilitation setting (O'Neill, Best, Gillespie & O'Neill, 2013).The NAP is reported along with a p value that indicates the probability of type 1 error and the 95% confidence intervals that indicate the measurement precision. The confidence intervals reported indicate that there is 95% certainty that the true NAP value will be found somewhere between the values reported. The p value is produced by the NAP calculator and is probability that the null hypothesis of no difference between the two phases is true. The p value is produced as a function of the overall number of observations and the difference between the result found and the NAP score that would be found if the null hypothesis was true (0.5). Alpha error probability was set at $p < 0.05$.The data for i) Number of times reminders were entered into the phone (B1 phase vs. B2 phase comparison only), ii) Number of relevant reminders entered into the phone (B1 phase vs. B2 phase comparison only) and iii) Everyday memory performance (all phases) were analyzed using NAP. . For everyday memory performance each phase was compared to the next (A1 to B1, B1 to A2, A2 to B2 and B2 to A3) and the B phases were also compared.

Descriptive analysis was performed for the TLX and UTAUT data, and when reporting the efficacy of relevant reminders on task performance for each participant.

5.2.11 Hypotheses

It was hypothesized that:

i. There would be more reminders and more relevant reminders set when UPs were provided (B1 versus B2);

ii. Memory performance would be better in B phases compared to A phases;

iii. Memory performance would be better when UPs were provided (B1 versus B2);

iv. Memory performance would be better on tasks for which relevant reminders set compared to tasks for which no relevant reminders were set.

There was no specific hypothesis regarding the TLX and UTAUT ratings; our aim was to discover trends of user experiences between the B phases with and without UPs.

5.3 Results

5.3.1 Neuropsychological Profile

Table 5.2 summarises cognitive profile on each of these neuropsychological tests and sub-tests for the participants included in the study.

Table 5-2. Cognitive profile on tests of intelligence, memory and executive function for the study participants.

Tests of intellectual functioning

Tests of memory

Tests of executive processing

Test	LE	KT	CD
WAIS-IV verbal comprehension score (summary)	98 (average)	-	70 (Borderline impaired)
WAIS-IV full scale IQ (summary)	89 (Low average)	91 (Low average)	74 (Borderline impaired)
TOPF score (summary)	38 (Average)	58 (Above average)	28 (Low average)
RBMT percentile rank (95% CI) (summary)	<0.1 (<0.1- 0.7) (Impaired)	0.5 (<0.1 - 3) (Impaired)	1 (0.2 – 6) (Impaired)
CAMPROMPT score	8	6	8

(summary)	(Borderline impaired)	(Impaired)	(Borderline impaired)
BADS age corrected score (summary)	63 (Impaired)	81 (Low average)	73 (Borderline impaired)

5.3.2 Efficacy

5.3.2.1 LE - Reminder-setting

LE was given the app with UPs first in Weeks 2 and 3 (B1 phase), and given the app without UPs in Weeks 5 and 6 (B2 phase). The mean number of reminders set during each of these phases is shown in Table 5.3. NAP analysis compared the overlap between the number of reminders set each day from the B2 phase (without UPs) and the B1 phase, giving a significant NAP score of 0.83 (medium effect) (0.83 (p= 0.016, 95% CI = 0.451 to 1)). B1 and B2 were compared again with only the relevant reminders included. NAP score for relevant reminders was 0.81 (a significant, medium effect of phase) (p = 0.025, 95% CI = 0.428 to 1).

Table 5-3. Mean number of reminders and relevant reminders set per day in each intervention phase for CD, LE and KT.

Intervention Phase	Mean (SD) number of reminders set per day		
	LE	KT	CD
With UPs	2.5 (1.7)	1.7 (1.5)	6.3 (2.6)
With UPs relevant	1.9 (1.1)	1.2 (1.0)	2.5 (1.3)
Without UPs	0.7 (0.9)	0.1 (0.3)	2.5 (1.8)
Without UPs relevant	0.7 (0.9)	0.1 (0.3)	1.2 (0.8)

5.3.2.2 LE - Memory performance

Figure 5.2 shows that LE's memory performance improved between A and B1 and decreased between B1 and A2. Memory performance also improved gradually over the study period and then levelled off.

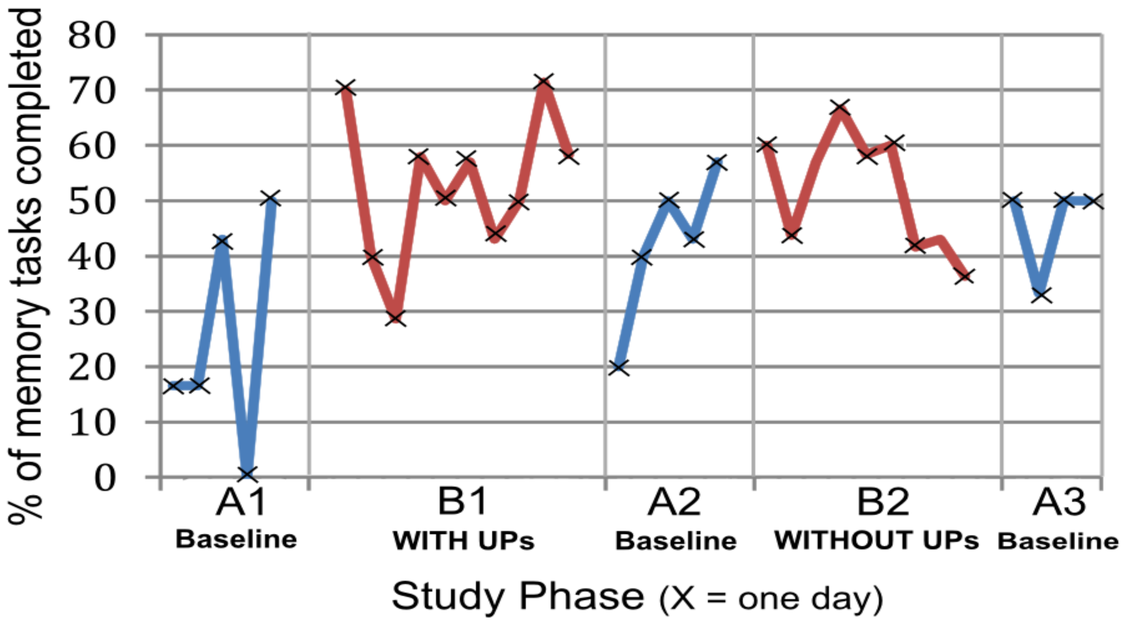


Figure 5-2. Percentage of memory tasks successfully completed in each study phase by participant LE.

The Y axis shows percent performance and X axis shows study day (each data point (x) in the figure represents one day in the study).

NAP analysis confirmed that LE's memory performance significantly increased between A1 and B1 (medium effect of change) (NAP= 0.87, p = 0.02, 95%CI = 0.42 to 1). There was then a non-significant medium decrease between B1 and A2 (NAP = 0.73, p = 0.159, 95% CI = 0.277 to 1 (). This was followed by a non-significant medium increase from A2 to B2 (NAP = 0.73, p = 0.16, 95% CI = 0.27 to 1)() and a futher, non-significant, medium decrease between B2 and A3 (NAP = 0.66, p = 0.35, 95% CI = 0.168 to 1). (). Finally, NAP analysis indicated that memory performance during B1 (with UPs) was no better than performance in the B2 (without UPs) phase (NAP = 0.49 (NAP = 0.49, p = 0.97, 95% CI = 0.128 to 0.883).

5.3.2.3 KT - Reminder-setting

KT was given the app with UPs first in Weeks 2 and 3 (B1 phase), and given the app without UPs in Weeks 5 and 6 (B2 phase). The mean number of reminders set during each of these phases is shown in Table 5.3. The NAP score comparing these phases was 0.81 (significant medium effect of phase) (p = 0.022, 95% CI = 0.434 to 1. B1 and B2 were compared again with only the relevant reminders included. NAP score for relevant reminders was 0.81 (significant medium effect of phase) (p = 0.022, 95% CI = 0.434 to 1).

5.3.2.4 *KT - Memory task performance*

Figure 5.3 shows that memory performance improved between A and B1. Performance was highest during B1, but performance varied markedly from day to day during the study.

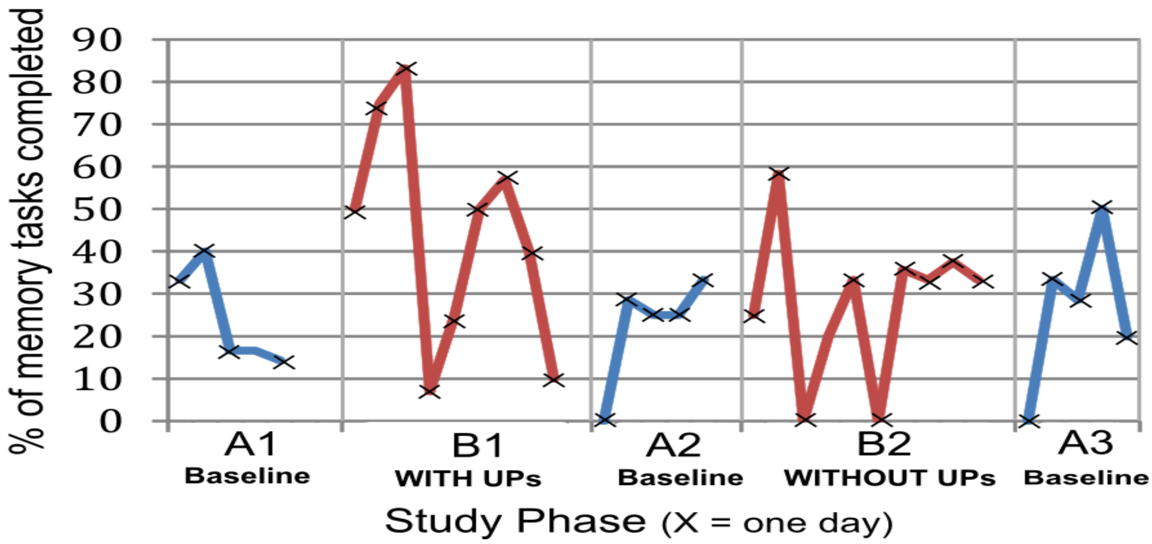


Figure 5-3. Percentage of memory tasks successfully completed in each study phase by participant KT.

NAP analysis indicated a non-significant increase (medium effect of phase) between A1 and B1 (NAP = 0.72, p= 0.18, 95% CI = 0.26 to 1). There was also a non-significant decrease between B1 and A2 (medium effect of phase) (NAP = 0.76, p = 0.13, 95% CI = 0.29 to 1). There was then a non-significant increase (small effect) between A2 to B2 (NAP = 0.65, p = 0.36, 95% CI = 0.19 to 1)() and a small non-significant decrease between B2 and A3 (NAP = 0.56, p = 0.71, 95% CI = 0.11 to 1)(). NAP analysis indicated that memory performance during B1 (with UPs) was better than performance in the B2 phase (without UPs), though this was not significant (NAP = 0.71; medium effect) (p=0.13, 95%CI = 0.083 to 0.672).

5.3.2.5 *CD - Reminder-setting*

CD was given the app without UPs first in Weeks 2 and 3 (B1 phase), and given the app with UPs in Weeks 5 and 6 (B2 phase). The mean number of reminders set during these phases is shown in Table 5.3. The NAP score comparing these phases was 0.90 (p = 0.003, 95% CI = 0.533 to 1), indicating a significant medium effect of UPs on reminder-setting. B1 and B2 were compared again with only the relevant reminders included. NAP score for relevant reminders was 0.78 (significant medium effect of phase) (p = 0.035, 95% CI = 0.413 to 1).

5.3.2.6 CD - Memory task performance

Figure 5.4 shows that memory performance increased between A and B1. B1 and B2 appear to show better performance than the A phases. There was a drop in memory performance when the phone was removed for the last phase.

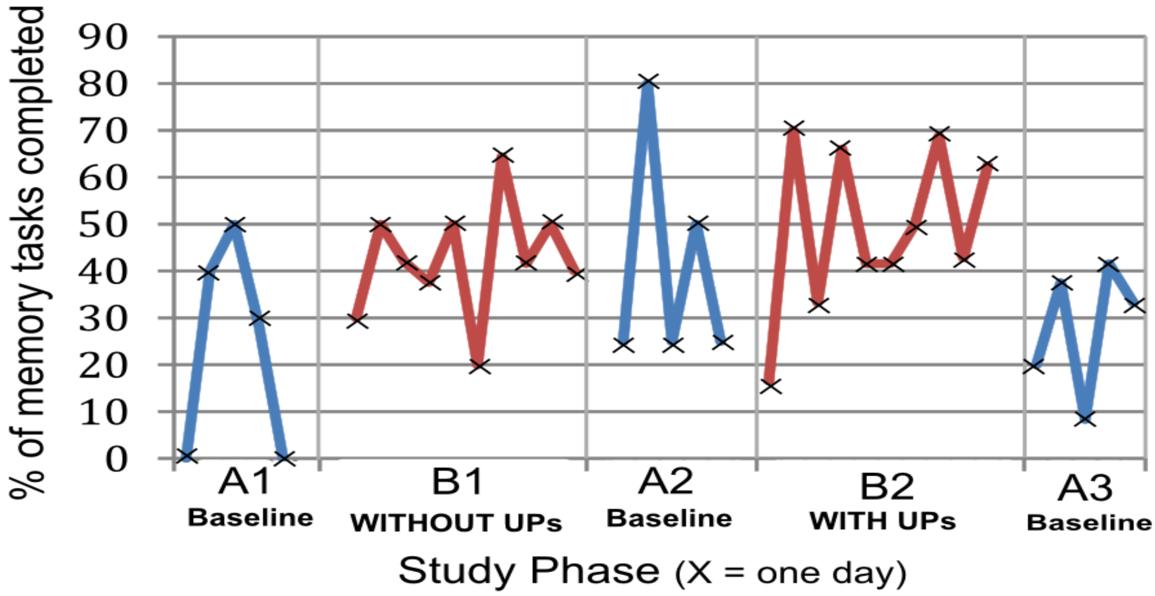


Figure 5-4. Percentage of memory tasks successfully completed in each study phase by participant CD.

NAP analysis confirmed that CD's memory performance increased between A1 and B1, although this was not significant (NAP = 0.76, p = 0.11, 95% = 0.31 to 1, medium effect of phase). There was no difference significant between B1 and A2 (NAP = 0.59, p = 0,58, 95% CI = 0.14 to 1, small effect of phase)() and a small non-significant increase between A2 and B2 (NAP= 0.63, p = 0.43, 95% CI = 0.18 to 1). () There was a medium significant decrease between B2 and A3 (NAP = 0.85, p = 0.03, 95% CI = 0.4 to 1).(). There was a small, non-significant improvement in memory performance between B1 (without UPs) and B2 (with UPs) phases (NAP = 0.64, p=0.31, 95% CI = 0.268 to 1

5.3.3 Efficacy of a relevant reminder

Table 5.4 shows the percentage of memory tasks successfully performed by LE, KT and CD when a relevant reminder was set and when no relevant reminder was set for phases with and without UPs.

Table 5-4. Task performance when relevant and non-relevant reminders were set.

Task performance for each participant in each phase grouped into tasks for which a relevant reminder was set (% when relevant) and tasks for which no relevant reminder was set (when not set or not relevant).

PHASE	LE proportion (%) when relevant	LE proportion (%) when not set or not relevant	KT proportion (%) when relevant	KT proportion (%) when not set or not relevant	CD proportion (%) when relevant	CD proportion (%) when not set or not relevant
WITH UPs	10.5/21 (50)	17.5/34 (52)	7/11 (64)	16/41 (39)	12.5/25 (50)	9/25 (36)
NO UPs	3.5/6 (58)	23/43 (54)	1/1 (100)	15.5/54 (29)	5/12 (42)	15.5/50 (31)
Total	**14/27 (52)**	**40.5/77 (53)**	**8/12 (67)**	**31.5/95 (33)**	**17.5/37 (47)**	**24.5/75 (33)**

5.3.4 User Experience

Table 5.5 shows mean scores for each TLX category in the WITHOUT UPs and WITH UPs conditions for each participant. Scores which were lower in the condition with UPs compared to the condition without UPs (indicating a positive impact of the UPs) by more than five points are highlighted in green. Those which were higher in the condition with the UPs compared to the condition without the UPs (indicating a negative impact of the UPs) by more than five points between conditions are highlighted in red. Five points was chosen because it represents a quarter of the 20 point TLX scale.

Table 5-5. TLX scores on each category for CD, LE and KT.

Scores highlighted in red indicate a higher score (by 5 points or more) of the app with UPs compared to without UPs. Scores highlighted in green indicate a lower score (by 5 points or more) for the app with UPs compared to without UPs.

TLX domain	LE Mean score NO UPs	LE Mean score WITH UPs	KT Mean score NO UPs	KT Mean score WITH UPs	CD Mean score NO UPs	CD Mean score WITH UPs
Mental Demand	**7.3**	**14.5**	1.8	1	**15.5**	**10**
Physical Demand	2	5.5	1	1	1	1
Temporal demand	**1.8**	**8.5**	1.5	1	**7**	**1**
Performance	14	14	2	1	10	10
Effort	12.5	12	1	3.5	7	11
Frustration	**5.5**	**14.5**	**1**	**7.5**	**17.5**	**8**
Total score	**43.1**	**69**	**8.3**	**15**	**58**	**41**

Table 5.6 shows mean scores for each UTAUT domain in WITHOUT UPs and WITH UPs conditions. To allow quick interpretation of this table, scores which indicated a positive impact of the UPs and which changed more than 1.5 points between conditions are highlighted in green. Those which indicated a negative impact of the UPs and which changed by more than 1.5 points between conditions are highlighted in red. 1.5 points was chosen because it represents a quarter of the 6 point UTAUT scale. An increase in score equates to better user assessment in all constructs except anxiety, where a lower score equates to lower anxiety when using the system and therefore more positive user experience.

Table 5-6. Scores for each UTAUT construct in both conditions for CD, LE and KT.

Scores highlighted in red indicate a poorer rating (by 1.5 points or more) of the app with UPs compared to without UPs. Scores highlighted in green indicate a better rating (by 1.5 points or more) in the condition with UPs compared to without UPs.

UTAUT domain	LE Mean score NO UPs	LE Mean score WITH UPs	KT Mean score NO UPs	KT Mean score WITH UPs	CD Mean score NO UPs	CD Mean score WITH UPs
Performance Expectancy	**2.38**	**4.88**	**5.63**	**4.06**	4.88	4.50
Effort Expectancy	**4.8**	**2.20**	6.00	5.50	4.50	4.60
Attitude	3.00	2.40	5.50	4.30	5.38	5.44
Social Influence	3.69	4.88	4.82	4.00	4.63	5.50
Facilitating Conditions	5.06	4.06	4.81	4.75	4.94	5.06
Self-Efficacy	**6.00**	**4.31**	6.00	6.00	4.50	5.88
Anxiety	**1.13**	**3.94**	1.00	1.63	**5.25**	**3.56**
Behavioural Intention	**3.50**	**5.33**	4.67	5.00	5.67	5.83

5.4 Discussion

5.4.1 Efficacy of the UPs

Significant medium NAP scores in the UP vs non UP phase comparison for all participants highlight that the number of reminders set per day increased markedly with the introduction of UPs. This was also the case when only relevant reminders were included in the analysis. This shows that all participants noticed the prompts and used them to open the app and set reminders. The setting of relevant, timely reminders to prompt a future intention was considerably more frequent when prompted by a UP than when they had to initiate this action with no prompt. When comparing the two B phases, the NAP analyses showed that no participants had significantly improved memory performance when receiving UPs compared to when not receiving the UPs. Based on recommendations in the literature (Tate, Perdices, Rosenkoetter, Wakim, Godbee, Togher & McDonald, 2013), five or more data points were collected for each participant per study phase. Despite this, the limited size of the data sets meant that small or smaller medium NAP results were non-significant. The NAP analysis was intended to give an indication of the trends in the data which may be harder to interpret using visual inspection alone. Even so, the results should be taken with caution, especially those which are not significant.

5.4.2 Efficacy of ForgetMeNot

The memory performance results show that the percentage of memory tasks successfully completed during each day was consistently higher in the intervention B phases compared to the baseline A phases. The NAP effect of phase mostly indicated a small to medium effect (NAP between 0.5 and 0.91) of the technology between A and B phases. However, only two NAP effects of phase contrasts showed significant differences in memory performance across the three participants. These were a medium increase between the first baseline phase and the UP phase for LE, and a medium decrease between the UP phase and the final baseline phase for CD.

The effect sizes for the increase in memory performance after the introduction of a technological memory aid intervention (the ForgetMeNot app) were slightly lower than previous findings; the meta-analysis of seven group study efficacy trials in chapter two gave a large effect size of technology vs practice as usual or a pencil and paper equivalent (Cohen's d = 1.27). Single case experimental design studies which tested the efficacy of prompting devices showed a similar level of improvement to these larger group studies.

A possible explanation for the effect of ForgetMeNot being lower than previous studies is that the participants were not using the app to send relevant or timely reminders. The impact of the technology on memory performance was investigated in more detail by analyzing the number of tasks which were successfully performed after a relevant prompt compared to the number successfully performed when no relevant prompt was set. LE did not complete a higher proportion of memory tasks when he received a relevant prompt compared to when he did not. KT and CD showed improved memory performance for tasks for which they received a relevant prompt, although this was not a large increase. These results are surprising because, intuitively, it seems like receiving a relevant prompt should have a large impact on the ability to successfully remember and carry out an intended task. Furthermore numerous papers have shown that relevant and timely prompts from a device do lead to an improvement in task completion (Boman, Bartfai, Borell, Tham, & Hemmingsson, 2010; Svoboda & Richards, 2009). This suggests that even if the participants were reminded to do something at a relevant time, there were other factors which prevented them from completing the task. The further insights section below uses participant feedback and observations by the experimenter to attempt to understand these results more clearly.

De Joode and colleagues (2012) did find a smaller effect from a technology based memory aid which is comparable to our findings. In their study, participants were given extensive training with a pencil and paper diary as well as with a technological reminder and the authors report only a small and non-significant difference between participant's memory task performance between the two conditions. They speculate that being given specialist training with a memory aid is likely to improve memory performance. In the study reported in this chapter, only minimal training was given with the device. However, the control condition in the ForgetMeNot study was practice as usual within a dedicated rehabilitation hospital, so participants had received extensive training with pencil and paper based reminders and other non-technological strategies as part of their rehabilitation. Therefore, in this case, ‘practice as usual’ may have been a difficult control condition to improve upon.

5.4.3 User Experience

LE’s TLX ratings indicated increased workload when UPs were present while CD showed the opposite trend and KT showed little change. Looking at the specific categories in the TLX and UTAUT questionnaires, it seems that LE’s perception of the app was affected the most by the UPs. He reported that ForgetMeNot took more of his time, was more mentally demanding and was more frustrating when the UPs were present. Looking at the UTAUT scores, he perceived that ForgetMeNot took more effort to use, and reported lower self-efficacy and increased anxiety, when the UPs were present. He did report a greater expectancy that the ForgetMeNot would be useful for its purpose and reported a higher behavioural intention to use the system when the UPs were present. LE used the app with UPs first and had little experience with smartphones. This may explain the difference in ratings as he may have become used to using the phone over time and so become less frustrated. He also used the phone quite rarely during the ‘B’ phase without the UPs (< 1 reminder set per day on average) and so would be less likely to find it mentally or temporally demanding, or find it to be useful for its intended task (performance expectancy). In summary, the UPs seemed to be successful in encouraging the use of the app however, this came with increased perceived task load, frustration and anxiety.

KT gave very similar responses to the TLX and UTAUT questions. However, he did report more frustration and a lower performance expectancy score and a poorer attitude towards the technology during the UP condition. He did not appear to prefer prompts from the phone to those from staff. KT barely used the phone at all during the condition without UPs (average of 0.1 prompts set per day) so rating the app would have been more difficult for him. Perhaps his lower ratings of performance expectancy and attitude reflect his opinion about the app (which he thought was limited because it only reminded about selected activities). Importantly, he only used the app enough to assess it negatively when he was receiving the UPs. CD showed a very different trend in his user experience responses. He reported less mental demand, temporal demand and frustration when receiving the UPs. He also reported less anxiety during the condition with UPs. These differences could have been because he received the UPs in the second intervention stage and so felt less anxious, less frustrated and more confident using the app by the second week. He also used the app a lot more during the condition with the UPs and so this also may have helped increase his confidence. The differing attitudes towards the UPs are discussed with reference to participant's verbal feedback in the Further Insights section below.

Overall, there were no clear trends in terms of the task load and reported acceptability of UPs within the ForgetMeNot app. The fact that participants used the phone much more during the condition with UPs indicates the prompts were not so annoying that they put people off using them. Even participants LE and KT who rated the app quite poorly were encouraged to use it more by the UPs. The UPs in this study were designed to be difficult to ignore (they would beep and flash every 30 seconds until responded to). ForgetMeNot was designed this way because if people did not notice the UPs then it would not have been possible to measure their effect.

5.4.4 Further Insights

The thesis author was present in the rehabilitation centre throughout the seven week study to train participants with the phone, give them memory tasks, give participants questionnaires and neuropsychological tests and record memory performance. Therefore it was possible to obtain detailed field notes in the form of observations and verbal feedback from participants about their memory, ForgetMeNot and UPs. In particular, it was possible to gain insight into participants' differing perception of the UPs and to understand why memory performance did not really improve even when more reminders were set.

5.4.5 How were the UPs perceived by the users?

The changes in task load and user experience questionnaire results between UP and non UP conditions varied between participants. Frustration and anxiety was larger for KT and LE in the UP condition compared to the non UP condition. However the differences may have been due to issues with learning to use the phone, rather than being because of the UPs. In sessions with the experimenter during the weeks in which UPs were received, participants were asked what they thought about the UPs and why, as well as how they felt about the frequency and timing of the UPs.

When first asked about the UPs in week 2 when they were first introduced KT reported that he had noticed them but usually pressed the ‘no’ option. He said, “Well they (the UPs) all say the same thing. Presumably you’d have to go and check the phone but eh… I don’t know I just always press no”. The next week he was observed to have put the phone off and stated that this was because, “it kept going off. It was annoying.” When asked if he ever found it useful to press the ‘yes’ option in order to set reminders he said, “No because I did press ‘yes’ a couple of times and it just came up with the same options. Unless I sent you a million texts, I didn’t have anything to remember”. He then agreed that he didn’t think that he had enough to remember to justify it going off all the time, though this did not seem to be specific to the events entered into the phone. For example he went on to say, “There is just not enough going on here for me to have to remember anything to merit a device like that you know”. This highlights that KT did not feel that he needed to remember very much within the rehabilitation centre and this was why he chose to respond to the UPs by pressing ‘no’. It was this perceived lack of need for reminding that made the UPs annoying to KT.

When interviewed in the first week of the UP condition LE stated that he did not find the UPs annoying saying, “No it’s not annoying beeping me no. I’ve put it in my drawer so I might hear a faint beep.” However, at a later time he did report feeling frustrated with the notification, “No my memory is fine. I get to stage when that goes 'beep' I think not again!” This quote echoes comments made by KT indicating that UPs were annoying when they were not perceived as necessary either because he believes he will remember, or because he does not believe there is anything to remember. For LE his belief was highlighted when he said, “right, so when it goes in my pocket that’s the alarm going off to tell me to take my medicine. But I don’t do medicine, it gets brought to me. So the alarms for the medicine is not really my problem. The staff give me my medicine. I can’t go… give me the meds!”

In contrast to LE and KT, CD had a positive attitude towards the UPs throughout the UP phase. He indicated that he did not find the UPs annoying and when asked about the number of prompts he said, “There’s never too many you know. If you need them, it’s just if you’ve got them and done it all – but it’s nothing against it you just don’t need it. I just press no. As you say just press no. Ah I’m just, it’s new to me so I’m amazed”. This did not change throughout the two weeks of the UP phase, and CD indicated that he felt the prompts from the app could help to compensate for memory impairment, though he did feel anxious when using the phone in general. For example he said, “I think yeah it’s terrific. I’m sill lacking that confidence with it but that’s me, it’s nothing to do with the phone, I’ve nothing against the phone at all. Yeah I can see, I can see how handy it can be. In fact I’ll end up probably I need, that’s my brain there, my thoughts”.

The difference in attitudes towards the UPs between participants illustrates the importance of understanding insight into memory difficulties and motivation for rehabilitation, and the influence this can have on the acceptability of prompts. For example, KT and LE indicated that they did not set reminders because they did not believe they had anything to remember and reported that they felt their memory was fine. As a consequence the UPs were occasionally perceived as annoying by these participants, especially into the second week of the UP condition. In contrast, CD was anxious about his memory, motivated to remember his schedule and appreciated that the app could really help with this. He was very happy to receive the UPs and perceived them as helpful.

When asked about the frequency of the UPs, KT and CD both stated that they thought the number of UPs was about right. CD was happy with the semi-random firing of the UPs, while KT indicated that, ‘first thing in the morning, before my brain has engaged’ would be the best time to be prompted. He elaborated by saying, “You could just set the alarm and it goes off. Now normally you’d just remember, but… no it helps to let you know. It’s like you wrote a letter to yourself (from) last night you know”.

5.4.6 Why did relevant reminders not substantially increase successful memory performance?

There was not a big difference between the number of tasks successfully completed when relevant reminders were set, compared to when relevant reminders were not set (Table 5.4). Field note analysis also offers some insights into why this might have been.

In many of their comments KT and LE allude to their belief that they did not have much to be reminded about, either because they didn't believe that they had anything to remember or because they did not believe they would forget. It was also the case that the rehabilitation centre where the study took place had a very set schedule and there was little chance that participants would experience very negative consequences of reminding. For example KT said, "Eh… Well I don't really have a chance to forget because I've got a timetable. I've got various things that remind me and that". Additionally, as part of their rehabilitation, services users in the unit were provided with, trained and prompted to use pencil and paper memory aids and memory aid strategies. For example LE said, "Well I like my diary, I like keeping my diary cos I put everything in there" and, "…I write everything down. Its just… I don't really need that (points to phone) I write it all down".

These factors may have contributed to the lack of impact of the prompts because if the participants had no motivation to perform the tasks at the right time then they may not have done it even if they were prompted about it. If other memory techniques were being used (for example LE using his diary and prompts in his room) then these may have contributed to performance of memory tasks during baseline and intervention phases, masking the impact of the phone on memory performance. Additionally, especially in the cases of LE and KT there were indications that they may have stopped using or ignored the phone, at least during some of the intervention days. For example KT put the phone off for a day during the first week of the UP phase and LE stated that he put it away in his drawer at one stage preventing him from perceiving the prompts saying, "I've put it in my drawer so I might hear a faint beep". LE was often observed to have put the phone in a drawer, often saying that he was keeping it safe. He had to be prompted to keep the phone in his pocket a number of times during the first week of use.

Finally, CD also used pencil and paper memory aids and used his own phone to make notes of future events, though these did not prompt at set times. A strange aspect of CDs use of ForgetMeNot, especially during the UP phase, was the number of non-relevant prompts which he set. He was observed to be setting several reminders per day on ForgetMeNot, all of which had the same content, namely to remind the nurse about medication. In spite of these reminders he actually repeatedly forgot to remind the nurse at the right time. When asked about this he revealed that he was setting this reminder in order to receive the auditory notification at the set time. However he was entering different content into his own feature phone to match these reminders. When the ForgetMeNot notification fired it would remind him that he had something to do and he would look at the notes on his phone to find out what the task was. In the following conversation he describes this method,

CD: “See when I get my diary of what I’ve got on today, where is it? Oh it’s just in there. Ok so that’s all the things I’ve got on. Putting that (paper diary) in that (phone). But it’s all under…”

Exp: “The sort of options that you get?”

CD: “Aye it’s under your medication. I just write it all in and put it in there as I know it’s a basic whatever…”

Exp: “And then you use that phone (his own feature phone) to back it up?”

CD: “Yeah. I’ve not put it all in regularly but normally I do.”

This may explain why there was not an increase in task performance relative to the increase in number of reminders set between the non-UP and UP conditions. The tasks he would input into the phone did not match the events which he was entering into his feature phone. For example, he would remind himself about going food shopping, attending rehabilitation sessions and going to the betting shop. Therefore the way that CD used the phone was to remind himself about his own tasks using prompts about the experimental tasks. He did not always carry out the experimental tasks but they did remind him to check his schedule.

The insights which can be made from field notes taken during this lengthy trial testing the efficacy of ForgetMeNot and UPs highlight the advantages of single case experimental design studies with embedded involvement from the researcher. The rich details which can be obtained can be used to help interpret and understand the findings and can inform future research in this area. For example the insights described here highlight the importance of cognitive factors (such as insight into memory difficulties) and the environment and context (a highly structured rehabilitation setting) which influence the use of a technological memory aid intervention.

5.4.7 Future Research

Smartphone users may receive high numbers of unsolicited notifications, often referred to as pro-active or 'push' notifications. In 1991, Weiser imagined future technology as *quiet and invisible servants* which *create calm* (Weiser, 1991) and phones which offer frequent notifications, especially ones which were not solicited by the user, are anything but quiet and invisible. Even useful notifications may put people off using technology if they become a nuisance. When prompting people with ABI this problem is exacerbated. It is difficult to use prompting to encourage people to use technology without causing annoyance, especially if someone does not believe they need the memory support in the first place.

5.4.7.1 When to prompt

The purpose of our study was to investigate the impact of UPs, rather than to investigate when or how to present UPs. The UPs were received at random times, within the hours possible given the participants' rehabilitation schedules. ForgetMeNot is limited as it requires a carer or clinician to enter UP times. UPs could also be programmed to prompt randomly, or even predict when to prompt based on environmental cues. Decision making algorithms which are informed by sensors could also help determine the best times to interrupt. For example, Fischer and colleagues (2011) showed that people reacted faster to notifications if they were delivered after finishing a call or reading a text message (Fischer, Greenhalgh & Benford, 2011) and Ho and Intille (2005) suggest that notifications may be received more positively if they occur between two physical activities (e.g. walking or sitting). Alternatively, an algorithm could mute users phones in a personalized way in order to avoid unwanted interruptions (see Rosenthal, Dey and Veloso, 2011), which would allow notifications to be sent at any time without fear of an embarrassing disturbance. The study in this chapter has shown that UPs do lead to increased reminder entering. This effect could be enhanced if algorithms can predict and select the most opportune times to send UPs.

5.4.7.2 How to prompt

ForgetMeNot had to be noticeable to test the efficacy of UPs. The UPs beeped and flashed every 30 seconds if unanswered and this is likely to be more aggressive than the ideal UP. Future studies could test UPs which would balance nuisance with timely prompting. For example, some modalities of notification may be less disruptive than others (McGee-Lennon, Smeaton & Brewster, 2012); Warnock, McGee-Lennon & Brewster, 2013). It is telling that, despite two participants reporting that the UPs were annoying, they still entered more reminders into the app and showed better or equal memory performance during the UPs phase compared to the non-UPs phase. It seems that being annoyed with the app did not put people off using it or negatively impact the efficacy of its use during the two weeks in which users received the UPs.

5.4.8 Methodological Issues

The SCED methodology allowed us to observe day-to-day behaviour in the rehabilitation unit, report cases in great detail and perform a controlled trial with a group which could not be recruited in large numbers. In the context of research investigating behaviour over time in a real-world setting, a field test is often the only way to collect data on performance of intended activities. Given the time it takes to collect this kind of data with each participant, it makes sense to use a method which maximized the strength of the findings when there are small sample sizes. If the guidelines are correctly followed, SCED methodology allows studies to have experimental control and scientific rigour. HCI researchers could use SCEDs in the future to gather convincing preliminary evidence of the efficacy of assistive technology.

The study reported in this chapter followed the majority of the RoBiNT recommendations for SCED studies (Tate et al., 2013). However it was not possible to blind the therapist and participants to the study condition, there was no independent assessment of study adherence and there was no measure of generalisation of memory ability. The study was rated on the RoBiNT scale by the thesis author and received a score of 18/30. In a trial investigating the use of assistive technology it is difficult to blind the participants and experimenters to the intervention condition, especially when training has to be provided prior to the intervention condition. The fact that the experimenter calculated the outcome variable but was not blinded to study condition and study hypotheses may have meant that the results were biased to confirm the hypotheses. However, the potential influence of this bias was tempered by asking staff, blinded to condition and hypothesis, to participate in the data collection and by using automatic measures. On average, 79.05% of the data was assessed in this way. As the different types of memory performance assessor measured the performance of different tasks, it was not possible to calculate the inter-rater reliability. The content of the study sessions was not examined by an independent assessor and this may have led to bias (e.g. more time given to training in the UP condition compared to the non-UP condition). However, the fact that the study took place within the constraints of a rehabilitation centre meant that the number and time duration of the study sessions were independently regulated. A limitation of the study was that there were no generalisation measures taken. This means there was no way of investigating whether or not the memory compensation provided by ForgetMeNot had an impact on caregiver-rated, self-rated, or objectively measured memory ability.

While the NAP is a useful tool for understanding the difference between performance at two phases it is limited in its measurement of the size of an effect. For example a data set in which performance was at zero during every measurement in the baseline phase would receive an NAP score of 1 if the B phase data was all above zero, regardless of how far above zero each data point was. However it is argued that in the case of the study reported in this chapter, a mixture of the NAP analysis and visual inspection of the graph was sufficient to understand, and draw conclusions about, the data.

5.4.9 Conclusions

People with ABI often have cognitive difficulties including poor prospective memory (PM) which can be supported by reminder apps. However, PM difficulties can make it difficult for this group to remember to enter reminders in the first place. Unsolicited prompting from the reminding software is a potential solution to this problem. In this chapter SCED methodology was used to test the impact of unsolicited prompts (UPs) from a reminder app on reminder setting, memory performance and user experience for people with memory impairments after ABI. It was found that UPs increased the number of reminders set. However it is not possible to conclude from the results that this increase in reminder setting had a positive impact on memory performance. Reminding technology has great potential in memory rehabilitation and UPs could be a useful solution to a problem which people with memory impairments face when using this technology.

6 Chapter Six - Investigating the User Interface Design of a Reminder App for People with ABI

6.1 Introduction

Chapter five investigated an adaptation to a smartphone app with the aim of increasing reminder setting behaviour. Once the user initiates reminder setting behaviour they need to be able to enter the relevant information into the software via the device using the user interface (UI). If people with acquired brain injury are going to set reminders, then the UI design needs to be usable by people with cognitive impairments. Usability is defined as the ability of the users to set appropriate and accurate reminders using an app on a smartphone. This chapter aims to investigate the UI of a reminder app; how does the design of the reminding software impact the ability of the user to successfully enter reminders? How does the cognitive profile of the user impact the usability of different UI designs?

Firstly the human computing interaction, assistive technology and neuropsychology literatures was synthesised to give indications about how a reminders user interface (UI) influences usability for people with cognitive impairments, and how UI can support cognition during reminder entry. Both this literature and the findings from the focus groups reported in chapter three were used to develop ApplTree[1]; an app designed with different UI features to those found in existing reminder apps. A study then is reported which investigated the usability of ApplTree for people with ABI when setting six reminders. A within group design was used to compare the usability of ApplTree with a commonly used calendar based reminding app (Google Calendar). User experience when

[1] The app used in this study (named ApplTree) was designed by the thesis author and the software built using HTML5 (by Rachel Haugh, a level 4 computing science student at Strathclyde University as part of her project). All other work for this chapter was undertaken by the thesis author with input from PhD supervisors.

using the apps, and the impact of the cognitive profile of the participants on usability of each app, was also investigated.

6.1.1 Setting a reminder on a smartphone

Chapter five described the design of a reminder app called ForgetMeNot that limited the user to setting a small number of tasks for the current day. FogetMeNot was designed to reduce the cognitive demand during use for the purposes of the study (to test the impact of unsolicited prompting). This chapter focuses on reminder apps that allow any type of reminder to be set for any day, and which also allow the addition of notes and event repetition. The key processes involved in setting reminders are defined below.

1) Open the app
2) Select a date and time to add a reminder or select 'add reminder' option or equivalent
3) Enter title / event name
4) Select the day / date
5) Confirm day / date and enter exact times
6) Set repetition options
7) Set reminder options
8) Enter further information if required (e.g. writing a note)
9) Confirming / saving the reminder
10) Editing or deleting previous reminder, and / or creating a new up-to-date reminder when presented with new information

A usable reminder app would allow the user to complete each of these steps described above. There is a growing literature which outlines design features which can improve software's usability for cognitively impaired groups. The majority of this research has investigated web page design to enable users to navigate the web (Hu & Feng, 2015) or email layout to enable users to enter emails successfully (Sutcliffe, Fickas, Sohlberg & Ehlhardt, 2003). In this chapter the design concepts which come from this research are applied to enable users to set reminders using software on a smartphone.

6.1.2 Cognition and Usability in HCI

Human Computing Interaction researchers have developed web interface design guidelines for people with cognitive impairment. The research which helped to develop these guidelines was carried out with people with different types of impairment such as developmental difficulties (Davies, Stock and Wehmeyer, 2001), ABI (LoPresti, Kirsch, Simpson and Schreckenghost, 2005) and dementia (Freeman, Clare, Savitch, Royan, Litherland & Lindsay, 2005). The consensus from researchers working to create guidelines for accessible computing for people with cognitive impairments has been that while these groups may be diverse, they have many overlapping difficulties which make general guidelines valuable. Two influential papers have listed the top four recommendations which they synthesised from the literature. Friedman and Bryen (2007) reviewed the literature and collated the most common web recommendations for designing for people with cognitive impairments. The top four recommendations, cited in the majority of papers, were:

1) Use pictures, graphics, icons, and symbols along with the text
2) Use clear and simple text
3) Use consistent navigation and design on every page
4) Use headings, titles, and prompts

Freeman *et al.* (2005) developed very similar guidelines after reviewing the web accessibility literature for people with dementia:

1) Use colour and contrast cues to direct the user around the website
2) Use visual cues such as pictures and icons in addition to verbal cues
3) Use simple language
4) Minimize the number of choices on each page

Several of these guidelines were echoed in the feedback from the focus group described in chapter three. Participants called for a reduction of the amount of information presented on each screen. As well as being a visual accessibility issue due to the small screen size, participants also mentioned the role of attentional difficulties. For example people said they would find it difficult to find relevant information when a large amount of information was presented at once, especially if the feature they were trying to find was obscured from view. Participants also reported difficulty understanding the abstract symbols such as waste paper basket for delete.

The difficulty with the application of these guidelines is that the software which they apply to have a number of functional requirements, such as setting reminder name, date, time, repetition, notes etc. Therefore a large amount of content is needed to allow a user to set an effective reminder. It can be challenging to present this on a small smartphone screen while still adhering to the accessibility guidelines, many of which inevitably lead to an increase in content size or a reduction of functionality. For example, consistently cited recommendations such as using visual cues or pictures, and using clear (and presumably large) text, icons, and symbols would require more information to be added to an already cluttered screen.

To counter this, designers may reduce the amount of content presented. It may be possible to reduce some of the content presented within a reminding app without critically compromising the functionality. An example of this approach is presented by Newell and colleagues (2006) who radically reduced the amount of content of an email system, improving usability for older users (Newell, Dickinson, Smith and Gregor, 2006). However this study highlighted the challenge of creating commercial software that meets the demands of the general population and which is also usable for inexperienced or cognitively impaired users. Simplifying by removing content may be a limiting solution. For example ForgetMeNot did not have date, repetition or note taking functions, and new types of events could not be added. This limited the reminder to prompting about only a few tasks for the current day. Furthermore, it was clear from the focus group study in chapter three, and from participant KT's feedback about

ForgetMeNot in chapter four, that participants wanted more functionality from a reminding system, or for new content to replace features which were not perceived as useful with different ones. For example participants suggested the removal of the time zone selector from Google Calendar but also requested a more prominent notes function and the ability to change the notification modality. In order to both improve accessibility of smartphone reminding software according to research led recommendations, and retain key reminder setting functionality, it may be necessary to alter the structure of the UI and increase the number of screens over which the content is presented.

6.1.3 Narrow vs. broad UI structures

A recent study investigated the impact of the structure of a web search interface on site navigation success for people with cognitive impairments from various aetiolgies (Hu & Feng, 2015). They compared ‘Narrow/deep’ interfaces; which have little information on each screen but have several screens, to ‘Broad/shallow’ interfaces; which have large amounts of info on each screen but few screens. Their findings indicate that a narrow/deep web search interface is preferable compared to a broad/shallow UI for people with cognitive impairments. This is different from findings with people without cognitive impairments and people with visual impairments without cognitive impairments who have the opposite preference; liking, and performing better with, broad/shallow web search interfaces compared to narrow/deep interfaces. For example Parush and Yuviler-Gavish (2004) found that broad/shallow structure on feature-phone mobile and personal computer (PC) was preferred by healthy young participants who regularly used technology. Hochheiser and Lazar (2010) found similar results for blind participants using screen readers to navigate a computer screen.

The research described above took place in the context of web browsing on PCs and mobile phones. It is likely that the findings would translate to smartphone reminder interfaces because they have a similar UI structure trade-off; a lot of information could be presented on a small number of screens (sometimes leading to the need to scroll though larger amounts of information) or a small amount of information could be presented on a large number of screens. Calendar based apps such as Google Calendar have broad / shallow designs. For example, Google

Calendar has two main screens but a very large number of interactive elements on each screen (e.g. calendar time-slots and event name, time, date etc.). Calendar based reminding software, with this type of UI structure, has been investigated by researchers interested in the use of smartphone prompting by people with cognitive impairments (e.g. de Joode, Proot, Slegers, van Heugten, Verhey & van Boxtel, 2012; McDonald, Haslam, Yates, Gurr, Leeder & Sayers, 2012; Svoboda & Richards, 2009; Svoboda, Richards, Yao & Leach, 2015; Evald, 2015). However, if findings from the literature investigating web-browser structure are also true for reminder software, then a narrow/deep structure would be preferable for people with cognitive impairments. It may also allow the accessibility guidelines described above to be applied without reducing the functionality of the software. This chapter describes an experiment involving ApplTree, a reminder designed with a large number of screens, each with a limited amount of information.

6.1.4 Decision Tree Processing

A difficulty with narrow/deep structures is that it could lead to a very large number of screens which could frustrate more experienced users and lead to a large amount of time being taken to set reminders, compared to a broad/shallow structure. One solution to this problem is to build decision tree processing into the software so that the information already entered by the participant alters the content presented to the user. For example, if the user tells the system that the reminder is for a birthday party, then the system could specifically prompt them about the location or birthday presents. Alternatively if the user indicates that the reminder is for medication then the location and birthday present prompts are irrelevant, and the system would prompt about type of medication or about events after which the medicine should be taken (e.g. meal times).

As well as reducing the number of screens required, decision tree processing could help to guide people with cognitive impairments through the process of setting reminders. This kind of programming is used in GUIDE, a micro-prompting assistive technology developed to help people with cognitive impairment perform medical or everyday tasks such as donning prosthetic limbs (O'Neill, Moran & Gillespie, 2010) and self-care during a morning routine (O'Neill, Best, Gillespie & O'Neill, 2013). In GUIDE the user's 'yes' or 'no' responses to the system's questions lead to different subsequent questions or prompts. For example, when GUIDE is being used to help with prosthetic limb donning during a morning routine it would ask check questions such as, 'have you got your socks?' If the user answered 'yes' to this question then GUIDE would move onto the next step. However if the user answered no then the system would move onto a problem solving routine prompting about common places where the socks might be. In the GUIDE system, decision tree processing scaffolds cognition to guide people through everyday tasks with several sub-steps. Decision tree processing can work in a similar way within a reminding app to scaffold cognition during the sub-steps of reminder setting.

6.1.5 Neuropsychological theory

Some studies have investigated the abilities of people with cognitive impairments after ABI to complete tasks on a calendar based user interface in a rehabilitation setting. De Joode *et al.* (2012) used a mixed methods approach to compare the use of standard calendar software on a PC by people with ABI (n=15) compared with control participants (n=15). A series of reminding tasks was given to participants, and experimenters gathered both quantitative measures of their performance (ability to set the correct reminders, and their speed when setting them) and qualitative data concerning their interaction with the system. Qualitative results indicated that the participants with ABI experienced stronger negative emotions and became tired more quickly than controls, particularly when they had difficulty using the software. Quantitative results showed that while both groups made the same kinds of errors, the healthy group made errors less often, and needed less time and less mental effort to complete the tasks. The cognitive abilities that were reported to have an effect on task performance were self-monitoring, ability to learn from mistakes and successes, remembering the assignment long enough to enter all of the reminder, and devising problem solving strategies such as searching the screen or trial and error. Other studies have shown that processing large amounts of information at one time is difficult for people with ABI (Ruttan, Martin, Liu, Colella & Green, 2008) and that people with dysexecutive syndrome, which is common after ABI, may have difficulties with error monitoring (Manly, Ward & Robertson, 2002). For people with severe memory impairment, trial and error learning is ineffective and this has led to the development of errorless learning strategies (Wilson, Emslie, Quirk & Evans, 2001). When applying errorless learning strategies clinicians aim to reduce the number of errors that are made during learning and utilise procedural memory to aid the development of skills. Errorless learning has been used during training with standard calendar software on a smartphone (Svoboda et al., 2009; Svoboda et al., 2012), however software that has been designed to reduce trial and error learning has not been tested in a rehabilitation context. When discussing the results of their study, de Joode *et al.* (2012) suggest that more appropriate software for this population should have an interface which presents only a small amount of relevant information at a time and which uses step-wise serial data entry to minimise burden on working memory and executive abilities. This kind of design may also reduce the need for trial and error strategies, for example when figuring out which button to press from a number of options.

Sutcliffe and colleagues (2003) investigated the use of a PC based emailing system for people with ABI (n=8) and made user interface recommendations for users with different cognitive profiles. Recommendations include reduced task and dialogue complexity, and clearly presented progress status displays to reduce memory load and support error monitoring for people with working memory impairment. They also suggest that people with limited attention span would benefit from an interface which limits distractions and makes current task objects salient in order to support continuous engagement.

A narrow and deep web search structure will allow people to choose between a small number of options, decreasing the amount of demand on working memory and attention required on each page. In a reminding system, if each piece of information required to set an understandable reminder could be input on its own screen, it could reduce the amount of cognitive load required to focus attention on one part of the screen. A narrow / deep structure could also guide the switching of tasks (e.g. between inputting the event name and event date) using a 'NEXT' button to prompt the user, making it less likely that a crucial piece of information would be left out. Having one screen for each piece of information being input into the device would also allow more guidance about what information is required (e.g. examples of event names). Decision tree processing, while reducing the number of screens required to enter a coherent reminder in a narrow/deep UI, may also support cognition by reducing working memory load. Once the user has established that the task they are setting a reminder for is an appointment then software with decision tree processing could keep them informed about the type of reminder they were setting (e.g. by asking 'What is your appointment for?' or 'What time is your appointment?'). This may prevent people from losing track of which event they were setting before they have entered all information for that reminder. Decision tree software could also prompt them to input information relevant to that type of reminder (e.g. name of the medication if a medication reminder is selected). This could reduce working memory load compared to a system which prompts generic information (e.g. one that prompts the user to input the name, time and date of the event regardless of what type of activity the user is trying to enter).

These examples provide a basis for preliminary predictions; that working memory and executive abilities, which are required to successfully use a standard calendar app with a broad / shallow structure, will be at least partially supported when using an app with narrow / deep structure and decision tree processing. In particular, abilities involving executive attention such as self-monitoring, switching between tasks and selectively attending to a specific feature in an array, as well as working memory capacity, should be supported by such design features.

6.1.6 ApplTree

The ApplTree reminder app was designed based on some of the recommendations from literature outlined in the introduction to this chapter. Some of the design features are noted within figure 6.1 alongside screen-shots of the app;

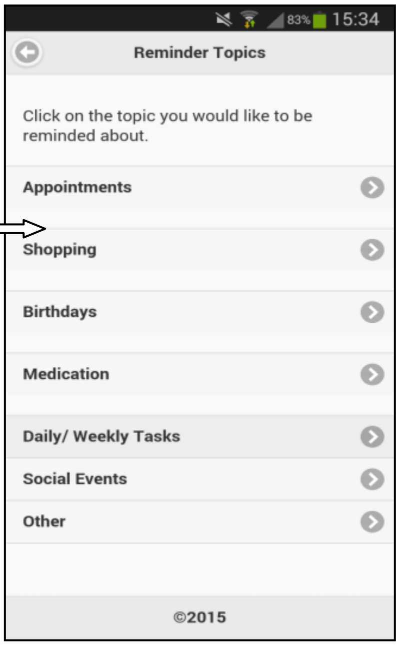
1) **A narrow / deep structure of several screens each requiring a small amount of information to be entered.** This frees up screen space to allow extra information to be added. For example a text based explanation in the opening screen of the icons used in the app (e.g. left pointing arrow for back one screen and a house symbol for home screen)

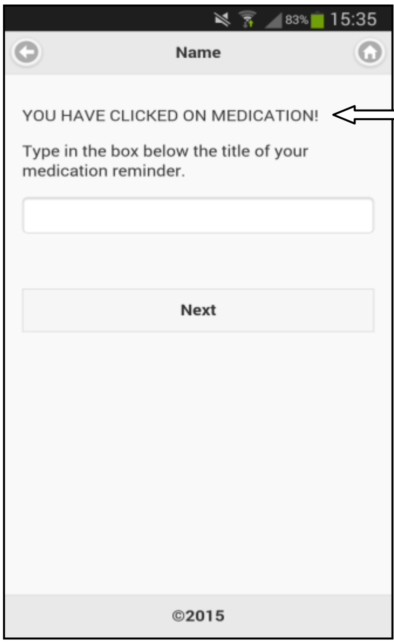
2) **Some element of decision tree processing so that the input options differ depending on the type of event chosen.** To facilitate this, there is a selection of types of reminders instead of a calendar screen as the home screen.

A narrow / deep structure cannot easily include a calendar screen with several interactive elements and so a selection list of different categories of reminding task was used to prompt reminder entry. Furthermore this selection list in the home screen was necessary in ApplTree in order to create the decision tree design because it allowed the subsequent screens to be ‘branches’ of the reminding task category which was selected. In a broad / shallow design it is not desirable to explain every symbol used, and is desirable to use more abstract symbols in order to save space (e.g. plus sign for add reminder, X for delete). In a narrow / deep design there is more space to explain symbols and less need for abstract symbols (only back arrow and return to home screen symbols were used in ApplTree). ApplTree was built on HTML for the Android platform and standard Anroid date and time selector widgets were used. Date could be selected by scrolling date, month and year and time could be selected by scrolling through hours and minutes on a digital time selector.

Narrow / deep structure: ApplTree has a small number of interactive elements on each screen but has many screens.

The home screen of the app is a list of different kinds of events. This prompts the user to think about what type of reminder they are

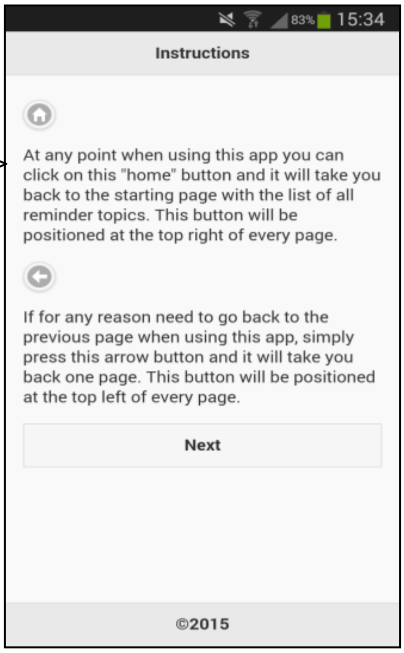


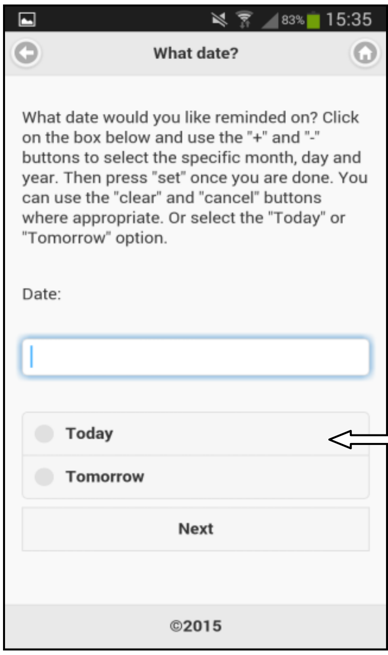


The input options presented on subsequent screens are altered when different types of reminders are selected. For example, if medication is selected then the next screen asks for the title of the medication

Narrow / deep design reduces the amount of information which needs to be presented on each screen. This frees up space for 'home' and 'back' symbols to be consistently presented on each screen. Increased screen space also allows more options to be added to certain inputs, for example 'today' and 'tomorrow' options on the date screen.

Abstract symbols representing 'home screen' and 'back one screen' are explained clearly in the app's opening screen.





'today' and 'tomorrow' tick-box options are added to the date selection screen, to supplement the date selector widget.

Figure 6-1. Screenshots from ApplTree with examples of how the design criteria were implemented.

6.1.7 Study: aims and predictions

The following study aimed to evaluate the use of an app with a narrow / deep design and decision tree processing (ApplTree) by people with acquired brain injury. To do this, use of the app when setting six everyday reminders was closely examined and usability was evaluated by rating the reminders which were set to an ideal set of reminders. For comparison, a standard and widely used reminding app which has a different type of interface design was also evaluated using the same reminder setting assignment in a within group design. Google Calendar has a broad / shallow design and does not use decision tree processing.

It was predicted that ApplTree would be more usable for people with ABI compared to Google Calendar. It was also predicted that ApplTree would support cognition such that people with ABI would experience less task load when using ApplTree than when using Google Calendar. A detailed analysis of the use of both apps was carried out to understand which features of both apps are difficult to use for this group. A secondary aim was to investigate the influence that neuropsychological profile has on the usability of reminding apps with different interface designs.

6.2 Methods

6.2.1 Participants

Participants (n=14) were recruited during a regular head injury support group meeting for people with acquired brain injury in the Glasgow area run by the charity Headway (n=12) and from Graham Anderson House, a rehabilitation hospital for people with severe acquired brain injury (n=2). Adults aged 18 or over who had experienced an acquired brain injury and who had self-reported memory impairment were considered for this study. Exclusion criteria were the inability to provide informed consent for research participation or inadequate writing or reading (self-reported or observed) which would prevent them from completing the tasks required in the study. Included participants did not have severe verbal communication difficulties that would impair their ability to communicate, or severe physical impairment that would prevent their use of a smartphone device. Nineteen participants who met the study criterion were initially approached. Three participants did not take part in the study because they did not wish to participate (n=1, from Graham Anderson House), or because, after providing their contact details, they did not respond after being contacted by the experimenter (n=2, Headway). Two participants were removed from the study after randomisation to group because, after further assessment by the experimenter and caregivers, they were adjudged to have behavioural difficulties that would have made the study too difficult for them to complete (n=2, from Graham Anderson House). The cognitive profile of participants is reported in table 6.1 (see section 6.3 Results).

Ethical permission was granted from the National Health Service Regional Ethics Committee (NHS REC) on 10.04.15 (reference number 15/WS/0064) and from the Disabilities Trust Research Ethics Committee (DTREC) on 07.08.15.

6.2.2 Materials

Participants were asked to enter the same set of reminders into two reminding applications with different user interface designs. The reminding tasks were adapted from assignments used in de Joode *et al.* (2012). They were developed by these researchers to represent normal everyday reminding tasks. The tasks used in this study can be seen in figure 6.2. There were differences between the assignments used in De Joode *et al.* (2012) and the current study. For example assignment 3c and 4b were removed in order to reduce the overall time that the study would take and therefore increase the likelihood that the participants would complete all of the assignments. When making decision about which particular assignments would be removed, three factors were considered (these judgements were made by the thesis author). These were; how cognitively demanding or confusing the task was, maintaining the important aspects of each assisgnment so that there was something new in each assignment, and maintaining a gradual increase in task complexity from the first assignment to the last in order to ensure that as many tasks as possible could be completed. This alteration was made because several of the participants with ABI did not complete all of the assignments in the De Joode *et al.* (2012) study. References to an electronic calendar were also removed because the ApplTree app did not use a calendar-based interface. Assignment three was changed to involve medication because this is a common type of reminder for this group, and inclusion would allow a comparison of the medication specific reminder setting UI in ApplTree with the generic reminder setting UI in Google Calendar. Dates were updated to match the dates which were current when the participants were recruited (between June and October 2015).

Assignment 1 You have just made an appointment with your GP for June 8th 2015 April 14th 2011, from 2 to 2.30 p.m. A. Put this appointment in your reminding app electronic calendar. B. Include the name, address and telephone number of your GP*. C. As you want to remember to ask for a repeat prescription of your medication, add a separate note. Assignment 2a Tomorrow you want to do your shopping. This has to be done between 10 and 12 in the morning; it will take you one hour. A. Enter this task in your reminding app electronic calendar. B. Be sure to include your shopping list*. *This information was provided with the assignment. Assignment 2b Your next-door neighbour just came by and asked you to come over tomorrow between 10 and 11 a.m. to have coffee with her. A. You have accepted this invitation, so enter this appointment in your reminding app electronic calendar. B. Make sure you have time left to do your shopping before noon. Assignment 3 Every day take medication (Aspirin) at noon you have lunch from noon to 1 p.m. – it usually takes you one hour. When you are very busy, half an hour is enough. A. Enter this medication lunch break into your reminding app electronic calendar, adding an alarm, for every day of the coming week. B. You have promised a neighbour to help him plant a tree in his backyard tomorrow on Thursday. He asked you to be there at 12.30 p.m. Make a note about this in your reminding app electronic calendar. Make an

entry in your electronic calendar for this appointment.

C. See to it that you have lunch before you go to the neighbour's.

Assignment 4

Starting next Tuesday, you are going to take a course on photography.

The classes are every Tuesday and Thursday, from

7 to 9 p.m.

A. Enter these appointments in your reminding app calendar, up to and including the last class on April 12th.

B. The class of March the 31st will be cancelled and will be transferred to April 1st. Adjust the appointments in your calendar.

C. There will be a return visit on Monday 20th July Monday 26th April, at the usual time. Enter this in your reminding app calendar too.

Assignment 5

Because you tend to forget to switch off the central heating or your computer at night, you have decided to put your evening's routine in your reminding app calendar.

Put these tasks down in your reminding app calendar for the next 3 days.

Please add an alarm to each of them:

A. 8:00 p.m. close shutters

B. 10.00 p.m. lower heating

C. 10.05 p.m. switch off TV and other appliances

D. 10.10 p.m. lock and bolt front door

E. 10.15 p.m. switch off computer

Figure 6-2. Reminding tasks adapted from De Joode et al. (2012). Deleted text is presented in red font, inserted text is presented in green font.

Demographic information was gathered by asking participants to report their age, gender, time since injury, aetiology of injury, education, phone ownership and smartphone ownership. Participants were also asked to indicate how often they used electronic and non-electronic calendars, and how useful they found these, and responses to these questions were scored on a five-point likert scale numbered from 0 to 4. When answering how often they used electronic and non-electronic calendars the choices were never, rarely, occasionally, often or very often. For answering how useful they found the memory aids the choices were not at all, somewhat, useful, very useful and extremely useful. Neuropsychological tests and questionnaires were also given to participants to develop a cognitive profile and to assess self-reported memory and cognitive impairment. The neuropsychological tests performed were the Dalis-Kaplan Executive Functioning Scale (DKEFS), fluency and sequencing sub-scales (Delis, Kaplan & Kramer, 2001), and Rivermead Behavioural Memory Test (RBMT) (Wilson, Cockburn & Baddeley, 1991). The primary reason for including these scales was to build a cognitive profile for the participants in this study. For example the Rivermead was chosen because it gives an overall indication of memory ability and also has four items which can be pooled together to give an indication of prospective memory ability. The fluency and sequencing subscales were chosen because they give an overall indication of executive functioning compared to the general population. The Delis-Kaplan tests also give more specific measures of the abilities which ApplTree may support such as monitoring performance (verbal fluency and letter number switching) processing speed (fluency and sequencing speed), selective attention (visual scanning) and executive switching ability controlling for processing speed (letter number switching vs. sequencing and category switching vs. fluency alone). Table 1 summarises cognitive profile on each neuropsychological tests for the participants included in the study.

Self-report questionnaires were also given to measure insight into cognitive (cognitive failures questionnaire (CFQ) (Broadbent, Cooper, Fitzgerald & Parkes, 1982)) and memory abilities (Prospective and Retrospective Memory questionnaire (PRMQ) (Crawford, Smith, Maylor, Della Salla & Logie, 2003)). Finally, it was of interest whether or not the participants experienced different levels of task load for each of the different interface types or had different user experiences while using each app. The task load and user experience were assessed using the NASA Task Load Index (TLX) (Hart & Staveland 1988), and through assessment on eight domains from the unified theory of acceptance and use of technology (UTAUT) (Venkatesh, Morris, Davis & Davis 2003). The TLX was chosen because it gives an indication of user preference which is centred on the amount of task load participants experience when using technology. Therefore it was considered a useful tool for comparing two apps, because the features and structure of the ApplTree UI were designed to reduce the task demand of setting reminders. TLX asks about mental demand, physical demand, temporal demand, evaluation of performance, evaluation of effort needed to achieve that performance and level of frustration. These scores (each on a scale of 1 to 20) were reported separately and aggregated together to create an overall task load score. The UTAUT was included to allow a detailed comparison of the participants' experiences when using both apps. It includes groups of items concerning the following: performance expectancy (expectancy that the tech will be useful for its purpose), effort expectancy (perceived effort needed to use it), attitude towards the technology, social influence (the influence of others on the use of the technology), facilitating conditions (the extent to which their environment facilitates use of the tech), self-efficacy (estimations of their own ability to use the technology), anxiety (levels of anxiety felt when using the tech) and behavioural intention (an indication of whether the participant is intending to use the tech in the next 6 months). Scores for each item (on a scale of 1 to 6) within each domain were aggregated to give overall scores for each domain at each time point.

The hardware which was given to participants was either a Samsung Galaxy S3 or Google Nexus 5 smartphone. Both of these are android phones with almost identical screen dimensions (S3 = 5.38 x 2.78 inches (136.6 x 70.6mm), Nexus 5 = 5.43 x 2.72 inches (137.9 x 69.2mm)), both have a depth of 0.34 inches (8.6mm), and have the same default keyboard and back button position (bottom right centre). Both phones were set to tap rather than swipe text entry with three predictive text options appearing just above the keyboard and phones were set to silent for the duration of the study. The reminding software was ApplTree apps (described above) and Google Calendar.

6.2.3 Google Calendar

Google calendar was chosen because it is in widespread use and because it has, along with apps with similar calendar based design, been used as rehabilitation tools in studies with people with acquired brain injury (e.g. McDonald et al., 2011; De Joode et al., 2012). Screenshots of this interface are presented in figure 6.3. The version of Google Calendar used was available to download from April 2014 onto a Samsung S3 device. This was the same version of Google

Calendar demonstrated in the focus group study in chapter three. It has the following design structure and features;

1) A broad / shallow structure of two main screens with several interactive elements

2) A generic reminder setting structure (the input options remain the same no matter what information is added)

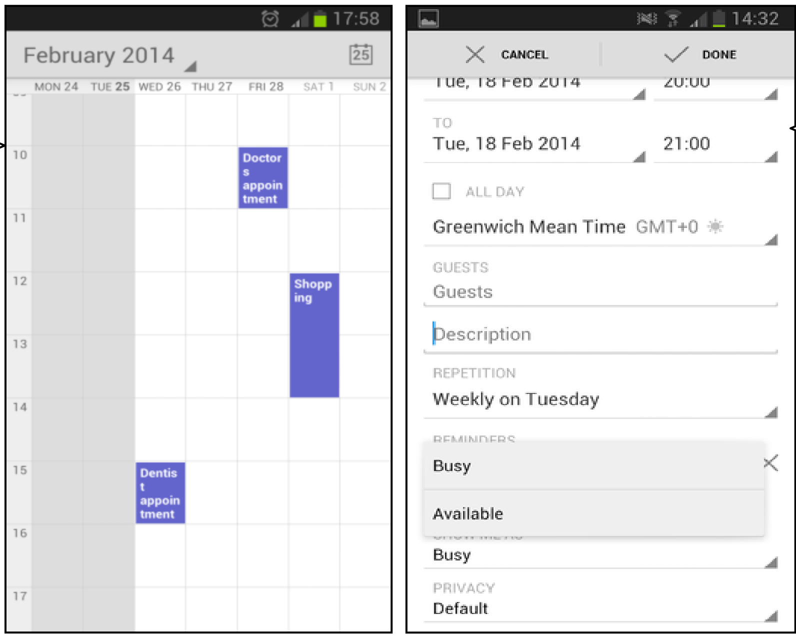
3) A calendar interface as the home screen which presents information about previously scheduled events

4) Abstract symbols (icons) with no text based explanation of their meanings (e.g. a trash can symbol for delete and a pencil symbol for edit)

Broad / shallow structure

Google Calendar has a large number of interactive elements on each screen but with only two main screens; calendar view (left) and reminder setting screen (right).

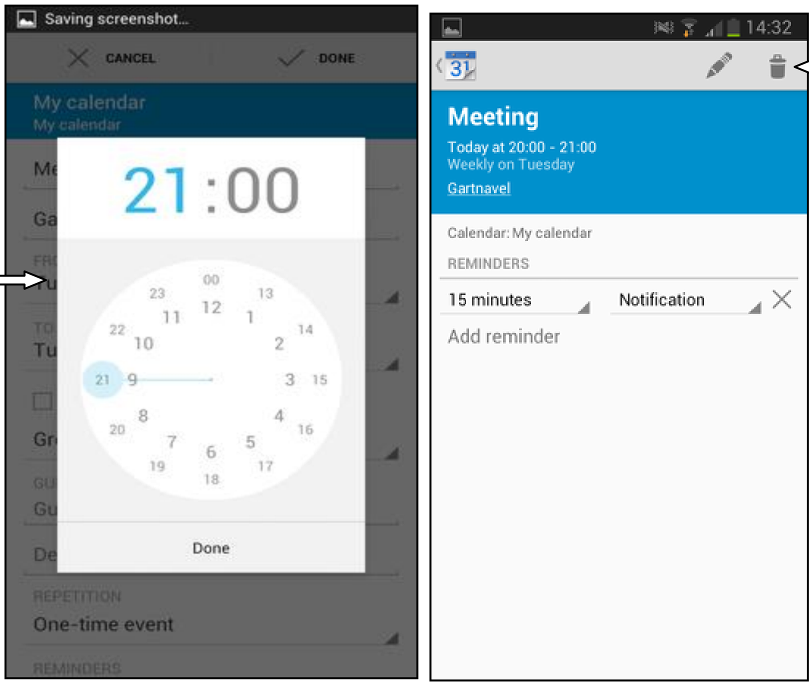
The home screen of the app is a Calendar with numerous interactive elements. Calendar view can be changed to monthly, weekly and daily



Reminder setting screen is generic and input options do not change when different information is entered

Broad / shallow design leads to a lot of information needing to be presented on screen. Designers have addressed this problem by creating widgets which pop-up when a button is pressed and by using abstract symbols to represent further options.

The analogue / digital clock pop-up widget is used for time selection.



On the top bar of the edit screen, abstract symbols are used for options to edit, delete and return to calendar screen.

Figure 6-3. Screenshots from the version of Google Calendar used in the study with examples of key design features..

6.2.4 Comparing the apps

ApplTree and Google Calendar have many different features. For example, the time selection in Google Calendar was an analogue clock interaction while a digital clock interaction was used in ApplTree. Date selection used a calendar based interaction in Google Calendar while ApplTree used a day, month and year display with plus and minus symbols to add and subtract each time unit. These time and date interactions were chosen in ApplTree in order to maintain a small number of interactive elements within each screen. The study described in this chapter was an evaluation of a newly designed reminder app developed with the cognitive difficulties which can occur after ABI in mind. Google Calendar is used as a comparison app in this study to provide a control condition to find out whether or not ApplTree is more usable than one of the most commonly used reminder apps. It also allows a detailed analysis of the usability errors which occur when apps with different designs are used to set reminders.

6.2.5 Design and Procedure

The primary independent variable was the app being used (ApplTree or Google Calendar). Secondary independent variables included demographic information and scores on the cognitive and memory self-assessment, and neuropsychological assessment measures. The primary dependent variables were the performance measures for the five reminder setting assignments (accuracy, speed and amount of guidance needed) as well as the TLX and UTAUT scores.

This study had a within-subjects design to compare various performance and preference outcome measures when using Google Calendar and ApplTree. Study sessions took around three hours; however this varied considerably because of participants' different speeds completing the reminding tasks. Some participants completed the study in one session and others were seen in a number of shorter sessions. The main experimenter (MJ) was present with the participant at all times during the study. The study procedures took place in the following order - however the order in which the apps are presented to participants was randomised using an online research randomiser (www.randomizer.org). Six of the participants who provided data used in the analysis were randomised to use ApplTree first and eight used Google Calendar first. This slight mismatch occurred because the two participants who left the study after randomisation were both assigned to use ApplTree first.

1) signing of consent forms
2) demographic information
3) Assignments for first app
4) TLX and UTAUT completed after app one
5) Break
6) Assignments for second app
7) TLX and UTAUT completed after app two
8) Cognitive Failures Questionnaire and Prospective and Retrospective Memory Questionnaire
9) Delis-Kaplan subtests and Rivermead.
10) Debriefing

Participants were asked to complete the tasks as quickly and accurately as they could and were told to attempt to complete the assignments by themselves first, but to ask the experimenter for help if they became stuck. Prior to the study it was considered likely that some participants would not complete all of the assignments for both apps. This was due to the large number of reminders that the assignments required participants to set for both apps (see Figure 2), the cognitive and behavioural difficulties which participants experience because of the brain injury and because several participants with ABI in De Joode *et al.* (2012) failed to complete all of the assignments. The outcome variables speed, guidance and accuracy were calculated as a mean of the completed tasks, rather than an overall score. This was to allow comparison between participants who did not complete all the assignments and participants who did complete all five assignments.

Mean speed in seconds to complete an assignment was calculated for all completed tasks. For the measure of guidance the number of times guidance was requested was tallied by the experimenter each time a participant asked the experimenter for help. When help was asked for, the experimenter would inform the participant of the next step. The guidance score used in the analysis was average number of times guidance required for each task (overall number of times guidance was needed divided by number of assignments completed). Total TLX score was calculated out of 120 and total UTAUT score calculated out of 174 were included in the analysis as well as each individual sub-score (total out of 20 on TLX and a mean out of 6 for the UTAUT items).

The thesis author documented each reminder set by the participants for each task. An independent, blinded rater was used to help calculate accuracy because the quality of the reminders set by the participants could be interpreted in different ways and the accuracy score given to each participants could change depending on the scoring method created. For example, if a reminder is set at the wrong time because it is early and on the correct day, should this get the same score as a reminder set after the event? If these kinds of decisions were made by the experimenter, who knew the study hypothesis, then it may have led to scoring biases or the development of a scoring system which would bias the results towards supporting the hypothesis. Therefore the reminder tasks were transcribed onto a word document, anonymised for participant and information about which app they were using was removed. This document and the list of assignments were sent to a colleague who was uninvolved in the study and blind to the study aims or hypotheses. This blinded assessor created a scoring method (shown in section 6.6 Appendix) and used it to calculate each participant's mean accuracy score for each app. This scoring method was then used by the main experimenter to create a second set of accuracy scores. A one-way, average score Intraclass Correlation (ICC) was conducted to investigate the level of consistency between raters. A high degree of reliability was found between the rater's scores. The average measure ICC was 0.961 with a 95% confidence interval from 0.916 to 0.982 ($F(27,28)= 25.5$, $p<0.001$). Since the IRR was high it was decided that there was no need for a third rater. The small differences between the scores were resolved after discussion between the two scorers and these compromise scores were used in the final analysis. The accuracy score that was used in the final analysis was a percentage of the total score that participants could have received for the assignments they completed.

Neuropsychological data from the Rivermead and Delis-Kaplan tests were either converted into a percentile rank or scaled score using test manuals. The CFQ (out of 150) and PRMQ scale (out of 80) total scores were calculated. A pooled cognitive profile score was also calculated and used in the analysis. For this, the neuropsychological variables reported in table 1 were converted into z-scores and aggregated together.

6.2.6 Hypotheses

The hypotheses below relate to the primary aim of the study which was to find out if there were any differences in reminder setting performance and user experience between the apps.

H1: People with ABI will perform the reminding tasks more accurately overall with ApplTree compared to Google Calendar.

H2: People with ABI will require less guidance during the reminding tasks when using ApplTree compared to Google Calendar.

H3: People with ABI will rate Appltree as requiring less task load than the Google Calendar app on the Task Load Index scale.

The narrow / deep structure of ApplTree may lead to the users having more screens to navigate and therefore it may take people longer to set reminders. However since decision tree processing has been added to reduce the number of screens required, and because the same information needs to be added into each app regardless of app structure, it was predicted that there would be no difference between ApplTree and Google Calendar in time required to complete the tasks. Exploratory analysis was carried out to investigate the difference between the accuracy/speed trade-off, UTAUT total, UTAUT sub-scores and TLX sub-scores for the two apps.

Secondary and tertiary aims: Exploratory analysis was also carried out to investigate the influence of neuropsychological test scores on the performance of the tasks with each app. Exploratory descriptive analysis was carried out to explore the data concerning the types of errors made by participants when setting reminders using both apps.

6.2.7 Statistical Analysis

6.2.7.1 Power Analysis

As there have been no group studies directly comparing one app to another for people with ABI, the study by De Joode *et al.* (2012), which looked at the difference in personal computer calendar reminder setting performance between people with ABI and healthy controls, was used as the basis for a power calculation. The justification for this is that the ApplTree app is predicted to scaffold reminder setting performance to the extent that it makes participants with ABI perform to the level of healthy controls. In The De Joode *et al.* (2012) study, Cohen's *d* for difference between people with ABI and control participant's performance was 1.1, (X^2 analysis; X^2 = 6.51, n = 29, p<0.05). Participant performance using the app was the primary outcome variable in this study and so this effect size was used in the power analysis. Using G-power, it was calculated that a two-tailed Wilcoxon signed-rank test (matched pairs) with an effect size of 1.1, an alpha probability of 0.05 and a power of 0.95 would require a minimum of 14 participants. Fourteen participants were recruited in the study with two failing to complete all the study measures (see Primary Aim section of the results for more details).

6.2.7.2 Data Analysis

Non-parametric tests were used for this analysis because normality could not be assumed for a sample of 14 participants. This was confirmed through inspection of histograms of the main outcome variables (accuracy, speed and guidance) that showed both positively and negatively skewed data.

Wilcoxon signed-rank tests were used to compare the participants who used Google Calendar first (n=8) with the participants who used ApplTree first (n=6) on demographic variables and to investigate order effects by comparing performance on the app participants used first vs. performance on the app participants used second.

Wilcoxon signed-rank tests were also used to investigate the differences between the two apps on the performance, task load and user experience measures. Pearson's r coefficient was calculated to give effect sizes for Wilcoxon signed-rank test if the result was found to be significant when alpha error probability is set at $p < 0.05$. Spearman's Rank correlations were used to examine the relationship between demographic factors and selected outcome variables using the two apps.

When investigating the influence of neuropsychological test on performance of both apps Spearman's Rank correlations were conducted between each of the neuropsychological test score and outcome measures. Wilcoxon signed-rank tests were carried out to explore the relationship between Neuropsychological measures and the differences between the usability and user experience of Google Calendar and ApplTree. A Fisher's r to z transformation was used to analyse the difference between the correlation between pooled neuropsychological test score (a proxy for overall cognitive ability) and performance (accuracy) when using Google Calendar and ApplTree. The pooled neuropsychological test score was calculated for each participant as the average of the z-scores for each test score reported in table 6.1.

The errors which participants made using both ApplTree and Google Calendar when setting the 5 reminders in the assignments were reported descriptively. A tally was created to count the frequency of different types of error. The errors were then grouped by the thesis author according to which reminder setting step the mistake was made (i.e. when entering the time, date, notes and repetition or title of the reminder). The actual reminders set by a representative participant are also reported as an example of the types of error made, and the differences between performance using the two apps.

6.3 Results

6.3.1 Demographic information

The participants in the study had an average age of 52.2 (SD = 8.2), six (42.9%) were female. The median time since their most recent head injury was 286 weeks (range = 52 to 1300). The mean number of years that participants reported spending in education (n=13 because one participant did not give this information) was 13.9 years (SD = 2.99). Cognitive failures total score mean was 59 (SD = 28.2, n = 12) (over 1.5 standard deviations above the mean for male car factory production workers (mean = 35.02 , SD = 11.52, n = 90) and 'Skilled' men (mean = 36.65, SD = 9.41, n = 115) (Broadbent, Cooper, FitzGerald and Parkes, 1982). PRMQ mean was 49.88 (SD = 13.84, n = 13) (over 1.5 standard deviation above the mean for the general population (mean = 38.88, SD = 9.15, n = 551)) (Crawford, Smith, Maylor, Della Sala & Logie, 2003). All participants reported owning a mobile phone and ten (71.4%) reported owning a smartphone. Eight participants (57%) reported that they never or rarely used an electronic calendar. Two reported that they occasionally used them, two reported often using them and two used them very often. Those who did use electronic calendars all stated that they found them useful. All of the participants stated that they used non-electronic calendars sometimes (28.6%), often (21.4%) or very often (50%). Only two participants (14.27%) stated that they did not find non-electronic calendars to be useful. Participants reported a number of different aetiologies including traumatic brain injury (50%), brain tumour (14.3%), stroke and transient ischemic attack (7.1%), acute disseminated encephalomyelitis (7.1%), hypoxic brain injury (7.1%), superficial siderosis (7.1%) and brain haemorrhage (7.1%).

6.3.2 Neuropsychological Profile Information

Table 6.1 shows the cognitive profile information including percentile rank or scaled score and summary of level of ability compared to the general population in the same age-range. Much neuropsychological data was unavailable for participant 12. Clinical notes described 'particular difficulties with encoding of information' during the RMBT assessment and reported that their BADS score was in the low average range.

Table 6-1. A summary of each study participant's cognitive profile.

RBMT and D-KEFS neuropsychological tests and self-assessed memory and cognition on the Prospective Retrospective Memory Questionnaire, and the Cognitive Failures Questionnaire.

Battery	Test (score type)	Mean (SD)	Median (range)	Summary compared to healthy contro
RBMT (n = 14)	Full-scale (percentile rank)	15.2 (12.97)	13 (0.8 to 37)	Low average
RBMT (n = 13)	prospective memory items (percentile rank)	29.96 (16.8)	5 (4.5 to 63)	Low average
DKEFS (n = 13)	verbal fluency (percentile rank)	26.7 (21.21)	25.2 (2.3 to 63.1)	Low average
DKEFS (n = 13)	verbal category switching correct responses (percentile rank)	19.75 (30.24)	2.3 (0.1 to 90.9)	Borderline impaired to lov average
DKEFS (n = 13)	visual scanning (scaled score)	4.77 (3.79)	5 (1 to 1 0)	Borderline impaired
DKEFS (n = 13)	letter sequencing plus number sequencing score (scaled score)	5.92 (4.15)	6 (1 to 12)	Low average
DKEFS (n = 13)	letter number switching (percentile rank)	28.04 (25.91)	36.9 (0.1 to 63.1)	Low average

%ile cut-offs < 2.5 = impaired*; 2.5 to 5 = borderline impaired; 5 to 40 = low average; 40 to 60 = average; 60+ = above average

Scaled score cut-offs <5 = impaired*; 5 = borderline impaired; 6 to 9 = low average 10-11 = average; 12+ = above average

*when compared to standardized scores on these tests from the normative samples (Wilson et al., 1991; Delis et al., 2001).

RBMT = Rivermead Behavioural Memory Test

DKEFS = Delis Kalpan Executive Functions System

Twelve of the 14 participants who took part completed all six of the assignments. One participant (Participant 11) completed one assignment with each app and one (Participant 12) completed three assignments with each app. The assignments were not fully completed because the participants decided that they no longer wanted to take part in the study, or wished to move on to a different section of the study. TLX scores for both apps were recorded for both participants and UTAUT scores for both apps were recorded for one of these participants (participant 11). Mean speed and guidance for each completed assignment, and percentage accuracy of completed assignments could still be calculated for these participants and their results were included in the analysis. However, as there are less data for these participants, small differences (e.g. failing to set the correct time for a reminder) in their individual performances with each app will have more impact on the overall results than the same difference by a participant who completed all of the assignments. This disproportionate impact is particularly acute for participant 11 because they only completed one assignment with each app. Therefore, each statistical test reported below was also performed without participant 11, and without participant 11 and 12. If the removal of these participants changed the significance of the statistical test then it was reported. All analysis reported in the results included participants 11 and 12 unless noted. This issue is considered in the limitations section of the discussion.

6.3.3 Order effects on performance and UX

6.3.3.1 Comparison of Baseline Demographics

Wilcoxon signed-rank tests were used to investigate whether there were any differences in demographics between the six participants who used ApplTree first compared to the eight participants who used Google Calendar first. A chi-squared test was used to compare gender. Groups were compared in age (W = 29.5, p = 0.52), gender (X^2 = 0.39, p = 0.53), time since injury (W = 24, p = 1), education (W = 15, p = 0.42), Cognitive Failures Questionnaire score (W = 11, p =

0.34), and PRMQ score (W = 10, p = 0.14). No significant differences were found for any of these variables. The group who were given Google Calendar first reported poorer memory in the PRMQ test (mean 55.8, SD = 8.1) than the group who received ApplTree first (mean = 43, SD =16.6), although this difference was not significant.

6.3.3.2 Order effects on performance

The difference in reminder setting accuracy between the app the participants used first (either ApplTree of Google Calendar) and the app which participants used second was investigated. The results suggest that accuracy improved slightly between the first and second apps (mean difference in percentage score = 2.91, SD = 18.25). The difference, however, was non-significant (W = 40, p = 0.44).

The same tests were run to investigate the impact of order effect on the other main outcome variables in the study. Participants were slightly slower when using their second app, (mean difference = -2.75 seconds, SD = 115.61)). More guidance was required by participants when using the first app (mean difference = 0.06, (SD = 1.69). TLX total score decreased indicating a reduction in task load from the first to second apps (mean difference = 2.61, SD = 31.71). UTAUT scores declined indicating declining user experience from the first to second apps (mean difference = 3.88, SD = 18.73). No significant differences were found for any of these variables; speed (W = 47, p = 0.73), guidance (W = 42, p = 0.81), TLX total score (W = 44, p = 0.6), and UTAUT total score (W = 31, p = 0.53).

6.3.4 Primary Outcomes

All means with each app, mean differences for each participant and standard deviations for each of the primary outcome variables are reported in table 6.2 along with confidence interval for the mean difference, T and *p* statistics for within subject t-tests.

6.3.4.1 Hypothesis 1

Mean percentage accuracy for the assignments when using Google Calendar was 58.85% (SD = 21.1). Mean percentage accuracy with ApplTree was 68.5% (SD = 13.8), a mean difference of 9.65%. This difference was significant (W = 20, df =

13, p = 0.042). An effect size was calculated for this difference (r = 0.39). This is considered to be a medium effect size (Cohen, 1992). Figure 6.4 is a bar chart showing the percentage accuracy scores for both groups.

This difference became non-significant at a significance level of $p < 0.05$ if participant 11 was removed (mean difference = 7.12, W = 20, df = 12, p = 0.08) and when participants 11 and 12 were removed (mean difference = 6.6, W = 19, df = 11, p = 0.13). The effect size was still medium when both participant 11 was removed (r = 0.34) and when participants 11 and 12 were removed (r = 0.30).

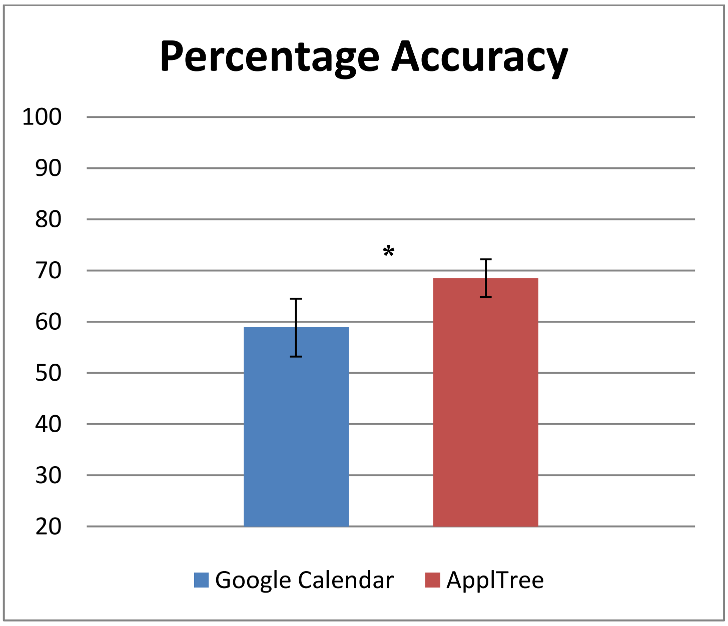


Figure 6-4. The percentage accuracy mean and with standard error bars for participant's using Google Calendar and ApplTree. (n = 14)

A Wilcoxon signed-rank test showed that this difference was significant (p<0.05).

6.3.4.2 Influence of demographics on accuracy

Since there was a significant difference between accuracy when using the apps, the influence of demographic factors on this outcome variable was investigated. Spearman's Rank correlations were performed between Google Calendar accuracy and age (rho = 0.07, p = 0.8), time since injury (rho = 0.48, p = 0.09), education (rho = 0.58, p = 0.04), cognitive failures score (rho = -0.08, p = 0.82), PRMQ score (rho = 0.06, p = 0.85), or how often they used electronic calendars (rho = 0.12, p = 0.69). Education was significantly positively correlated with

Google Calendar accuracy. Time since injury also positively correlated with Google Calendar accuracy although this was not significant.

Spearman's Rank correlation were also performed between ApplTree accuracy and these demographic variables; age (rho = -0.45, p = 0.11), , time since injury (rho = 0.76, p = 0.002), education (rho = 0.57, p = 0.04), cognitive mistakes score (rho = -0.19, p = 0.56), PRMQ score (rho = -0.19, p = 0.54), and frequency of electronic calendar use (rho = 0.52, p = 0.06). Time since injury and education significantly positively correlated with ApplTree performance and frequency of electronic calendar use also positively correlated although this was not significant.

A Mann-Whitney-U test found no significant differences were found between men and woman on accuracy with either Google Calendar (U(11.72) = 14, z = -1.23, p = 0.22) or ApplTree (U(10.4) = 17.5, z = -0.77, p = 0.44).

6.3.4.3 Hypothesis 2

The sample mean for the average number of times guidance was requested from the experimenter during each assignment when using Google Calendar was 1.93 (SD = 2.65). The average guidance for each assignment was lower when using ApplTree (mean = 1.46 (SD = 1.46)). This difference was not significant (W = 33, df = 13, p = 0.4). Figure 6.5 is a bar chart showing the guidance scores for both groups.

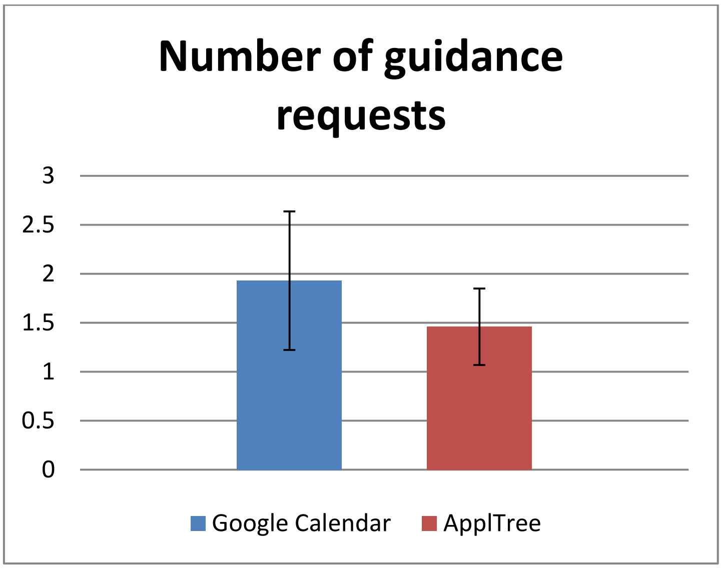


Figure 6-5. Mean and standard error for the number of times participants asked for guidance when using Google Calendar and ApplTree. (n = 14)

6.3.4.4 Hypothesis 3

The total TLX score sample mean was 61.6 (SD = 30.35) for Google Calendar and 52.1 (SD = 25.16) for ApplTree. Lower scores indicate lower task load. This difference was not significant (W = 33.5, df = 13, p = 0.25). Figure 6.6 is a bar chart showing the TLX mean score and sub-scores for both groups.

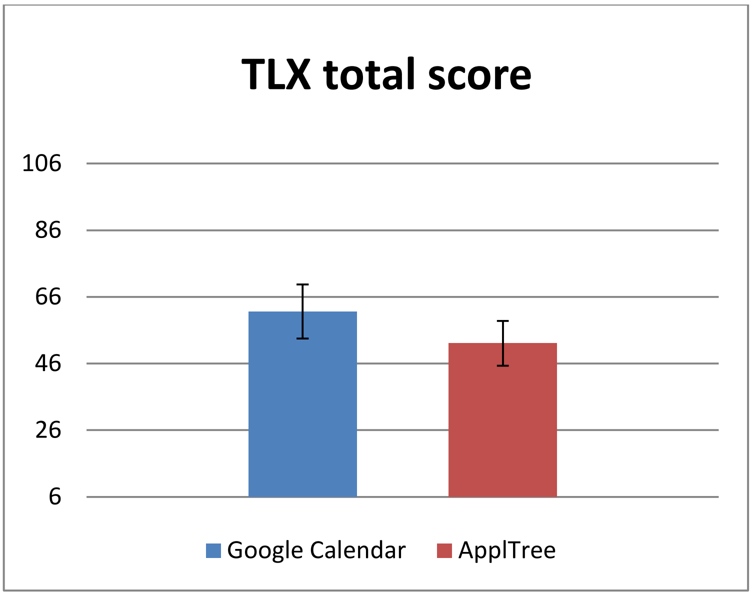


Figure 6-6. Mean and standard error for TLX scores given after use of Google Calendar and ApplTree. (n = 14)

6.3.5 Exploratory analysis

For the accuracy variable a higher score means better accuracy on the assignments. For guidance a higher score means that more guidance was needed from the experimenter. A higher speed score means that more time was taken on average to complete each task. A higher accuracy / speed trade-off score means that participants had faster and more accurate performance. Higher scores on TLX items indicated that task load was high. Higher scores on the UTAUT items reflected better perceived user experience.

The table shows that the only variable that was significantly different between ApplTree and Google Calendar was total accuracy. The difference between apps on reported mental demand and effort sub-scale scores on the TLX was not significant at p < 0.05 level. The effect sizes for these differences were r = 0.27 for mental demand and r = 0.27 for effort. These are small effect sizes but are close to the cut off for medium effect size of 0.3 (Cohen, 1992). When both participants 11 and 12 were removed, the difference in the TLX mental demand sub-scale rating between the two apps remained non significant; mean of difference = 3.54 (W = 13.5, df = 11, p= 0.09). Removing both participant 11 and 12 also changed the results of the Wilcoxon signed-rank test comparing the TLX effort sub-scale between the two apps although this difference remained non-significant; mean of difference = 3.79 (W = 7.5, df = 11, p= 0.09). When both of these participants were removed, medium effect sizes found for these differences were r = 0.32 for mental demand and r = 0.32 for effort.

Table 6-2. Mean outcome variable scores with both apps, mean difference between the apps and results of Wilcoxon signed-rank tests investigating this difference.

Outcome variable (mean unless otherwise stated)	ApplTree	Google Calendar	Mean difference^	W score	*p* value
Total Percentage Accuracy (SD) (n = 14)	68.5 (13.8)	58.85 (21.1)	9.65 (15.48)	20	0.042*
Guidance for each assignment completed (SD) (n = 14)	1.46 (1.46)	1.93 (2.65)	0.47 (1.62)	33	0.4
Average speed in seconds to complete each assignment (SD) (n = 14)	393.61 (198.47)	395.76 (184.23)	2.15 (115.63)	51	0.95
Total TLX score (SD) (n = 14)	52.1 (25.16)	61.6 (30.35)	9.5 (30.28)	33.5	0.25
Mental demand (SD) (n = 14)	9.68 (5.03)	12.43 (6.06)	2.75 (6.46)	25	0.16
Physical demand (SD) (n = 14)	6.18 (5.59)	7.54 (7.2)	1.36 (7.57)	35.5	0.51
Temporal demand (SD) (n = 14)	7.4 (5.1)	7.7 (6.48)	0.32 (3.34)	22	1
Performance (SD) (n = 14)	9 (6.04)	10.46 (4.7)	1.46 (4.83)	27.5	0.22
Effort (SD) (n = 14)	9.54 (6.62)	12.5 (5.92)	2.96 (6.43)	16.5	0.15
Frustration (SD) (n = 14)	10.32 (6.45)	10.93 (7.41)	0.61 (8.8)	39	0.68
Total UTAUT score (SD) (n = 13)^^	129.15 (22.8)	130.7 (22.49)	-1.58 (19.09)	38	0.97
Performance (SD) (n = 13)	4.45 (1.37)	4.65 (1.24)	-0.19 (0.77)	12.5	0.48
Effort Exp. (SD) (n = 13)	4.85 (1.19)	4.68 (1.4)	0.16 (1.06)	33.5	0.58
Attitude (SD) (n = 13)	4.33 (1.22)	4.55 (1.1)	-0.22 (1.11)	21.5	0.58
Social influence (SD) (n = 13)	4.08 (0.97)	4.4 (1.24)	-0.32 (1)	10	0.29
Facilitating conditions (SD) (n = 13)	4.03 (1.07)	3.99 (1.02)	0.04 (0.98)	15	0.93
Self-efficacy (SD) (n = 13)	4.91 (1)	4.99 (0.97)	-0.08 (0.45)	18.5	0.68
Anxiety	4.04	4	0.04	27.5	1

(SD) (n = 13)	(1.87)	(1.72)	(1.26)		
Behavioural Intention (SD) (n = 13)	4.81 (1.7)	4.71 (1.63)	0.1 (2.34)	29.5	0.88

*Significant result when alpha error probability is set at $p < 0.05$

^Mean difference and 95% confidence interval has been adjusted so that positive scores indicate better performance (e.g. faster or more accurate) using ApplTree and negative scores indicate better performance using Google Calendar.

^^N=14 for all measures except UTAUT total and sub-scales for which N = 13 because participant 12 did not complete these measures.

6.3.5.1 Types of Errors

Figure 6.7 shows describes all of the different errors which the participants made which lead to points being deducted from their accuracy score. The numbers of each type of error are recorded for ApplTree and Google Calendar. To aid interpretation the errors were organised by the thesis author into five groups; issues with the keyboard or text input, and event, time, date, and note and repetition input errors.

Figure 6.8 shows Calendar representations of the reminders set by participant three on Google Calendar (left) and ApplTree (right) alongside the ideal set of reminders which would have scored 100% on the assignments (centre). This participant was chosen as representative because their percentage accuracy difference of 15.6% was closest to the mean difference for the eleven participants who had improved accuracy with ApplTree (15.48%). Reminders set by participant three using Google Calendar and ApplTree and the ideal reminders if 100% was received on the task.

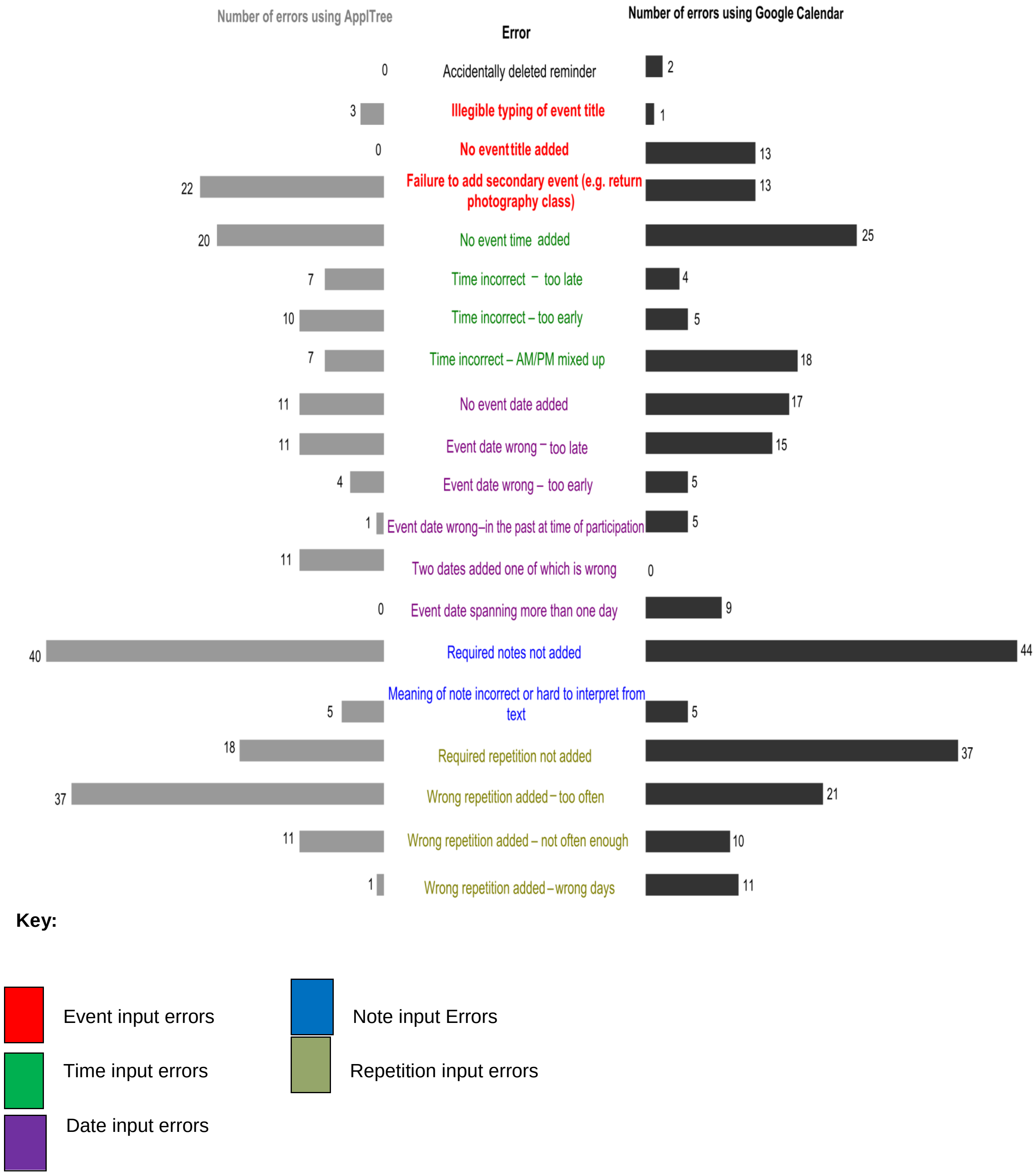


Figure 6-7. Descriptions and counts of all errors made by participants when entering reminders into ApplTree and Google Calendar. (n = 14)

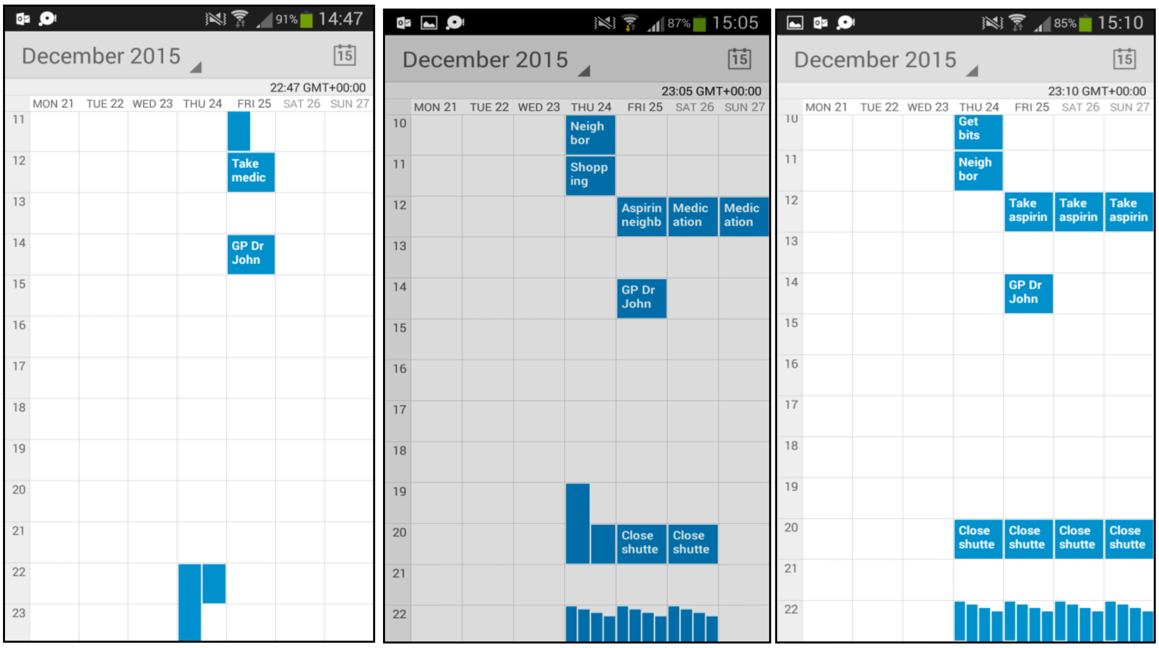


Figure 6-8. Reminders set by participant three on Google Calendar (left) and ApplTree (right)

Represented in a Calendar view. The reminders are contrasted with the ideal set of reminders in the centre.

6.3.5.2 Cognitive profile and performance and use of app

Only outcome variables that were significantly different between the apps, or which approached significance, were included in the exploratory analysis of the influence of cognitive profile on assignment performance and user experience when using the apps. These were percentage accuracy on all completed tasks, mental demand TLX sub-score total and effort TLX sub-score total. Higher accuracy meant better performance. Higher scores on the mental demand and effort sub-scales indicates higher task load. Higher scores on the neuropsychological tests indicates better memory or executive functioning. Only RBMT percentile rank was available for participant 12 and so their accuracy, mental demand and effort scores were not included in the analysis involving any of the other neuropsychological measures, nor the analysis involving pooled neuropsychological test scores. Table 6.3 shows the correlations between each of the neuropsychological tests and sub-tests and accuracy, mental demand and effort for ApplTree and Google Calendar. It also shows Wilcoxon signed-rank tests investigating the difference between the two sets of correlations.

A small, non-significant positive correlation (rho = 0.09, $p = 0.77$) was found between a pooled cognitive profile score and accuracy when using ApplTree. A large positive non-significant correlation (rho = 0.53, $p = 0.06$) was found between a pooled cognitive profile score and accuracy when using Google Calendar. A Fisher r to z transformation found no significant difference between these two correlations ($Z = 1.12$, $p = 0.13$).

Table 6-3. Spearman's Rank correlations (rho) between each of the neuropsychological tests and sub-tests and accuracy, mental demand and effort for ApplTree and Google Calendar.

Wilcoxon signed-rank tests are used to assess the difference between the two sets of correlations.

Neuropsychological Test / Sub-test	Accuracy AT	Accuracy GC	Mental Demand AT	Mental Demand GC	Effort AT	Effort GC
RBMT^ (n = 14) percentile rank	0.02	0.03	-0.32	0.1	-0.39	-0.02
RBMT prospective memory items percentile rank (n = 13)	0.17	0.18	-0.58*	-0.3	-0.48	-0.08
DKEFS verbal fluency percentile rank (n = 13)	-0.05	-0.09	-0.11	0.08	-0.3	-0.26
DKEFS verbal category switching correct responses percentile rank (n = 13)	-0.02	0.37	-0.07	0.29	0.11	0.35

DKEFS visual scanning scaled score (n = 13)	0.19	0.42	-0.59*	0.25	-0.17	0.29
DKEFS letter sequencing plus number sequencing scaled score (n = 13)	0.59*	0.48†	-0.44	0.01	-0.43	-0.28
DKEFS letter number switching percentile rank (n = 13)	0.47†	0.68*	-0.42	-0.37	-0.02	-0.29
Median correlation (range) (n = 13)	0.17 (-0.05 to 0.59)	0.37 (-0.09 to 0.68)	-0.32 (-.59 to -.07)	0.08 (-0.37 to 0.29)	-0.3 (-0.48 to 0.11)	-0.08 (-0.29 to 0.35)
Wilcoxon signed-rank comparison (n = 13)	W = 7, $p > 0.05$		W = 0, $p < 0.05$*		W = 4, $p > 0.05$	

Correlations reported are Spearman's rho

^n=14 for correlations involving this measure. For correlations involving all other measures, n = 13 because participant 12 did not complete these measures.

†$p<0.1$; *$p<0.05$

6.4 Discussion

6.4.1 Usability and UX measures

This study aimed to investigate the difference in performance and user experience between two reminding apps with different user interface structures and designs. One of the three hypotheses of the primary aim was supported. People set significantly more accurate reminders when using ApplTree than when using Google Calendar. They took the same amount of time with both apps. There was no difference between the two apps in terms of the amount of guidance needed by participants. There were also no differences in overall task load as measured by the TLX total score. The exploratory analysis indicated that perceived mental demand and effort were reduced when using ApplTree compared to Google Calendar, although these differences were not significant. There were no significant order effects.

A medium effect size was calculated for the difference in accuracy between the apps and the mean difference was around 10% on average. This finding indicates that the design of ApplTree was more accessible than Google Calendar for people with ABI. However, it is important to understand the implications of this improvement in everyday life and figure 6.8 gives a good indication of this. In contrast to ApplTree, reminders which should have been added were missed when using Google Calendar because the wrong date was entered. Furthermore, when this participant used Google Calendar, reminders were set at the wrong time because 10pm time was selected instead of 10am, and did not repeat because the repetition option was not selected. These omissions would clearly impact upon the effectiveness of the reminder system because they would not receive prompts for some events and would be prompted at the wrong time for other events. Therefore, the results indicate that an app which was developed based on design criteria from the cognitive accessibility and rehabilitation literature does improve the accuracy of reminders set by people with cognitive impairment after ABI, and that this improvement is meaningful in the context of everyday reminder setting.

It is encouraging that participants did not take any longer when using ApplTree than when using Google Calendar. One of the constraints of the narrow / deep UI structure is that it leads to a large number of screens which may take time to navigate through. In ApplTree the number of screens needed was reduced by the use of decision tree processing and it is likely that this also reduced the amount of time required to set a reminder. On average, using either app, the participants took over 6 minutes and 30 seconds to complete each assignment, and nearly 40 minutes for the full six assignments. This is very similar to the times reported for both the ABI and control participants when using a calendar based system on a PC in the De Joode *et al.* (2012) study.

When using either of the apps, participants needed help on average around one to two times per assignment. However this was far greater for some of the assignments, for example Assignment 5 which required the most steps to be entered. It was expected that the amount of guidance needed by participants would be less for ApplTree than Google Calendar because the design features of ApplTree would support people to complete the reminding task. However, while slightly less guidance was requested overall by participants when using ApplTree this difference was not significant.

A large number of TLX and UTAUT items were completed by participants to measure perceived task load and perceived user experience. Medium mean TLX totals and high UTAUT totals (Table 6.2) reflected the fact that most participants experienced moderate task load and reported that their experiences when using the apps was positive. The comparison between the two apps would have been very salient to participants when completing the second set of measures. There were no significant differences between any of these items.

Correlations between demographic variables and accuracy using each app showed similar patterns for both apps. One exception was that experience with calendar based electronic reminders had a medium positive correlation with ApplTree accuracy, although this was notsignificant. This contrasted with a non-significant small positive correlation between electronic calendar use and Google Calendar accuracy. This is surprising because it was predicted that Google Calendar would be more similar to the kind of UI which people used previously. If this was the case it would be expected that people with more electronic calendar experience would perform better with Google Calendar but that there would be no association between the less familiar UI of ApplTree and experience with technology. It may be that people who have more experience with technology are better able to adapt to a novel interface. However this result was non-significant and so no reliable conclusions can be made.

From this study it is not possible to understand which of the design features influenced accuracy and task load because ApplTree and Google Calendar differed in several ways. The results do indicate that designing software with consideration of the HCI and neuropsychological rehabilitation literature can be effective for creating cognitively accessible software for people with cognitive impairments after ABI. Further analysis is needed in order to understand the mechanisms underlying the differences between the apps. This can be investigated by looking at the relationship between performance, perceived task load, and the neuropsychological measures.

6.4.2 Reminder setting errors

The errors that people made when setting reminders on both apps offer an interesting insight into the usability issues which participants experienced. These errors were split into groups based on the key reminder setting processes required to set accurate reminders in the assignments given (event title, time, date, notes and repetition). Figure 6.7 shows that, overall, similar errors were made by participants when using ApplTree and Google Calendar and that the participants frequently failed to add the event title, time, notes and repetition. If the time was entered wrongly it was more likely to be too late than too early and if repetition was entered wrongly it was more likely to be too often than too rarely. As the accuracy analysis shows, there were more errors made when using Google Calendar than ApplTree. The types of errors which were made more often with Google Calendar can be established from the further error analysis. Errors which occurred more often with Google Calendar included failing to add repetition when required, adding repetition on the wrong days, failing to add a time, date or an event title, mixing up AM and PM when entering a time, entering an event with a date spanning more than one day or a date which was in the past at the time of study and accidentally deleting the reminder. Errors which were made more often when using ApplTree were failing to enter a second reminder on the same task in the assignments (e.g. add in the return visit to the photography class), entering a date which was too early, entering two dates one of which was wrong and adding repetition too often.

This analysis was descriptive and aimed to highlight the errors which are made when entering reminders. While no firm conclusions can be drawn about the differences in types of error between the two apps, these differences are intuitive when examining the app designs. For example, in Google Calendar the option to select repetition requires scrolling through several other entry options while ApplTree presents one screen devoted to setting repetitions. Therefore it is likely that participants missed out required repetition more often in Google Calendar because they could not find the repetition option or because they forgot that they needed to set repetition and were not prompted by the app to do so. Another example is the failure to enter an event name which was a common mistake in Google Calendar. In contrast when using ApplTree it is impossible not to enter an event title because it is automatically selected when selecting an event category (e.g. ‘shopping’ or ‘medication’).

Another difference between the two apps was the errors in time and date selection. For example participants made more AM / PM errors when using the Google Calendar clock widget (shown in Figure 6.3) and wrongly added events which spanned more than one day or which were ‘all day’ when using Google Calendar. While these errors were not made when using ApplTree, there was a different date selection error of adding two dates of which one was wrong. This reflects differences in the app’s presentation of date and time selection. In ApplTree the ‘quick’ options of today and tomorrow in the date selection screen lead to errors which, if made when setting real reminders, would result in receiving more than one reminder for the same event, on different days. The analogue clock widget in Google Calendar, ‘all day’ option and ability to set different from and to times and dates lead to errors which, if made when setting real reminders, would result in receiving a reminder at the wrong time of day or night and incorrect ‘all day’ events which would fail to alert the user at the correct time.

Errors which were more common in ApplTree highlight some of the usability issues with this app. One example is entering repetitions which would fire too often. Repetition options only included daily, weekly and monthly and did not allow users to stop the repetition or select specific days in which to repeat the reminder. If used to set real reminders then events which were selected to repeat daily would keep repeating every day. Another common error was the failure to set a separate reminder for the return photography class in assignment four. This is likely to be because when the user had finished setting a reminder, the app did not prompt further reminder entry by returning to the reminder selection screen. Instead it offered a list view of the previous reminders which had been set. This contrasts to Google Calendar which returned to the calendar screen after each reminder had been set.

6.4.3 Influence of Neuropsychological Profile

A secondary aim was to investigate the influence of neuropsychological test score on performance and task load with the apps and explore the mechanisms behind any differences between the two apps. It is not advisable to pick out results from a series of multiple correlations in a study with a low sample size. Therefore no conclusive findings can be described and those reported below should be interpreted with caution.

Exploratory analysis indicated that accuracy with Google calendar had a medium positive correlation with overall cognitive functioning as measured by the DKEFS and RBMT measures. Accuracy with ApplTree had a smaller positive correlation with the test scores. This indicates that cognition had more influence on Google Calendar performance than it did on ApplTree performance. However, the two correlations were not significantly different. Positive correlations indicate that as participants scores increased on the neuropsychological tests, accuracy also improved.

The results from the exploratory analysis do indicate that the correlations between different sub-tests and app performance have large variations. For example letter and number sequencing, a measure of processing speed and executive attention was significantly positively correlated with ApplTree accuracy. Measures of processing speed and executive attention from the DKEFS (such as the visual scanning and letter number switching sub-tests) had medium positive correlations with Google Calendar accuracy. The tests which correlated most with performance were DKEFS letter sequencing plus number sequencing and letter number switching which had medium positive correlations with accuracy on both apps. These results indicate that executive switching, processing speed and selective attention are involved in accurately setting a reminder.

Compared to the findings for accuracy, the correlations between mental demand and effort score from the two apps and the neuropsychological tests and sub-tests showed a different trend. Task load on both of these measures had larger correlations with the neuropsychological tests for ApplTree than they did with Google Calendar. This suggests that cognition influenced perceived task load during the use of ApplTree but that it did not influence task load during the use of Google Calendar. Looking at specific neuropsychological tests, the biggest correlations were significant negative, medium sized correlations between perceived mental demand when using ApplTree and prospective memory items from the RBMT (measuring prospective memory ability) as well as visual scanning (measuring processing speed and selective attention). Better performance on these tests was associated with lower reported mental demand. This could mean that those with poorer performance on these cognitive tests found ApplTree, in particular, to be mentally demanding to use. However, it could also mean that those with better performance on these cognitive tests found that using ApplTree was not mentally demanding. It could also be a combination of the two interpretations, with ApplTree being especially mentally easy for those with better cognition but mentally demanding for those with poorer cognition. The participants' mean score for mental demand were lower for ApplTree than for Google Calendar, although the difference was not significant. There was also quite a low standard deviation for the ApplTree mental demand scores (5.03), the second lowest of the TLX measures indicating a relatively narrow range of scores. With this in mind, the most likely explanation of the results of the correlation analysis is that the difference in mental demand score was due to the participants with better prospective memory, processing speed and visual attention finding ApplTree particularly mentally easy to use and consequently, less demanding than Google Calendar. The scores from the letter number sequencing DKEFS subtest are more related to accuracy and task load scores for both apps than the scores of the verbal fluency DKEFS subtest. This may be because the letter number sequencing tests involve motor skills and visual attention which are also required to perform the assignments.

6.4.4 Future research

Google Calendar software and similar calendar software have been included in neuropsychological rehabilitation trials. Compared to practice as usual or a non-technological memory aid, calendar software has been shown to be a feasible intervention for prospective memory difficulties for people with ABI. (Petrie, Goudie, Cruz and Kersel, 2012; McDonald et al., 2011; Svoboda et al., 2009; Svoboda et al., 2012). Most of these studies provided training (e.g. Svoboda et al., 2009) and caregivers or experimenters often helped to enter the reminders (e.g. McDonald et al., 2011). ApplTree was being used for the first time by participants in the current study and it led to improved reminder setting accuracy compared to Google Calendar. This indicates that it may be more effective as an intervention in clinical practice than Google Calendar, especially when people enter their own reminders and when only limited training is possible. Future studies could test the efficacy of ApplTree, or a reminder app which uses similar design features, in a rehabilitation setting compared to practice as usual, a pencil and paper reminder, or calendar based reminder app such as Google Calendar.

The results imply that ApplTree did support some cognitive processes involved in setting reminders accurately. It was not clear which individual cognitive processes were supported by ApplTree. Exploratory analysis indicates that prospective memory ability, sustained attention, motor-based processing speed and executive switching are processes which play a role in reminder setting. In neuropsychological rehabilitation a carer would use prompts and questions to guide the client to perform a task with several sub-steps. Micro-prompting technology such as the GUIDE (O'Neill, Moran & Gillespie, 2010) or COACH (Mihailidis, Barbenel & Fernie, 2004) systems reviewed in chapter one perform this type of cognitive scaffolding or step-by-step prompting to guide people through tasks such as washing or making tea. This kind of scaffolding might be the mechanism behind UI with a narrow/deep structure being preferred and used more effectively by people with cognitive impairments compared to UI with a broad/shallow structure. Future work could investigate the impact of cognitive scaffolding built within the UI of assistive technology software. It would also be interesting to build on the results of the current study with further investigation of the types of cognitive processes which are involved in reminder setting, and which are supported by accessible design.

Previous research indicated that narrow / deep web-search layouts were preferable for people with cognitive impairments (Hu and Feng, 2015), and that broad / shallow UI structures were better for people without cognitive impairment (Parush et al., 2003). This study investigated setting reminders on a smartphone and so it is not possible to tell if the design features of ApplTree are better for the specific group of people (those with cognitive impairments), or whether it would also lead to better performance, and be preferred by, people without cognitive impairments. Future work could test these design features with cognitively able groups and with groups with cognitive impairments from different aetiologies (e.g. learning disability or dementia).

6.4.5 Limitations of the study

The number of participants was decided apriori, using a power analysis based on the De Joode *et al.* (2012) study which developed the reminding tasks. Even so, if the sample had been larger it would have allowed for more conclusive results from the exploratory analysis, in which multiple correlations were performed. Furthermore, only 12 of the 14 participants completed all of the assignments. There was no significant difference between the two apps on assignment accuracy when participant 11, and participant 11 and 12 were removed. The effect size of the difference was medium whether these participants were included or removed. This indicates that the result became non-significant due to a lack of power and not because participants 11 and 12 had results which changed the overall trend dramatically.

The Google Calendar app is continually updated and it is possible that more current versions of the app have more appropriate design features than the 2014. For example, the newest version offers a plus symbol presented on the calendar screen which allows the user to avoid the calendar interface and move straight on to setting the reminder. However, no updates have altered the broad / shallow structure of the app. Furthermore, the purpose of the study was to compare two contrasting UI designs. The version of Google Calendar used in this study was representative of a design common to many reminder apps, including those which are automatically available after the purchase of a smartphone.

Much of the literature which was used to develop the design criteria of ApplTree came from the PC web-based interface design literature. It was assumed that general design concepts which come from this research can be generalised to smartphones and to reminder setting. For example, similar design considerations need to be made about the level of content, functionality and user interface layout. This assumption seems to have been supported because ApplTree did lead to better performance than Google Calendar.

6.5 Conclusions

This chapter reviewed the human computing interaction and neuropsychological rehabilitation literatures to develop guidelines for the design of reminding apps on a smartphone. A study was then reported which compared an app which was designed based on these recommendations (ApplTree), with a commercially available app with contrasting UI features (Google Calendar). People with ABI set reminders more accurately when using ApplTree than when using Google Calendar. Other performance measures, task load, and user experience were similar for both apps. Similar types of errors were made when completing the tasks using the two apps. Exploratory analysis indicated that memory and executive function are involved in smartphone reminder setting, particularly prospective memory ability, selective attention, motor-based processing speed and executive switching. It is proposed that the UI design of ApplTree supported successful performance of the reminder assignments, particularly for those with better cognition.

6.6 Appendix

Scoring system for the ‘accuracy’ variable:

2 for every relevant field completed with correct, understandable information

1 point if something has been entered: 1 point if it is correct and understandable

-1 point for every piece of incorrect information or irrelevant information which may be potentially confusing or distracting when the reminder is received.

Assignment 1 = name[max=2], date[max=2], time (begin time of event is sufficient) [max=2], note 1 (name, address, telephone of GP) [max=2], note 2 (ask for repeat prescription) [max=2]. MAX score = 10

Dr name	Date	Time	Address	Phone	Note: prescript	Total
2	2	2	2	2	2	12

Assignment 2a = name[max=2], date[max=2], time (begin time is sufficient) [max=2], note (shopping list) [max=2].

MAX score = 8

Shopping	Tomorrow	Between 10 - 12	Shop list	Total
2	2	2	2	8

Assignment 2b = name[max=2], date[max=2], time (begin time is sufficient) [max=2], note or alteration of previous appointment (which addresses request to, ‘leave time to do shopping before noon’) [max=2].

MAX score = 8

Neighbour	Tomorrow	Time	Leave time for shopping	Total

2	2	2	2	8

Assignment 3 = name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (every day of coming week) [max=2], note 1 (something like; 'take medication before helping neighbour plant tree') [max=2].

MAX score = 10

Asp	Date	Time	Repet	neighbour	Monday	12.05	Total
2	2	2	2	2	2	2	14

MAX score = 14

Assignment 4 = name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (every Tue and Thursday) [max=2], return visit name (can be in note or separate reminder) [max=2], return visit time (can be in note or separate reminder) [max=2], return visit date (can be in note or separate reminder) [max=2].

MAX score = 14

Course	Date	Time	Rep	Return	Date	Time	Total
2	2	2	2	2	2	2	14

Assignment 5 =

Task A: name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (next 3 days) [max=2]

Task B: name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (next 3 days) [max=2]

Task C: name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (next 3 days) [max=2]

Task D: name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (next 3 days) [max=2]

Task E: name[max=2], date[max=2], time (begin time is sufficient) [max=2], repetition (next 3 days) [max=2]

Task	Date	Time	Repetition	Total
2	2	2	2	8

Separate reminders need to be set for each assignment to achieve max score

MAX score = 40

Total Score for all assignments = / 96

7 Chapter Seven - The use of smartwatches as a prompting device for people with ABI

7.1 Introduction

The results from the review in chapter two show that a prompting technology which can remind people about a task at a set time is effective in improving the frequency of remembering, and successfully completing, everyday activities compared to practice as usual or a non-technological equivalent. However, the devices which were used to prompt participants in the reviewed papers differed in their form factors. For example, Svoboda, Richards, Leach and Mertens (2012) used a smartphone app, McDonald, Haslam, Yates, Gurr, Leeder and Sayers (2011) used a calendar program on a computer which sent text messages to the participant’s phone and Lemoncello, Sohlberg, Fickas and Prideaux (2011) used a television set to prompt participants about their exercise routines. Some of the papers tested wearable devices, most notably Wilson, Emslie, Quirk and Evans (2001) in a randomised controlled trial testing NeuroPage. Although this aspect of its use has not been tested explicitly, the wearability of Neuropage may be an advantage compared to pencil or paper reminding strategies and other prompting devices that cannot be worn. This is because, as long as it is accepted by the user, and provided the user remembers to put it on, worn devices do not risk becoming ineffective due to being misplaced, or placed in clothes or bags in a way which would prevent the prompt being detected. Furthermore, wearable devices have the advantage of sending tactile, audio or visual alerts that can be highly noticeable because of the proximity of the device to the user, but which can also be subtle (e.g. tactile notifications) in social situations, for example during a meeting or a meal with friends. Previous research with older users has highlighted the importance of developing appropriate notification modalities for different types of reminders and in different social situations (McGee-Lennon, Smeaton & Brewster, 2012) as well as the differing impact of different types of notification modality (Warnock, McGee-Lennon & Brewster, 2013).

In the last few years, smartwatch technologies have grown in popularity and affordability. The current state of the art hardware can sync up to a smartphone, usually communicating using Bluetooth. Information and notifications which pop up on the phone can then be displayed on the watch and manipulated using voice or touch input. Reminding software which prompts on a phone can be made to be compatible with the smartwatch so that the notifications display on the watch. Many reminder and calendar apps, including those already provided as standard with a smartphone, have already been made compatible with watch hardware.

Only one paper was identified that has tested the efficacy of a watch as a reminder for people with memory impairments. Van Hulle and Hux (2006) used 'Watchminder' wristwatches with a vibrating alarm to prompt two participants about their medication. Participants had memory difficulties after traumatic brain injury and were receiving rehabilitation in a transitional living facility. The Non-overlap of All Pairs (NAP) scores for both participants were between 0.5 and 0.66 indicating a small effect from the intervention. This was lower than the majority of NAP results for similar studies which used other types of devices to prompt participants with memory difficulties in single case experimental design studies (average NAP for these studies was 0.79). It is unclear from this study if the use of a watch with a vibration prompt is effective for people with ABI.

Smartwatches can provide much more detail for a reminder than a vibration alone (as was the case in the Watchminder study) because they have a display screen which can sync up to reminders set on a smartphone or computer based calendar. However, it is also possible that smartwatches may be unacceptable or unusable for participants with ABI because they are too complicated to use, especially for people living in the community who are unable to access daily help with the technology from clinicians or caregivers. Van Hulle and colleagues (2006) did not report details about participants' use of the technology and included participants in a supported living environment. They also did not test use of watch-based prompting devices used by people within the community. To the author's knowledge there is no study which has investigated the use of smartwatches as a prompting technology for people with memory impairment after ABI.

This chapter reports a single case experimental design (SCED) study with three community dwelling participants with ABI. An ABA design was used to investigate the efficacy of a smartwatch reminder for prompting people with memory impairment after ABI about various events[2]. SCED methodology was chosen because it allows a controlled trial to be performed to test efficacy when large scale recruitment is not possible (see *Single Case Experimental Design* section in chapter two). A secondary aim of the study is to help understand whether or not smartwatches using reminding software synced to a smartphone is a usable and acceptable off-the-shelf assistive technology to introduce within clinical practice.

7.2 Methods

7.2.1 Participants

Participants were identified and recruited by staff in the Head Injury Care Team located within the West Dunbartonshire Community Health Care Partnership, Dumbarton. This service assesses the client's neuropsychological profile and everyday functioning to establish their support needs and then helps to support clients in the community, working closely with other health and social services. Adults aged 18 or over who had experienced an acquired brain injury and who had been assessed as having memory impairment during clinical assessment by the recruiting service were considered for this study. Exclusion criteria were the inability to provide informed consent for research participation or inadequate writing or reading which would prevent them from completing the tasks required

[2] Contribution Note: This was a collaborative study run with RM: Dr. Rumen Manolov, University of Barcelona, investigating single case experimental design statistical methods and MM and GG: Mattia Monastra, Assistant psychologist and Graham Gillies, occupational therapist within the Dumbarton Acquired Brain Injury service.

For this study the thesis author was responsible for the design, development of the protocol, ethics application, all data analysis (apart from the efficacy analysis) and the write up (apart from a description of the efficacy analysis). Data collection was undertaken by MM and GG within the Dumbarton Acquired Brain Injury service. Efficacy analysis and reporting of the analysis was undertaken by RM and the thesis author.

in the study. Included participants did not have severe verbal communication difficulties, severe physical impairment (which would prevent their use of a smartwatch or smartphone device), nor did they currently use a smartwatch as a reminder, or any other high-tech reminding device which successfully compensated for self-reported memory problems prior to the study. Four participants, who were adjudged by clinical staff within the care team to meet the study criterion, were initially recruited. One paticipant engaged in the study for only the baseline phase and so their results will not be reported. The cognitive profile of each participant is reported in Table 7.2 (see section 7.3 Results).

National Health Service (Research Ethics Committee) ethical approval was granted for this study on 27.02.15 (reference number 15/WM/0079).

7.2.1.1 TS

TS was a 45 year old man who suffered a brain haemorrhage 12 years previously, and had a stroke within last year prior to commencing the study. His cognitive problems were associated with a basal ganglia bleed and colloid cyst in the lateral ventricle. He had symptoms of hydroencephalus and damage to corpus callosum. He has experienced memory loss, confusion, forgetfulness, gait disturbances, executive difficulty. His memory problems include language and communication difficulties and needing to rely on lists and calendars to aid prospective memory. Fatigue exacerbates these symptoms. He experiences decreased independence with cooking tasks after the haemorrhage. He previously did most of the cooking himself but after the haemorrhage his partner took over most of the cooking.

7.2.1.2 LA

LA was a 61 year old man who suffered spontaneous bleeding in his frontal lobe in 2004. This left some scarring which is now the focus for epileptic discharges. Scarring had a small impact on some but not all frontal lobe functions. The location of the damage is intra-axial and the symptoms he developed at that time were a poverty of conversation, reduced empathy and increased impulsivity. He has reduced independent initiation of activities including conversations, taking medication, cooking and chores. He also has poor insight into his difficulties as indicated by a discrepancy between the (self-report) scores on the DEX (Wilson et al., 1997) (score=4) and an independent observer (score=47). This confirms that LA does not yet have full insight into the level of his difficulties.

7.2.1.3 MA

MA was a 39 year old woman who was reported to have suffered reflex anoxic seizures when she was 4 and a drug overdose and head injury in April 2013 resulting in damage in the region of the basal ganglia. Her difficulties include apathy, social anxiety, lack of insight and difficulty keeping track of goals. She also experiences fatigue and has poor attention, impaired learning and impaired executive functions. Prior to the study she required substantial prompting to be more active in order to help anxiety, and increase social interactions and confidence.

7.2.2 Materials

The hardware that was given to participants was a Moto 360 smartwatch and a Samsung Galaxy S3 or Google Nexus 5 smartphone. The purpose of the study was to assess smartwatch use. The smartphones were provided because reminding watch software which allows the setting of a weekly schedule does not exist. The reminding software was Google Calendar which was already available on both phones and was synced to the smartwatch by the assistant psychologist at the service (MM). Participants were instructed to keep the smartphone on charge and connected to Bluetooth and store it in the same place where they charged the smartwatch. This allowed the watch and phone to sync every night so that the watch notifications would update.

Participants were given memory log sheets and asked to fill these out each evening. Memory log sheets were written by MM and the thesis author and when filling them out participants were asked to enter the tasks they were supposed to do that day, the time they were supposed to do them and the time they actually did complete the task (see sub-section 7.6.3 in section 7.6 Appendix).

The participants' test and sub-test scores from eight neuropsychological tests and questionnaires were used to develop a cognitive profile for the participants who completed the study. Many of the tests and sub-tests had already been completed prior to participation in the study (within the last three years) as part of their assessment by the neuropsychological team, although not all participants had completed the same tests. During the study further tests and sub-tests were administered by the experimenters. However, due to time constraints during the study it was not possible for all participants to complete all of the tests and sub-tests which were included (see Table 7.2 in section 7.3 Results). Therefore further tests and sub-tests were administered in order to ensure that some information was provided about each of the following for each participant; intellectual functioning, memory and executive functioning. Neuropsychological tests performed with clients were the Test of Pre-morbid Functioning (TOPF) (Wechsler, 2011), the Weschler Adult Intelligence scale version 4 (WAIS-IV) – perceptual reasoning, verbal comprehension and processing speed sub-scales (Wechsler, 2008), Weschler Memory Scale version 4 (WMS-IV) – auditory memory delayed and visual memory delayed sub-scores (Wechsler, 2009), the Behavioural Assessment of the Dysexecutive Syndrome (BADS) – including the key search and zoo map sub-tests (Wilson, Evans, Alderman, Burgess & Emslie, 1997), the Dalis-Kaplan Executive Functioning Scale (DKEFS) – verbal fluency and letter number switching sub-tests (Delis, Kaplan & Kramer, 2001), Rey-Osterrieth Complex Figure (ROCF) (Hubley & Jassal, 2006), Cambridge Test of Prospective Memory CAMPROMPT (Wilson, Shiel, Foley, Emslie, Groot, Hawkins & Watson, 2005), and Rivermead Behavioural Memory Test (RBMT) (Wilson, Cockburn & Baddeley, 1991). The assistant psychologist (MM) also noted demographic information, phone and technology use prior to the study, information about ABI and functional difficulties which the smartwatch could address.

Finally, it was of interest whether or not the participants could learn to use the technology and whether or not they found it acceptable. The acceptability and user experience with the smartwatch and smartphone were assessed using the NASA Task Load Index (TLX) (Hart & Staveland, 1988), also assessment on eight domains from the unified theory of acceptance and use of technology (UTAUT) (Venkatesh, Morris, Davis & Davis 2003) and finally with feedback from a recorded post-hoc interview in which participants were asked about their experience using the technology. TLX asks about mental demand, physical demand, temporal demand, evaluation of performance, evaluation of effort needed to achieve that performance and level of frustration. These scores (each on a scale of 1 to 20) were reported separately and aggregated together to create an overall task load score. The UTAUT includes groups of items concerning the following: performance expectancy (expectancy that the tech will be useful for its purpose), effort expectancy (perceived effort needed to use it), attitude towards the technology, social influence (the influence of others on the use of the technology), facilitating conditions (the extent to which their environment facilitates use of the tech), self-efficacy (estimations of their own ability to use the technology), anxiety (levels of anxiety felt when using the tech) and behavioural intention (an indication of whether the participant is intending to use the tech in the next 6 months). Scores for each item (on a scale of 1 to 6) within each domain were aggregated to give overall scores for each domain at each time point.

7.2.3 Design and procedure

The study design was an ABA single case experimental design. Throughout the study participants' memory performance was assessed on various tasks. Memory tasks included sending a message after a meal, going for a walk, texting and emailing the experimenter at set times, filling out the memory log and attending meetings with the experimenter. Participants documented their performance of these tasks on memory logs which they were asked to fill out each evening. Texts, emails, meeting attendance and memory log completion were recorded by the experimenter MM. The experimenters calculated the percentage of tasks successfully completed during each day for each participant. See table 7.1 for details of memory tasks for each participant.

The assistant psychologist (MM) was available by phone to answer queries about the technology. A manual with the same information given during the training session was given to participants to take away with them and refer to as required (see sub-sections 7.6.1 and 7.6.2 in section 7.6 Appendix for details about training with the smartwatch).

One of the memory tasks was to attend a meeting with the experimenter at the beginning of weeks 2, 4 and 6. These meetings were designed to allow the research team to catch up with the participant and, in week 4, to solve any problems with the technology. The purpose of these meetings was also to gather user experience, demographic and neuropsychological data. These meetings took up to two hours. After the study phases were complete for all participants, a further study session was held with each participant in order to gather any missing data.

7.2.4 Procedures to Improve Internal and External Validity

The RoBiNT scale (Tate, Perdices, Rosenkoetter, Wakim, Godbee, Togher & McDonald, 2013) details 15 recommendations which researchers should adhere to when conducting high quality SCED studies. Internal validity items include ensuring the design demonstrates experimental control, that phase sequence or commencement is randomised, and that there is sufficient sampling of data points for each participant in each condition or study phase. The design of this study was A-B-A which is a withdrawal / reversal design and is defined as a SCED because it does demonstrate experimental control. The order of the phases was not randomised. The study was designed so that at least five data points (the minimum recommended) would be collected for each phase of the study.

The RoBiNT scale also recommends blinding of participants, experimenter and assessors, the conducting of inter-rater reliability for at least 20% of the data, and an evaluation of treatment adherence. In the study reported in this chapter the experimenter was not blind to the study phase and it was not possible for participants to be blinded because the smartwatches had to be provided with some instructions about use. There was no independent assessor of memory performance. There was no external assessor of treatment adherence, to assess how the intervention was delivered by the experimenter (e.g. training with the smartwatches). However, the training and study session times were part of the client's ongoing treatment in the outpatient clinic. This meant that the experimenter (MM) kept to the pre-determined study schedule (e.g. meeting for one hour at the beginning of each study phase) because the study procedures were designed to fit around the schedules of the clients and the service.

External validity recommendations from the RoBiNT scale relevant to the study procedure include systematic or inter-subject replication and the inclusion of generalisation measures throughout each stage of the trial. The study reported in this chapter included three participants and so did provide inter-subject replication. There were no generalisation measures taken during the study reported in this chapter. While standardised measures of memory functioning were reported in order to form a clinical description of the cognitive profiles of the participants (Table 7.2 in section 7.3 Results), these measures were not expected to, nor used to, demonstrate any generalisation of the intervention's impact on memory performance.

7.2.5 Independent variable

The study phase.

Phase A for 14 days (baseline): A baseline control condition during which participants were instructed to use their usual memory strategies.

Phase B for 14 days (intervention): The intervention condition during which the smartphone and smartwatch were given to the participants along with training (see below).

Phase A for 14 days (return to baseline): A return to baseline condition during which the intervention was removed.

7.2.6 Primary Dependent variable

Memory performance: % of memory tasks successfully completed each day

Memory performance was measured using (i) the memory logs, (ii) logs of text messages and emails received by the experimenter from each participant. This was the primary dependent variable used to calculate the efficacy of the reminding technology intervention.

7.2.7 Secondary dependent variables

User experience (captured using X)

Demographic information (captured using Y)

Cognitive profile (generated from a battery of N neuropsychological tests).

7.2.8 Training

Training with the technology consisted of a 5-10 minute demonstration followed by an assessment lasting up to 20 minutes. The assistant psychologist set the reminders on the smartphone during a meeting with the participants. Once the reminders had been set on the smartphone, the smartwatch software automatically notified participants as long as the phone and watch were synced. Therefore training was given as a back-up in case there were issues with the device after they were in the participants' homes. The 5 to 10 minute demonstration covered switching the watch on and off, using the watch touchscreen and button interactions, charging the watch and smartphone, making sure that the Bluetooth was switched on for the smartphone and clearing notifications on the watch. The training with the watch also covered receiving reminders, getting back to home screen and accessing agenda. Following this training there was an assessment of use which lasted up to 20 minutes. Participants were asked to turn the watch off and on again, switch on the Bluetooth on the phone, syncing the phone to the watch, put the smartwatch on the wireless charger, clear watch notifications, return to the watch home screen (clock-face), access the watch 'agenda' screen using both the touchscreen and voice control.

Table 7-1. Details about the memory tasks on which each participant was assessed.

Initials	Daily tasks
TS	• Text experimenter • Send email • Fill out memory log • Come to an appointment
LA	• Send text after dinner • Send email after going for a walk • Come to an appointment • Fill out memory log
MA	• Send a text after lunch • Send an email after going for a walk • Come to an appointment • Fill out memory log

7.3 Results

7.3.1 Cognitive profiles of participants

Table 7.2 summarises cognitive profile on each of these neuropsychological tests and sub-tests for the participants included in the study.

Table 7-2. Cognitive profile on tests of intelligence, memory and executive function for the study participants.

Tests of intellectual functioning

Tests of memory

Tests of executive processing

Test	TS (45 years old)	LA (61 years old)	MA (39 years old)
WAIS-IV perceptual reasoning score (summary)	110 (high average)	105 (average)	73 (impaired)
WAIS-IV verbal comprehension score (summary)	-	89 (low average)	83 (low average)
WAIS-IV processing speed score (summary)	-	79 (low average)	59 (impaired)
TOPF score (summary)	105 (average)	94 (average)	-
RBMT percentile rank (95% CI) (summary)	2 (0.4-10) (impaired)	2 (0.3-9) (impaired)	-

CAMPROMPT score (percentile rank) (summary)	12 (<5) (borderline impaired)	-	-
WMS-IV auditory memory delayed score (summary)	-	81 (low average)	87 (low average)
WMS-IV visual memory delayed score (summary)	-	81 (low average)	81 (low average)
ROCF score (summary)	27 (impaired)	-	28 (impaired)
DKEFS verbal fluency percentile rank (95% CI) (summary)	2.3 (0.2-14.9) (impaired)	15.9 (4.7-37.4) (low average)	1 (0-22.2) (impaired)
DKEFS letter number switching percentile rank (95% CI) (summary)	74.8 (18.4-98.7)(high average)	15.9 (1-62.4) (low average)	4.8 (0.1 to 46.1) (borderline impaired)
BADS key search profile score (summary)	4 (average)	4 (average)	-
BADS zoo map profile score (summary)	2 (low average)	0 (impaired)	-
BADS age corrected score (summary)	-	93 (average)	83 (low average)

7.3.2 Efficacy

When viewing the efficacy data, the assistant psychologist (MM) and the thesis author decided that the memory log information was unreliable because dates when entered wrongly and because MM communicated that it was likely that some participants had completed it all at once just before their weekly meeting. For this reason only data which was automatically collected (e.g. through phone or email records) was used in the analysis.

The percentage of tasks completed successfully (memory performance) was the dependent variable. There was considerable variability both within and across cases and there were no clear baseline trends. Visual inspection of the data for all three participants, prior to inferential analysis, suggested a general upward shift in level; on average task completion seems to have improved when the smartwatch intervention was present. The effect of introducing the device was visually evident, although small. The effect of its withdrawal was more pronounced. Figures 7.1, 7.2 and 7.3 show the percentage memory performance for each participant over the three study phases.

7.3.2.1 TS

Figure 7.1 shows that TS's memory performance, while variable, was at a high level in phases A and B1. His memory performance then decreased between B and A2.

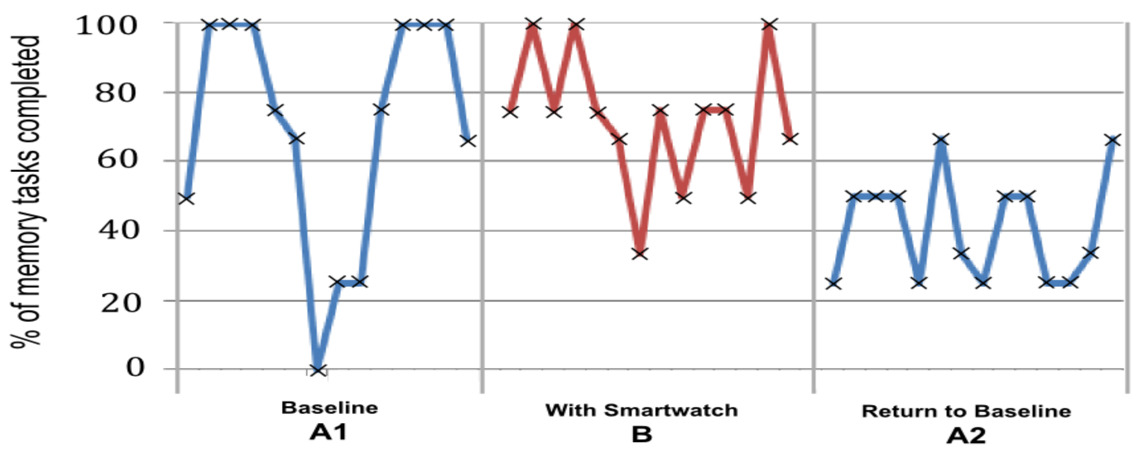


Figure 7-1. Percentage of memory tasks successfully completed in each study phase by participant TS.

The Y axis shows percent performance and X axis shows study day (each data point (x) in the figure represents one day in the study).

NAP analysis indicated that TS's memory performance did not change from the first A phase to the B phase (NAP = 0.48 (p = 0.89, 95% CI = 0.18 to 0.79) and the Cohen's *d* analysis confirmed that there was little impact from the intervention when first introduced (*d* = 0.09). NAP score between phases A2 and B was 0.90, indicating a significant medium effect of phase (p<0.01, 95% CI = 0.59 to 1). Cohens *d* analysis indicated a large decline between the phases (*d* = 1.34).

7.3.2.2 LA

Figure 7.2 shows that LA's memory performance was also highly variable. Overall his performance seemed to be highest during the intervention phase and lowest during the return to baseline phase.

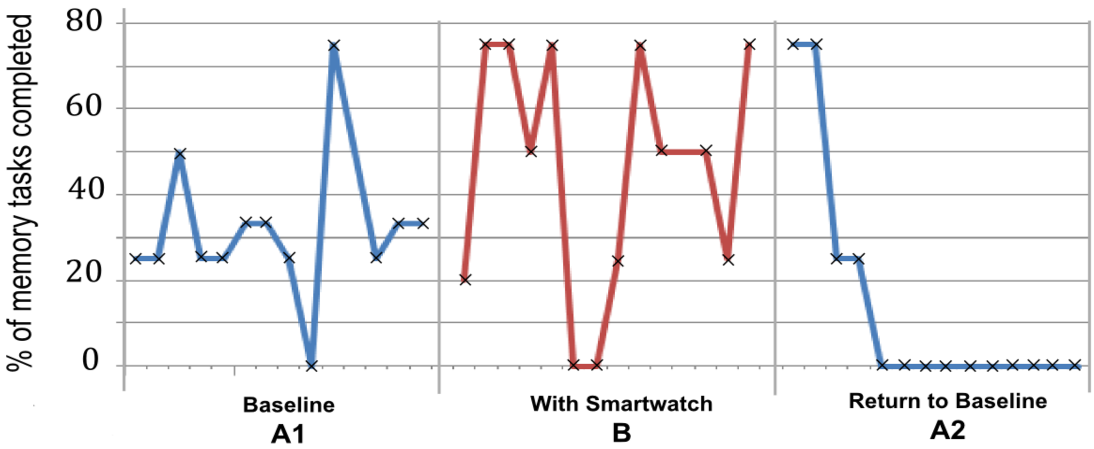


Figure 7-2. Percentage of memory tasks successfully completed in each study phase by participant LA.

NAP analysis indicated that LA's memory performance improved between the first A phase to the B phase, though this was not significant (NAP = 0.64 (p = 0.21, 95% CI = 0.23 to 0.78 (small effect of phase). Cohen's *d* analysis indicated that the increase between baseline A1 and the intervention B had a medium effect size (*d* = 0.56). NAP score between phases A2 and B was 0.79 indicating a significant, medium effect of phase change (p<0.01, 95% CI = 0.48 to 1). The Cohens *d* analysis indicated that there was a large decline between the phases (*d* = 1.01).

7.3.2.3 MA

Figure 7.3 shows that MA's memory performance was quite poor throughout the trial. Overall her performance was highest during the intervention phase and was consistently at floor level at the end of A1 prior to introduction of the intervention, and for the majority of A2 after the intervention was taken away.

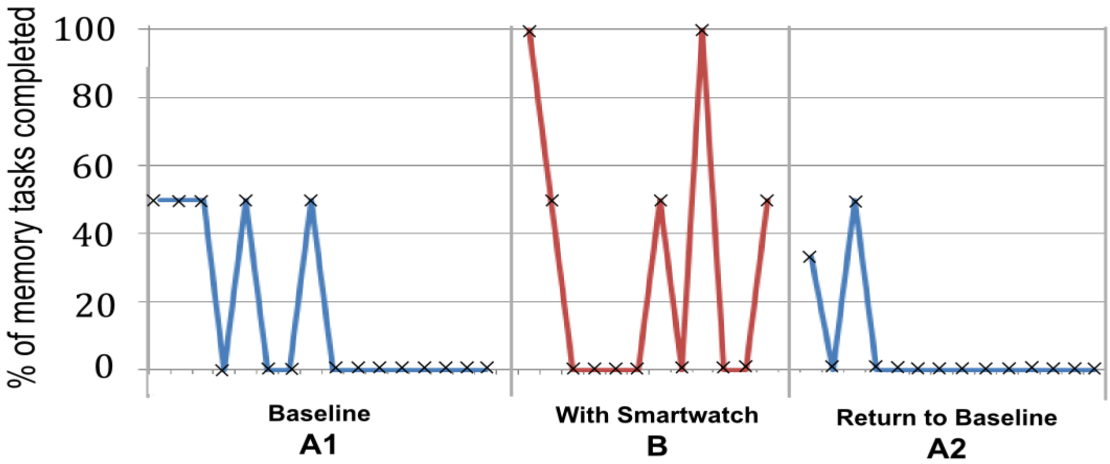


Figure 7-3. Percentage of memory tasks successfully completed in each study phase by participant MA.

NAP analysis indicated that MA's memory performance improved between the first A phase to the B phase, though this was not significant (NAP = 0.58 (p = 0.49, 95% CI = 0.27 to 0.89 (small effect of phase). Cohen's *d* analysis indicated that the increase between baseline A1 and the intervention B had a small effect size (*d* = 0.43). NAP score between phases A2 and B was 0.66 indicating a small, though non-significant effect of phase change (p = 0.17, 95% CI = 0.34 to 0.98). The Cohens *d* indicated that the decline between the phases had a medium effect size (*d* = 0.75).

7.3.3 Usability and User Experience

It was also of interest to know whether or not participants could be supported to use the smartwatch successfully and whether or not they found it acceptable. Participants were given a 30 minute training session detailing how to use the smartwatch and were given a manual to take home which further detailed the use of the device. The technology was set up so that there would be few technological demands on the participants. At the beginning of the study MM entered participant's reminders into the phone, and synced the watches to the smartphone and reminder app. The purpose of the manual was to help the participants in case anything went wrong with the technology during the study. No participants reported that the technology stopped working; however participant LA reported that the watch stopped prompting when it was taken too far from the phone. A usability problem reported by MA was that they could not feel the vibrations given by the watch and so would often miss the notification until they looked at the written prompt presented on the watch face.

Table 7.3 shows mean scores for each individual TLX and UTAUT category for each participant. Lower scores in the TLX indicate lower task load and higher scores in the UTAUT indicates a better user experience. TLX items are out of 20, the total is out of 120. UTAUT items are out of 6, the total is out of 174.

Table 7-3. TLX and UTAUT scores on each category for TS, LA and MA.

TLX domain	**TS**	**LA**	**MA**	**UTAUT domain**	**TS**	**LA**	**MA**
Mental Demand	5	3	10	Performance Expectancy	5.75	4.38	4.75
Physical Demand	1	3	1	Effort Expectancy	5.75	1.63	5.5
Temporal demand	1	2	2	Attitude	5.38	4.5	3.5
Performance	4.5	10	17	Social Influence	4.33	3	2.66
Effort	1	3	10	Facilitating Conditions	4.33	2.33	4.33
Frustration	1	3	1	Self-Efficacy	6	6	6
Total score	**13.5**	**24**	**41**	Anxiety	6	5.25	4.75
				Behavioural Intention	4.33	5.67	1
				Total score	**154.5**	**120**	**122**

7.4 Discussion

The results of theNAP analysis show that introduction of the smartwatch did not lead to any significant change in memory performance for any of the participants, with MA and LA experiencing an increase in memory performance, and TS experiencing no change. Memory performance of all participants declined when the smartwatch was removed. This effect was significant and was small for MA and LA and medium for TS. There are different possible interpretations of the meaning of the results.

One interpretation is that, while people were able to remember to perform these tasks prior to the introduction of the memory aid, they became reliant on using the watches and so had reduced memory performance when the intervention was removed. The anxiety that they will become reliant on memory aid technology has been expressed by participants in studies canvassing the attitudes of end users towards prompting technology. For example Baldwin, Powell and Lorenc (2011) reported that some people with memory difficulties after brain injury believed that relying on memory aids would lead to their memory becoming ‘lazy’ and that remembering things by themselves was a step forward. McGee-Lennon *et al.* (2012) reported that some older users would prefer to be given a content-free prompt which allows them to remember for themselves what the task was that they needed to do. While these attitudes and opinions about assistive technology may affect people’s willingness to use memory aids or memory aid technology, there is very little evidence in the literature of a decline in memory performance when the intervention is removed. In fact, many studies which have investigated the efficacy of prompts from technology to compensate for memory have found that task performance remains higher than it was at baseline, even after the intervention is removed. For example Wilson, Evans, Emslie and Malinek (1997) reported a mean baseline percentage memory performance of 37.05% for 15 neurologically impaired participants. This increased to 85.46% with introduction of the wearable NeuroPage intervention and reduced only slightly to 74.46% when the NeuroPage was taken away. This indicates that the use of the NeuroPage facilitated habitual performance of the memory tasks. A similar result was found by van Hulle and Hux (2005) when they investigated the efficacy of a watch based prompt. The participant who responded well to this intervention then continued to have a good memory performance after the intervention was removed. While the return to baseline performance in prompting technology efficacy studies is not always higher than the baseline performance, it is rarely substantially lower. This kind of result, in which the return to baseline performance is better than or at least equivalent to baseline performance, is the most common among other studies investigating the efficacy of prompting devices, even amongst those in which the intervention failed to improve performance (e.g. Wilson et al., 2001; Lemoncello et al., 2011; Stapleton, Adams & Atterton, 2007). Therefore the findings in the current study are contrary to the majority of findings in the literature.

Another explanation may be that the participants' motivation was higher during the first phase of the study than it was during the return to baseline phase. This may have been because the study was new to the participants in phase A and study stimuli such as increased contact with the brain injury services and memory aid logs were novel. Motivation may also have increased with the prospect of receiving the smartwatch and smartphone technology, especially given that the participants lived in a very deprived area. A disparity in motivation between the first and final phases of the study was reported by members of the service and the assistant psychologist who ran the study. If this is the case then it may have had an effect on memory performance, particularly performance of memory tasks which were associated with the study. For example, participant LA stopped filling out his memory logs after the second day of the return to baseline phase and reported that he "didn't feel like doing it anymore." This highlights the importance of motivation in the success of neuropsychological rehabilitation interventions.

The efficacy results from this SCED study indicate that the introduction of the intervention did have an effect on memory performance. The results are the first to detail the impact of a smartwatch prompting system on everyday memory performance for people with ABI. However the reasons for the pattern of results found here are open to interpretation. The results are also limited by the fact that a stable baseline was not reached in the A phase for TS and LA. This makes it difficult to analyse the trends in the data which may have given insights into the reason for the substantial drop in performance between the B and A2 phases. More research is needed to establish the clinical efficacy of a smartwatch intervention for people with ABI.

The secondary aim of this chapter was to investigate the user experience of participants when given the smartwatch and smartphone. The TLX and UTAUT scores are quite similar for all three participants and the measures were only given to the participants once. It is therefore necessary to interpret the findings with caution. The results show that MA reported the highest total task load when using the device and TS experienced relatively minimal task load with LA falling somewhere in between. It is clear that participants LA and MA viewed their own performance when using the technology as average or poor and that participant MA felt a lot of effort was required to achieve this level of performance. MA also reported relatively high mental demand when using the devices. Overall, the majority of the task load scores were low (only one item, for one participant (MA) was over 10/20) indicating that participants did not experience a high amount of task load when using the technologies for two weeks. The UTAUT results show that TS had a slightly better experience using the technology than LA and MA but all three give quite high scores on the UTAUT. Encouragingly, all three participants scored maximum points on the self-efficacy questions confirming that they believed they could use the system without any help from either an on-screen tutorial or a carer or family member. TS and LA indicated that they would use the smartwatch again within the next six months if it was available to them and MA said she did not intend to use it in the next six months. In contrast to his results on the TLX effort and mental demand scales, LA reported low scores on the effort expectancy questions in the UTAUT, indicating that he felt like it would take a lot of effort for him to become skilful at using the system.

These results indicate that it would be feasible to provide this technology in practice to people with brain injury in the community, with minimal training and support from a clinician, without requiring a great deal of mental, physical or time demand from the end users. It is not possible to draw any conclusions about which service users would make the best use of this type of intervention from these results. Future researchers could aim to further understand how the technology use differs between users with different cognitive profiles.

7.4.1 Methodological Issues

The study reported in this chapter followed the majority of the RoBiNT recommendations for SCED studies (Tate et al., 2013). However it was not possible to blind the therapist and participants to the study condition, there was no randomisation of study phase, there was no independent assessment of study adherence, and there was no measure of generalisation of memory ability. The study was rated on the RoBiNT scale by the thesis author and received a score of 17/30. The lack of blinding of the experimenter was unlikely to cause bias because only automatic measures such as text and email logs were used to calculate memory performance. Future studies investigating a tech based intervention may benefit from randomisation of the study phase. If one or two of the participants had been given the intervention first, then had it taken away and returned again before a final baseline phase (BABA design) then it would have given some insight into whether the drop in performance in the final A phase was due to participants becoming reliant on the device or because participants lost motivation because they knew they were not going to receive the smartwatches again.

7.5 Conclusion

This chapter aimed to investigate whether a smartwatch memory aid intervention was effective for, and could feasibly be used by, people with ABI living in the community. The results of an ABA trial with three participants provided some evidence supporting the effectiveness of the intervention; however future work is required to understand the pattern of memory performance more fully. The user experience results show that, within the two week window in which they were given the device, participants were able to use it without a great amount of effort and reported positive user experiences with the technology. This indicates that it would be feasible to introduce smartwatch reminding technology off-the-shelf into clinical practice.

7.6 Appendix

7.6.1 Smartwatch training

The training will consist of a 5-10 minute demonstration followed by an assessment lasting up to 20 minutes. Once the reminders have been set on the smartphone, the smartwatch software will automatically notify participants as long as the phone and watch are synced. This means training is given as a back-up in case there are issues with the device.

5 – 10 minute demonstration

- Switching on and off, touchscreen and button interactions, charging, bluetooth
- Clearing notifications, receiving reminders, getting back to home screen
- Accessing agenda, voice activation

Assessment of use – up to 20 mins

- Turn on / off
- Switching on Bluetooth on phone, syncing phone to watch
- Put smartwatch on charger
- Clear notification
- Return to home screen
- Access agenda using touchscreen
- Access agenda using voice control

The experimenter will be available by phone to answer queries about the technology. A manual with the same information given during the training session will be given to participants to take away with them and refer to as required.

7.6.2 Smartwatch Manual

Page 1

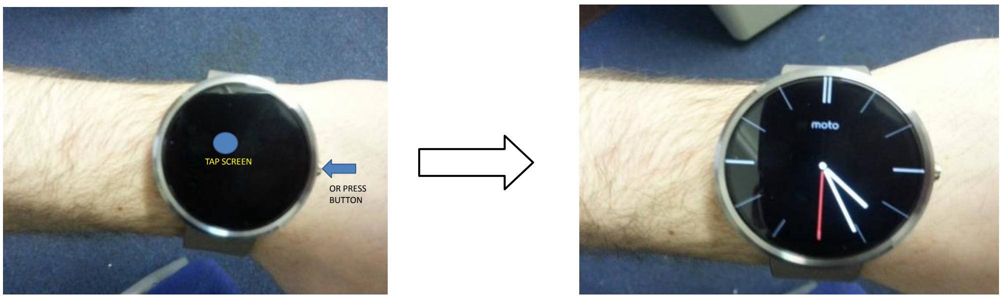
Turning smartwatch on and charging

The smartwatch will require charging every one or two nights depending on how much you use it. We would recommend that you charge the watch every night by placing it in the stand as shown.

Watch charging pic

To switch on the smartwatch press the button on the side once. When you are wearing the smartwatch it should also come on when you turn your wrist and look at the clock face. If it does not come on then try pressing the button or tapping the screen.

Blank (add tap and button arrows) -> clock face



Page 2

Selecting and deleting notification

To select notifications just tap them on the screen. To remove a notification swipe it to the right as shown.

Notification pic plus arrow for removal

Sometimes heart monitoring, number of steps or email information comes up on the watch. If this happens please remove the notifications by swiping them to the right.

Accessing agenda

Your reminders should appear on the watchface throughout the day. If you look at the watchface and cannot see any reminders then you can access them by viewing the 'agenda'. To access agenda simply tap the watchface and scroll down the list to agenda as shown.

Tap the agenda icon to see your events.

Pic - menu, arrows to scroll to agenda and tap icon. -> Agenda screen

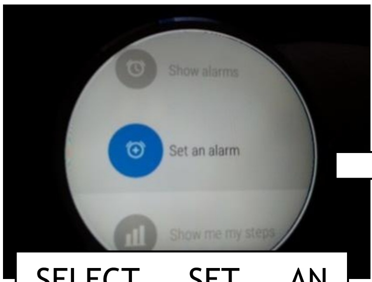
Page 3

Setting an alarm

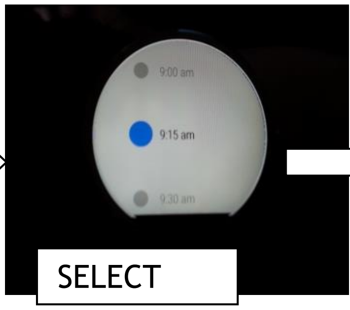
It may be helpful for you to set an alarm to remind you to do a task at a set time. To set an alarm tap the watchface until you get to the menu screen and scroll down to set an alarm option. Press the icon.

Scroll to the time you would like to set and select it – the watch will automatically set a one-off alarm for this time.

Scroll menu screen (selection) -> select time screen (selection) -> alarm setting screen

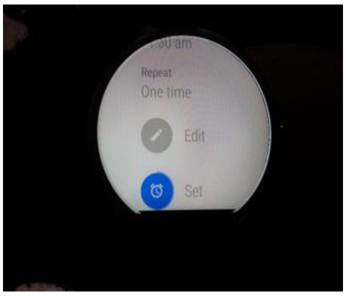


SELECT SET AN



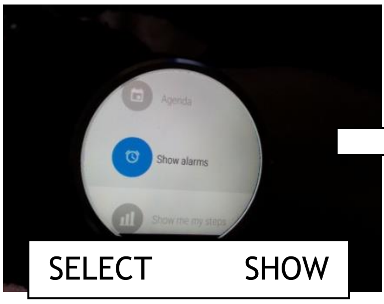
SELECT

ALARM WILL BE



To remove the alarm scroll to show alarms, edit alarm and delete as shown.

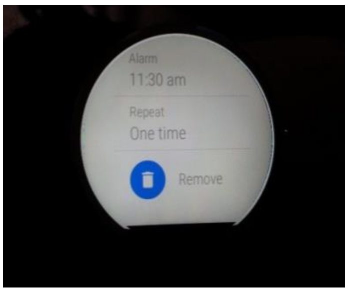
Scroll menu (select show alarms) -> edit alarm selection -> delete alarm selection



SELECT SHOW

SELECT PENCIL (EDIT)

SELECT

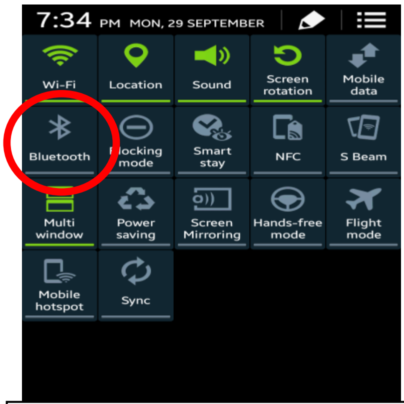


Page 4

Smartphone use

You may have been provided with a smartphone for this study. If you have been given a smartphone then please ensure that Bluetooth is activated (as shown)and that the phone is in near the smartwatch at some point every day.

Image of S3 bluetooth selection



SELECT BLUETOOTH SO THAT THE ICON TURNS

If possible we recommend keeping the phone on charge next to where you charge the watch every night.

7.6.3 Memory Log:

If you feel that memory difficulties might make it difficult to remember information such as whether or how often you use memory aids we would encourage you to ask a family member, friend or supporter to help.

Date________

You have indicated that you would like to try remember the following events which you often forget. Please indicate whether or not you remembered to do these tasks today. If you cannot remember whether you did the tasks or not then please ask a family member, friend or supporter to help.

Memory tasks*	At what time were you supposed to do	What time did you do this task?

	this task?**	
Memory task 1		
Memory task 2		
Memory task 3		
Memory task 4		
Memory task 5		

***memory tasks will be decided during discussions with participants after they have given their consent to take part in the study.**

**** individual items on this table may be altered depending on the type of task selected by participants (e.g. some participants may need a prompt to help them stop a task rather than start one, for example watching T.V.)**

Other notes or comments:

8 Chapter Eight - Discussion

8.1 Overview

The primary aims of this thesis were to:

1) Review the literature to find out what evidence exists for the efficacy of prompting and micro-prompting devices for people with memory and executive impairments after an acquired brain injury, stroke or after the onset of a degenerative disease (chapter two).
2) Understand which technologies are currently in use by these groups, and what the prevalence of technology use is amongst these groups compared with the use of non-technological memory aids and previous findings in the literature (chapter three).
3) Understand which factors predict use and what issues prevent the use of technology (chapters three and four)

Chapters four, five, six and seven focussed more specifically on smartphone based prompting technology for people with acquired brain injury. The primary aims of this work were:

1) To gain an understanding of the barriers to use of this technology by this group (chapters four, five, six and seven).
2) To use these findings to inform the development of new smartphone reminding software that can help people to overcome these barriers (chapters five and six).
3) To test the efficacy and usability of newly developed or newly available smartphone based reminding software that can help overcome these barriers (chapters five, six and seven).

The findings are discussed in depth within each chapter. Therefore in this chapter the main findings from the studies presented in the thesis will be discussed briefly and in relation to their overall contribution to the existing literature. It will be argued that the findings are of interest to clinicians, technologists and researchers. Directions for future research will be outlined. The strengths and weaknesses of the methodologies used to answer the research questions will also be discussed.

8.2 Summary of Main Findings

The initial findings from this thesis established that assistive technology is an effective memory compensation intervention but that it is rarely used compared to pencil and paper memory aids and strategies. The next step was to understand the barriers to technology use and to investigate how these barriers could be overcome. This work demonstrated that knowledge from the literature and feedback during focus groups can be used to develop novel assistive technology which can overcome the barriers to use. ForgetMeNot and ApplTree were smartphone apps with research led design features which were shown to increase use, (Unsolicited Prompting in ForgetMeNot) and improve the usability, (narrow / deep UI structure and decision tree processing) of smartphone reminding applications for people with ABI. Smartwatches, which are likely to overcome some of the practical issues surrounding prompting technology, were also demonstrated to be a feasible technological reminder for this group. This work demonstrated the benefit of using a range of methodologies which are relevant to the research question at hand. There are several contributions to the literature, implications for clinicians and technologists, and there are numerous possibilities for future research. These will be outlined in the remainder of this chapter.

Table 8.1 outlines the main findings from each chapter which added to the assistive technology literature. The column to the left outlines the information from previous literature which was built on by this thesis. The column to the right gives an overview of the main contributions to this literature from each chapter within the thesis.

Table 8-1. A summary of the knowledge synthesised from, and thesis contributions to, the literature.

Knowledge from prior literature	Thesis contributions
What kinds of memory aid technologies have been investigated? • The two types of technology which have most commonly been used to help people compensate for memory and executive impairments are prompting technology which reminds about an intention and micro-prompting which guides the user through a task with several sub-steps (Gillespie, Best & O'Neill, 2012) **What is the evidence for the efficacy of memory aid technology?** • That technology was generally considered to be useful in compensating for memory impairments, but the size of effect compared to practice as usual was not known and the methodology used when testing the technology was not highly rated in a rating system which used group study randomised controlled trials (RCTs) as the gold standard (De Joode, van Heugten, Verhey & van Boxtel, 2010).	**Chapter One** • Seven group studies investigating prompting technology with reasonable methodological ratings (mean Pedro-P score = 5.43 / 11) could be included in a meta-analysis and a large effect size was calculated (d = 1.27) which indicated that prompting technology is preferable to practice as usual or pencil and paper memory aids when compensating for memory difficulties after acquired brain injury (ABI). • Substantial Single Case Experimental Design (SCED) evidence from studies of reasonable methodological quality (SCED mean = 5.9 / 11) found that both micro-prompting (mean NAP score = 0.81, 9 studies) and prompting technology (mean NAP score = 0.96, 8 studies) were effective for improving memory task performance for people with ABI, stroke and after the onset of a degenerative disease. Combining well conducted, controlled SCED studies may be a good way to assess the evidence for neuropsychological interventions which have not been tested in large RCTs.
What is the prevalence of technological memory aid use?	**Chapter Two**

- In 2003 there was very little uptake of memory aid technology amongst people with acquired brain injury (ABI) (Evans, Wilson, Needham & Brentnall, 2003). The change in the prevalence of use by this group over the last decade was unknown. Memory aid technology uptake for people with degenerative diseases such as dementia was unknown.

What influences technological memory aid use?

- While the factors which predict memory aid technology use were unknown, previous research found that that people who were younger, had a greater amount of time since injury, used more memory aids prior to injury, had a higher level of independence and better attentional functioning used more of all types of memory aids amongst people with ABI (Wilson and Watson 1996; Evans et al., 2003).

- A review of the literature undertaken by the thesis author indicated eight important barriers to the use of assistive technology; *practical issues*, *personal preference*, *emotional and social factors*, *reverse effect*, *beliefs about memory*, *ethical issues*, *cognitive difficulties* and *physical* or *sensory impairment*. It

- The most commonly used memory aid technologies reported by a sample of 179 adults (81 With ABI, 98 with dementia) were reported. In the ABI group 38% of people used mobile phone reminders, 38% used an alarm/ timer and 37% stated they asked someone to text them. In the dementia group 8% of people used mobile phone reminders, 10% used an alarm/ timer and 6% stated they asked someone to text them.

- People with ABI in the study reported in chapter two used more memory strategies, technological and pencil and paper memory aids than participants with ABI in an equivalent study carried out in Cambridgeshire published in 2003 (Evans et al., 2003).

- Use of memory aid technology prior to injury or onset of dementia, current use of non-technological memory aids or strategies and age (ABI group only) were the best predictors of technological memory aid use for people with ABI (75.8% of the variance) and dementia (70.7% of the variance).

- Of the barriers to assistive technology use found in the literature, 'Beliefs about memory', 'Personal Preference' and 'Cognition' were the most important for people with ABI and dementia.

was not known which of these barriers were most important for people who may benefit from the use of assistive technology.	
What prevents uptake and continued use of smartphone based reminder applications for people with ABI? • Previous literature concerning assistive technology barriers indicated that difficulties with cognition, beliefs about memory and personal preferences would be important issues (chapter three). No study has looked at the issues which impact the uptake and continued use of smartphone reminding technology for people with ABI. •	**Chapter four** • *Social Acceptability* and *Perceived Need,* related to perceived usability that would influence whether or not someone would decide to use a smartphone reminder. Two themes, *Cognitive Accessibility* and *Sensory / Motor Accessibility*, related to actual usability of the software once the device is in use. Finally, two of the themes, *Desired Content and Functions* and *Experience and Expectation*, could influence both perceived and actual usability. • Given the number, and depth of themes which arose from the focus group study, two of the themes were chosen as the focus of future projects, based on their particular relevance to the ABI group, to the use of prompting technology, and because they lent themselves to design ideas which could be tested in subsequent studies; *perceived need* and *cognitive accessibility* (chapters five and six).
Initiating reminder setting behaviour • The *perceived need* theme which arose from the focus group study (chapter four), with sub-themes insight into cognitive impairment	**Chapter five** • Unsolicited Prompts (UPs) - A novel reminding software feature - was designed and described which could help overcome a barrier which

and motivation was one which seemed relevant when thinking about the uptake and use of prompting technology; if people don't set reminders in the first place then they cannot receive the prompt. This issue was considered in chapter five. **Unsolicited prompts** • It was unclear from the literature if unsolicited prompts from a smartphone reminder app can increase the reminder entry and efficacy of the prompting technology intervention while still being accepted by users. HCI research with healthy users indicated that acceptability is low for interruptions from technology which are deemed irrelevant and which are perceived by the user to prompt too frequently (Shirazi, Henze, Dingler, Pielot Weber & Schmidt, 2014; Pielot, Church & de Olivieira, 2014).	was described in chapter four (*insight and perceived need*). • In a Single Case Experimental Design (SCED) study, three participants were given a reminding app (ForgetMeNot) and used it both with and without UPs over a seven week period. Results showed that UPs increased reminder setting but no significant improvement in everyday memory performance. Observations of the use of ForgetMeNot and the effect of the UPs on acceptability provided insights highlighting the importance of cognition, social environment and insight into impairments when introducing a technological memory aid in clinical practice.
Setting reminders using reminding software • The *cognitive accessibility* theme gave more detailed insight into the *cognitive difficulties* theme which was reported in the literature review in chapter two, and which was very important to participants with ABI and dementia in the survey study. Again this was a very intuitive issue; if people are not able to set reminders, then how can they receive them?	**Chapter six** • An app which took a novel approach to the design of smartphone reminder software, 'ApplTree' was designed and prototyped. The justifications from the literature which informed the design of ApplTree are outlined and the design and central features are described. • Overall, similar errors were made when using ApplTree and Google

Usability and the user interface

- Several guidelines (Friedman and Bryen, 2007; Freeman, Clare, Savitch, Royan, Litherland and Lindsay, 2005) have been recommended to improve cognitive accessibility of the user interface of computer software for people with cognitive impairments. These criteria have never been applied when designing a smartphone reminding app for people with ABI.

- Google Calendar is representative (in terms of user interface structure and design features) of reminding software which is commonly used in studies with users with ABI (McDonald, Haslam, Yates, Gurr, Leader & Sayers, 2011; Svoboda & Richards, 2009) and which can be recommended within clinical practice (Baldwin and Powell, 2015; Petrie, Goudie, Cruz and Kersel, 2012). Previous research has found that people with ABI made similar mistakes as healthy participants but made more mistakes and were less able to finish a set of reminding tasks using calendar based reminding software on a personal computer (De Joode, Proot, Slegers, van Heugten, Verhey & van Boxtel, 2012).

Cognition and usability

Calendar apps. Differences were indicative of design features particular to each app which users found particularly difficult to use. These results can inform the future design of usable reminder apps for this group.

- Participants ($n = 14$) performed the tasks significantly more accurately when using ApplTree than when using Google Calendar (Mean difference in percentage accuracy was 9.65%, $W = 20$, $df = 13$, $p = 0.042$). This indicates that design principles synthesised from the universal accessibility and neuropsychological literatures can inform the development of smartphone reminding software which is more usable compared to reminding software which is commonly used in clinical practice and neuropsychology rehabilitation literature.

- Exploratory analysis indicated that executive switching, processing speed and selective attention are involved in accurately setting a reminder. There is preliminary evidence that when using ApplTree participants with better cognition experienced lower mental demand than they did when using Google Calendar. More research is needed to fully understand the impact software design of reminder apps can have on usability and user experience for people with different types of cognitive impairment and different levels of impairment.

• Few studies describe the impact of particular cognitive processes on the use of computer software. Some research indicates that attention and executive function difficulties have been found to impact the use of email and calendar software use (Sutcliffe, Fickas, Sohlberg & Ehlhardt, 2003; De Joode et al., 2012).	
Receiving reminders • In chapter two, the literature review indicated that practical difficulties were particularly important barriers to the use of assistive technology. These were issues such as losing a device, not hearing prompts or not being able to access the technology when they needed it (van den Heuvel, Jowitt and McIntyre, 2012; McGee-Lennon, Smeaton and Brewster, 2012). Practical difficulties were also rated as important by participants who took part in the survey study. While not all of these issues were included in the barriers questionnaire, many participants mentioned difficulties such as losing or misplacing devices in the additional comments. **Wearable devices** • A few studies have tested prompting technology which can be	**Chapter seven** • Three of four participants completed the study and reported being confident in their use of a smartwatch as a prompting device. This does appear to be a feasible intervention to introduce to people with memory impairments after ABI living in the community. • An ABA SCED study showed a particularly pronounced reduction in memory task completion when participants returned to practice as usual after the smartwatch intervention was taken away. • One interpretation of the findings, based on feedback from participants and the service staff who were involved in the study is that participant's motivation to receive the smartwatch had a large impact on their memory performance. This once again emphasises

worn. For example pagers (e.g. NeuroPage, Wilson, Emslie, Quirk & Evans, 2001) and watches with alarms (e.g. WatchMinder, van Hulle and Hux, 2006). However to date no study has investigated the efficacy and usability of a smartwatch as a prompting device for people with memory impairments after ABI.	the importance of *perceived need* (particularly sub-themes, *social* and *emotional motivation*) which was a theme which arose from the focus group in chapter four.

8.2.1 Implications for clinicians and clinical researchers

A number of considerations for clinicians and clinical practice can be made based on the findings of this thesis:

1) **Assistive technology can be a useful clinical tool for helping clients compensate for memory difficulties.**

There is good evidence that technology can be an effective tool for prompting memory about a future intention. There are several personal technologies such as mobile phones, computers and tablets which have software which is able to prompt memory and clients may already own and use these technologies. The findings from chapter two suggest that using these technologies as prompting devices is likely to be more effective than using pencil and paper methods. Chapter three highlighted the fact that use is quite low amongst people with ABI and dementia who could benefit from prompting technology. These findings indicate that it may be beneficial for clinicians to encourage the use of the clients' own personal technologies for memory prompting purposes.

However many clients may not own these personal technologies. In these cases health services would need to provide the technology. Although the evidence base remains quite small (the meta-analysis from chapter two only included 7 papers and 147 participants), the effect of prompting technologies (vs. practice as usual or a pencil and paper equivalent) on everyday memory performance for people with ABI was large (d = 1.24). The technology which can prompt such as mobile phones, alarms and timers, personal computers and tablets are fairly inexpensive. Therefore, this intervention could be provided by healthcare providers at low costs, especially compared to other neuropsychological interventions (Oddy and da Silva Ramos, 2013).

2) **There are a number of factors related to the successful use of technological memory aids which it may be possible to address in clinical practice.**

Previous literature indicated that people with ABI who were younger, had a greater amount of time since injury, used more memory aids prior to injury, had a higher level of independence and better attentional functioning used more of all types of memory aids (Wilson and Watson 1996; Evans et al., 2003). In chapter three it was established that use of memory aid technology prior to injury or onset of dementia, current use of non-technological memory aids or strategies and age (ABI group only) were the best predictors of technological memory aid use. Clinical rehabilitation was not investigated and may have played a role in technology uptake for the groups in the study reported in chapter five. However, it is clear that the majority of the variation in technological memory aid use amongst this group was explained by these other factors (75.8% for ABI group and 70.7% for dementia group). These findings indicate that a very brief interview with clients during a clinical appointment could establish the likelihood that people will use personal technology to aid them without clinical supervision.

An issue which came up in the focus groups in chapter four, and during the trials of ForgetMeNot and the smartwatch device in chapters six and seven, was *perceived need* which included issues concerning *insight* and *motivation*. Lack of motivation and insight can be difficult barriers to overcome when implementing any clinical intervention. For example van den Broek (2005) highlighted the importance of clinicians understanding their clients' stage of readiness for a behavioural change intervention. For example prior to the uptake of a technological intervention the potential users may be in the pre-contemplative stage (lacking awareness of need to change), contemplative (considering their needs), be preparing to change (actively seeking to change). Therapeutic conversations with the patient can then be focussed on harnessing intrinsic motivation to change (e.g. decide to use a technological intervention). In the case of prompting technology, people in the pre-contemplative stage may not realise, or not believe, that they will forget to do something and so will not set a reminder. In the contemplative stage they may realise they need to set reminders but may be apathetic or even simply forget to set reminders. The unsolicited prompts feature of the ForgetMeNot app was designed to help overcome this issue by prompting people to set reminders. The findings indicated that UPs might be a useful addition to reminding software used in clinical practice, particularly when a lack of motivation or insight has been identified.

One of the barriers to use which participants rated as highly important were practical issues. Not having access to, or having someone to show them how to use, the technology was the third most important issue for people with ABI and the second most important for people with dementia (out of the eight barriers presented in the barriers to use questionnaire). This indicated that simply having memory aid technology made available and having someone (a clinician or family member) to show them how to use it could considerably increase the uptake of ATC.

A barrier which was identified in chapter four was *experience / expectation*. When technology is introduced in clinical practice clients may not feel confident using it to help their memory. One way to overcome this is through training sessions. Many of the studies reviewed in chapter two gave participants extensive training sessions over a number of weeks, especially when participants entered their event reminders independently (Svoboda et al., 2009; De Joode et al., 2012). Training is likely to be important, especially when memory and learning are impaired (Wilson et al errorless learning; Svoboda et al., 2009). Training which helps clients to create procedural memories may also lead to the technology being used over the long term (Svoboda, Richards, Yao & Leach, 2015).

3) **Collaboration with computing science is important**

It is also important for clinical researchers investigating technology based interventions to use human computing interaction (HCI) models which aim to understand technology use. For example the Technology Acceptability Model (TAM) (Davis, 1989) and the most recent update the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, Morris, Davis & Davis, 2003) are models which explain the factors which can predict and influence technology use. The UTAUT is useful because it gives a brief overview of several domains of perceived acceptability and usability. From this researchers and clinicians can develop a deeper understanding of the factors which influence technology use for individual clients or participants. For example, in chapter seven, the UTAUT scores indicated that, like participants TS and LA, MA was confident in using the smartwatch (high self-efficacy). However, unlike the other participants she did not have people around her who were encouraging her to use the technology (low social influence) nor did she have a strongly positive attitude towards the technology (medium attitude score). In turn she indicated that she would not use the technology in the next 6 months (very low behavioural intention score). While the technology did have a positive impact on her memory performance, the technology had a smaller effect for her than for the other participants and her memory performance remained highly variable throughout the study.

8.2.2 Implications for Human Computing Interaction

The thesis results also revealed issues which are relevant for software developers and designers when creating technology which is universally acceptable and usable;

1) **Better design can improve levels of uptake and use and efficacy of ATC**

It is hoped that assistive technology can be a highly effective tool for compensating for cognitive impairment. Ideally, the technology will support cognition in everyday life (e.g. by prompting memory) but also support the cognitive processes required to use the technology effectively (e.g. setting reminders). This means that the design of assistive technology such as reminding software is crucial. Design which people with cognitive impairments find easy to use could reduce the need for training and increase the uptake and long term use of assistive technology. To achieve this it is important to build on research from human computing interaction such as the area of universal design.

Chapters five and six describe studies in which novel design is applied to smartphone reminding software and tested in rehabilitation (chapter 5) and experimental (chapter 6) settings by people with cognitive impairments after moderate to severe ABI. In chapter five unsolicited prompts (UPs) from the app increased use and positively, though not significantly, impacted the efficacy of the ForgetMeNot prompting app compared to use of the app without UPs. In chapter six the reminders set using ApplTree were more accurate than the reminders set using Google Calendar. These findings suggest that the design of reminding software impacts usability and that better usability leads to better efficacy. In both of these studies participants were given only minimal training, indicating that better design will allow people to use prompting technology successfully with less training.

2) A one size fits all approach is not ideal

Some HCI research, particularly research in the accessible technology and universal design literatures, often groups different types of 'cognitive impairments' together (Friedman et al., 2007; Hu and Feng, 2015). The reasoning behind this is that people with cognitive impairments have more in common than they do differences and that if these common issues are addressed in technology design, it will be more accessible (Friedman et al., 2007). Research on accessible technology is distinct from assistive technology research in that it investigates the accessibility of technologies which are used by the general public. However this often overlaps with assistive technology research (which looks at technologies which can rehabilitate cognitive impairments). Examples of this overlap are studies which investigate the accessibility of smartphone based prompting technologies such as Google Calendar which are used by the general public and which can be also used as a memory intervention for people with memory impairments. The one-size-fits all approach of grouping together people with different types of cognitive impairment is not ideal when investigating assistive technology for cognition because it makes it difficult to understand which technologies can compensate for different cognitive processes. The 'full circuit' of factors which influence technology use should be considered and these include individual differences, personal preferences, and the cognitive and physical abilities of the user (O'Neill and Gillespie, 2014).

The approach often used by researchers investigating assistive technology as a neuropsychological intervention (including within this thesis) is to group participants by aetiology of impairment such as acquired brain injury, dementia or stroke (Gillespie et al., 2012). In the context of designing and testing assistive technologies, and attempting to understand what influences the uptake of these technologies, this method of grouping participants may also fall short. This is because two people with ABI may have very different types of cognitive impairment. For this reason, researchers often give participants standardised neuropsychological tests in order to establish the cognitive profiles of participants (e.g. the cognitive profile tables in chapters five, six and seven). This allows the findings for each participant to be compared to their cognitive profile to provide insights into which processes impact the use of different technological interventions. Researchers investigating technology accessibility or universal design with groups with cognitive impairments could apply neuropsychological methods to their work, such as establishing and reporting the cognitive profile of participants. This would give future researchers more specific information about the efficacy of technologies with different functions, and the influence of design features on usability, for users with different profiles of cognitive impairments. This is one example of how collaboration between neuropsychology and human computing interaction researchers can increase the quality of research within the growing field of assistive technology for cognition.

3) Some reminding app features look very promising for people with ABI

A number of features were developed which could be combined to create an ideal reminding app for people with ABI. Some of the design features could also be brought together and used in different types of assistive technology:

- **Universal design principles:** Several design principles have already been identified and these can be applied when creating technology for people with cognitive impairments:
  - Use pictures, graphics, icons, and symbols along with the text
  - Use clear and simple text
  - Use consistent navigation and design on every page

- Use headings, titles, and prompts
- Use colour and contrast cues to direct the user around the website
- Minimize the number of choices on each page

- **Narrow / deep UI structure:** Evidence from the HCI literature indicates that a narrow / deep structure may improve web navigation usability for people with cognitive impairments. There is no indication yet which specific types of cognitive impairments are supported by this design feature. Chapter six applied a narrow / deep structure to a smartphone reminding app (ApplTree) and the results suggest that this type of design is favourable for people with ABI compared to a broad / shallow design. The results indicate that assistive technology software which uses a narrow / deep structure may be more accessible for people with cognitive impairments, with executive switching, processing speed and selective attention in particularly being supported. However ApplTree and Google Calendar had many differences in their design features and so research is required to establish the impact of broad / shallow design in a way which controls for the effect of other design features. More research is also required to understand the cognitive processes which may be supported by this design feature.

- **Decision Tree Processing**: Assistive technology research, most notably the GUIDE project (O'Neill, Moran & Gillespie, 2010), have used decision tree processing to guide participants through the processes involved in everyday tasks. ApplTree used decision tree processing to help guide people through the use of a smartphone reminding app. ApplTree performed favourably in a comparison with Google Calendar, an app which has no decision tree processing suggesting that decision tree processing could be a useful design feature to apply to prompting technology, and the software design of other types of assistive technology. More research is needed to establish whether this design feature does improve usability for people with ABI and, if so, which cognitive processes it supports.

- **Unsolicited Prompting**: Chapter five investigated the impact of unsolicited prompts (UPs) from a smartphone reminding app (ForgetMeNot) on the reminder entry and memory task performance of people with ABI. This design feature did increase the use of the app. It also lead to an improvement in memory task completion, although this was not significant compared to memory performance wth the app without the UPs. It may be a useful feature to add to future reminding applications. Future research could investigate the efficacy and acceptability of different prompts at different times, with different modalities, and using different form factors such as smartwatch to send UPs.

- **Wearability**: Chapter eight investigated a worn smartwatch device and results indicated that this is a feasible form factor for sending prompts to people with ABI. Smartwatches have recently increased in functionality and availability and they can sync with smartphones. Researchers and designers might be able to use them to create more effective assistive technologies because of their proximity to the users and because they are less likely to be misplaced than handheld portable devices.

4) **Methodological Considerations for HCI**

A number of different methods were used in the thesis to provide answers to different research questions. Single Case Experimental Design (SCED) methodology is particularly rare in HCI and could prove to be particularly useful. This is because designers, engineers and programmers who work in HCI are capable of creating novel assistive technologies, often after developing their requirements in co-design or participatory design with the intended users (e.g. Robinson, Brittain, Lindsay, Jackson, Olivier, 2009; Slegers, Wilkinson and Herdriks, 2013; Gordon, Dayle, Hood and Rumrell, 2003; Gómez, Montoro, Haya, Alamán, Alves and Martínez, 2013; Gómez, Alamán, Montoro, Torrado and Plaza, 2015). However, none of the studies referenced in the previous example tested their technologies in group studies. Even research which does go on to test the developed technologies often recruits only small numbers of participants (e.g. Gordon et al., 2003; Gómez et al., 2013). SCED is the best methodology to use when investigating the efficacy of an intervention with a small number of participants because it allows the use of the intervention to be compared to a control condition (Tate, Perdices, Rosenkoetter, Wakim, Godbee, Togher & McDonald, 2014). This method also allows the accumulation of support for particular interventions; as chapter two demonstrated the results of several SCED studies can be synthesised using an appropriate statistical method (e.g. Non-overlap of all pairs (NAP) analysis) and an overall effect size can be calculated. This could allow a large quantity of small studies to have the same level of impact (e.g. on clinical guidelines such as the Scottish Intercollegiate Guidelines Network (SIGN, www.sign.ac.uk) which impact health service provision) as larger group studies with control conditions.

8.2.3 Future Research

Each of the chapters which include experiments (two to eight) reported findings which suggested future research. In particular it would be interesting for future research to continue to bring together methods from both HCI and neuropsychology. Examples of this are investigating the usability, acceptability and user experience of technology based neuropsychological intervention and investigating the impact of accessible design features for people with different cognitive profiles as measured by standardised neuropsychological tests. Other examples would be to use, where appropriate, methodologies such as co-design and participatory design which are established in HCI and methodologies such as SCED which are established in neuropsychological research.

Looking at reminding technology more specifically, future research could take the design features described, developed and / or tested in this thesis and apply them to a reminding app. Participatory design with the intended user group (people with memory impairments) could then help to develop future iterations and even establish which design features are best for people with certain cognitive profiles. A larger scale trial could be undertaken to establish the effectiveness, usability and user experience of a reminding app which has been developed from the literature and designed iteratively based on the results of user feedback studies (such as the focus group study reported in chapter four) and usability trials (such as those reported for ApplTree in chapter six).

Using HCI and neuropsychological research methods to establish a list of evidence based design features could also inform the design of other types of assistive technology which could be useful for groups with the same types of cognitive difficulties, for example micro-prompting devices and retrospective memory aids. Furthermore, having research led design guidelines for smartphone prompting software would allow software which already exists to be reviewed using a standard checklist. A deeper understanding of the needs of people with particular cognitive profiles using smartphone software could also allow technologies to be reviewed based on their suitability for users with particular cognitive impairments. This type of review could be extremely useful for clinicians who may find it difficult to know which technologies are best for their client.

8.3 Conclusion

This thesis reported six research studies which offer several contributions to the HCI and neuropsychology literature regarding the efficacy, use and barriers to use of assistive technology for people with memory impairments, and the design, development and investigation of prompting software for people with acquired brain injury. The results have important implications for the use of technological memory aids in clinical practice and the design and development of prompting software by computing and neuropsychology researchers. The area of assistive technology for cognition will benefit from collaboration between researchers who aim to improve the lives of people with cognitive impairments through effective interventions and researchers who aim to understand and improve the usability, accessibility, and user experience of everyday technologies.

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