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### The efficacy of cognitive prosthetic technology for people with memory impairments: A systematic review and meta- analysis

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## The efficacy of cognitive prosthetic technology for people with memory impairments: A systematic review and meta-analysis

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Technology can compensate for memory impairment. The efficacy of assistive technology for people with memory difficulties and the methodology of selected studies are assessed. A systematic search was performed and all studies that investigated the impact of technology on memory performance for adults with impaired memory resulting from acquired brain injury (ABI) or a degenerative disease were included. Two 10-point scales were used to compare each study to an ideally reported single case experimental design (SCED) study (SCED scale; Tate et al., 2008) or randomised control group study (PEDro-P scale; Maher, Sherrington, Herbert, Moseley, & Elkins, 2003). Thirty-two SCED (mean = 5.9 on the SCED scale) and 11 group studies (mean = 4.45 on the PEDro-P scale) were found. Baseline and intervention performance for each participant in the SCED studies was re-calculated using non-overlap of all pairs (Parker & Vannest, 2009) giving a mean score of 0.85 on a 0 to 1 scale (17 studies,  $n = 36$ ). A meta-analysis of the efficacy of technology vs. control in seven group studies gave a large effect size ( $d = 1.27$ ) ( $n = 147$ ). It was concluded that prosthetic technology can improve

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performance on everyday tasks requiring memory. There is a specific need for investigations of technology for people with degenerative diseases.

**Keywords:** Memory aid; Assistive technology; Memory impairment; Cognitive rehabilitation; Brain injury; Degenerative disease.

## INTRODUCTION

Technologies such as those found in automobiles or mobile phones allow us to perform beyond our physical capabilities and travel faster or communicate over long distances. Technologies such as those in computers and calculators can also help us perform beyond our mental capabilities by storing and manipulating large amounts of information that we would otherwise be unable to process or remember. In the context of physical disability, technologies such as prosthetic limbs or hearing aids are commonly used and are provided within the healthcare system. In spite of growing evidence from burgeoning research, the same cannot be said for technological cognitive orthotic systems for people with cognitive difficulties (Gillespie, Best, & O'Neill, 2012; Cicerone et al., 2011).

Acquired brain injury (ABI) from accident or illness and degenerative diseases such as Alzheimer's disease (AD) and Parkinson's disease (PD) often lead to memory difficulties which can disrupt a person's independence in everyday life. Difficulties with retrospective memory (RM) and prospective memory (PM) can cause people to forget important information such as names and places and can lead to appointments or errands being missed. This can impact on quality of life and lead to social withdrawal or stigmatisation.

Non-technological memory aids, such as diaries and calendars, are ubiquitous in everyday life and can be useful for those with memory disorders (De Joode, Van Heugten, Verhey, & Van Boxtel, 2012; Yasuda et al., 2002). Technological memory aids have the potential to surpass their non-technological equivalents because they can offer time- or event-specific reminders in various modalities, can be programmed to help organise and plan daily activities, and can be interactive.

Assistive technologies 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 they are 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. For the purpose of this review, technologies were categorised in terms of the type of memory

function that they are designed to support. Prospective memory aids 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 even 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, Lahrman, Tradisauskas, & Harms, 2011). These reminders support the ability to retain future intentions in the medium and long term and are hereby referred to as prospective prompting devices (PPDs). 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). Portable devices have also been developed which support retrospective memory by playing back images of the previous day's activities (Hodges et al., 2006) or by helping with face recognition (DeVaul, Clarkson, & Pentland, 2000). All of the devices investigated in this review are prospective memory aids designed either to support future intentions – prospective prompting devices (PPDs), including portable digital assistants (PDAs) and static prompting devices (SPDs), or to support plan retention and task organisation – micro-prompting devices (MPDs).

Previous reviews have investigated various different aspects of cognitive aids such as the efficacy and usability of PDA devices (De Joode, Van Heugten, Verhey, & Van Boxtel, 2010), the efficacy of assistive technology for all cognition (Gillespie et al., 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 et al., 2009). No recent reviews have specifically examined all orthotic technologies which aimed to improve performance on memory tasks and which have been tested with memory impaired patients. 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 (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 PDA 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.

The purpose of this paper was to provide a detailed review of the quality of studies that 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 et al., 2003) for group studies and the SCED scale (Tate et al., 2008) for single case experimental design studies (see 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, 2013). 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 baseline phases for the single case studies which provided sufficient raw data.

## METHODS

### Eligibility criteria

#### *Participants*

Studies testing cognitive orthotic devices 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.

### *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).

### *Comparators/context*

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

### *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 the form of quotes and focus groups, usability outcomes, amount of usage outcomes or well-being outcomes. Outcome measures 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.

### **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.

### *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 in Figure 1), 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 et al., 2012; O'Neill, Best, Gillespie, & O'Neill, 2013).

### *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.



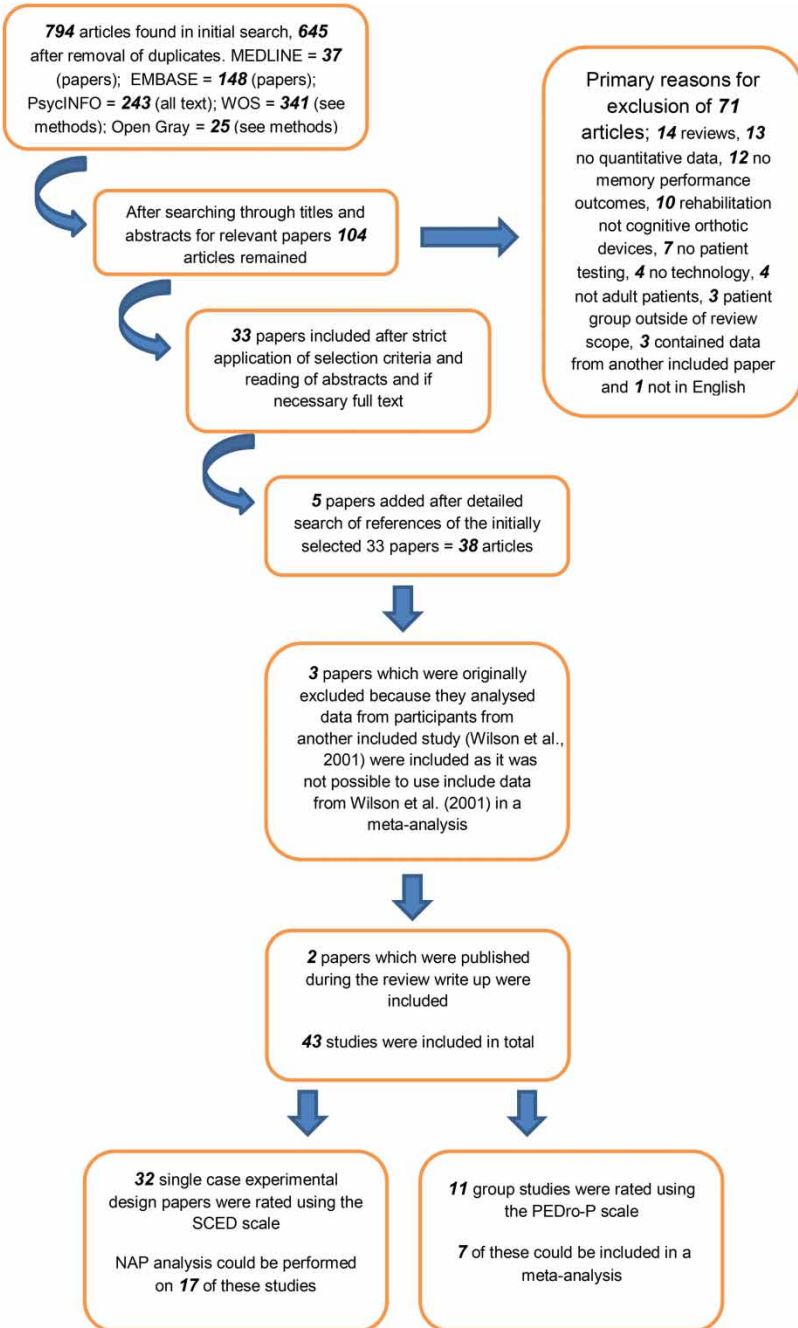


Figure 1. Flowchart of study selection processes and results.

### *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 were 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 1).

### *Data extraction*

The type of disorder which lead to the study participant's memory impairment, the type of technology which was tested (PDA, SPD or MPD) were extracted along with efficacy and methodological rating for each study.

### *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 10 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](http://www.psycbite.com) for more detail). The SCED scale also has 10 scored items and these concern the repeatability and generalisability 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).

### *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. Only group studies which included a control condition and which reported means and some form of variance of both conditions could be included in this analysis. 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 NAP (Parker & Vannest, 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 were 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 0 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 during, 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 were still collected then they were coded as a baseline score. These data were 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.

## RESULTS

### Study selection

Figure 1 is a flowchart showing details of the search process and results.

### Study characteristics

Table 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.

### All studies

Of the 43 studies, 30 (69.7%) investigated the efficacy of prospective 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.

TABLE 1  
Details of studies included

<i>Author (year)</i>	<i>Diagnosis of participants [aetiology if specified] (number)</i>	<i>Technology type (name)</i>	<i>Quality rating (Scale)</i>	<i>Effect size(s) (method) [reason for exclusion from meta-analysis or NAP analysis]</i>
Group studies Dowds et al. (2011)	ABI [TBI] (36)	PPD – portable (Palm Zire 71/72 and Dell Axim X30)	5 (PEDro-P)	n/a [not enough data reported]
De Joode et al. (2012)	ABI (34)	PPD – portable (PEAT)	6 (PEDro-P)	0.21 ( <i>d</i> statistic)
Fish et al. (2007)	ABI [TBI (14), CVA (4), damage after surgery (2), myocardial infarction (1)] (20)	PPD – portable (mobile phone)	7 (PEDro-P)	0.63 ( <i>d</i> statistic)
Fish et al. (2008)	ABI [CVA] (36; subjects from Wilson et al., 2001)	PPD – portable (NeuroPage)	5 (PEDro-P)	0.82 ( <i>d</i> statistic)*
Gentry (2008)	Degenerative disease [MS] (20)	PPD – portable (Palm Zire 31)	1 (PEDro-P)	n/a [no control group]
Gentry et al. (2008)	ABI [TBI] (23)	PPD – portable (Handspring Visor or Palm Zire 31)	1 (PEDro-P)	n/a [no control group]
Lemoncello et al. (2011a)	ABI [TBI (15), CVA (5), anoxia (1), brain tumour(1) and unreported(1)] (23)	PPD – static (TAP)	5 (PEDro-P)	3.02 ( <i>d</i> statistic)*
Manly et al. (2002)	ABI [TBI (9), ischaemic incident (1)] (10)	PPD – static (Goal management cue)	6 (PEDro-P)	1.02 ( <i>d</i> statistic)
McDonald et al. (2011)	ABI [TBI (4), haemorrhage (2), haematoma (2), CVA(1), encephalitis (1), anoxic injury (1) and toxic-metabolic encephalopathy (1)] (12)	PPD – portable (Google calendar)	6 (PEDro-P)	2.84 ( <i>d</i> statistic)*
Thöne-Otto and Walther (2003)	ABI [CVA (2), TBI (6), other neurological disease (4)] (12)	PPD – portable Palm m100 and mobile phone with agenda function	3 (PEDro-P)	0.68 ( <i>d</i> statistic)
Wilson et al. (2001)	ABI [TBI (63), CVA (36), anoxia, meningitis or encephalitis (21), other conditions (13)] and degenerative disease [AD or MS (10)] (143)	PPD – portable (NeuroPage)	4 (PEDro-P)	n/a [not enough data reported]

SCEDs				
Boman et al. (2010)	ABI [ <i>haemorrhage (3) and cerebral infarction(s) (2)</i> ] (5)	PPD – static (“Home-based electronic memory aid”)	8 (SCED)	0.92, 0.69, 0.98, 0.8 and 0.81 (NAP)
Burke et al. (2001)	ABI [ <i>TBI (3) and haemorrhage (2)</i> ] (5)	PPD – portable (Patient locator and minder (PLAM))	5 (SCED)	n/a [not enough data reported]
Chang, Chou, Wang, and Chen (2011a)	Degenerative disease [ <i>dementia (1)</i> ] and ABI [ <i>brain injury (1)</i> ] (2)	MPD (Kinemtp)	8 (SCED)	1 and 1 (NAP)*
Chang, Wang, and Chen (2011b)	ABI [ <i>TBI (1) and developmental disabilities (1)</i> ] (2)	MPD (Locompt)	7 (SCED)	1 and 1 (NAP)*
Emslie et al. (2007)	ABI [ <i>encephalitis</i> ] (5)	PPD – portable (NeuroPage)	5 (SCED)	n/a [not enough data reported]
Evans et al. (1998)	ABI [ <i>CVA</i> ] (1)	PPD – portable (NeuroPage)	6 (SCED)	0.81 (NAP)*
Giles and Shore (1989)	ABI [ <i>Haemorrhage</i> ] (1)	PPD – portable (The Psion Organiser)	4 (SCED)	n/a [not enough data reported]
Kirsch, Levine, Fallon-Kreuger, and Jaros (1987)	ABI [ <i>damage after surgery to remove haematoma</i> ] (1)	MPD (COGORTH)	5 (SCED)	1 (NAP)
Kirsch et al. (1988)	ABI [ <i>TBI (1), anoxic injury (1)</i> ] (2)	MPD (COGORTH)	5 (SCED)	1 and 0.85 (NAP)
Kirsch, Levine, Lajiness-O’Neill, and Schneider (1992)	ABI [ <i>TBI</i> ] (4)	MPD (ITG (COGORTH))	7 (SCED)	1, 0.99, 0.78 and 0.92 (NAP)
Kirsch, Shenton, and Rowan (2004a)	ABI [ <i>TBI</i> ] (1)	PPD – portable (Generic “in-house” paging system)	5 (SCED)	0.94 (NAP)
Kirsch et al. (2004b)	ABI [ <i>TBI</i> ] (2)	PPD – 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 et al. (2011)	ABI [ <i>CVA</i> ] (2)	PPD – static (ISA)	9 (SCED)	0.95 and 0.97 (NAP)*
Labelle and Mihailidis (2006)	Degenerative disease [ <i>Dementia</i> ] (8)	MPD (“Automated prompting system” updated version of COACH; Mihailidis et al., 2000)	7 (SCED)	0.91 (NAP)* and n/a [individual results reported for one subject only]

(Continued)

TABLE 1  
Continued

<i>Author (year)</i>	<i>Diagnosis of participants [aetiology if specified] (number)</i>	<i>Technology type (name)</i>	<i>Quality rating (Scale)</i>	<i>Effect size(s) (method) [reason for exclusion from meta-analysis or NAP analysis]</i>
Lemoncello, Sohlberg, Fickas, Albin, and Harn (2011b)	ABI [ <i>TBI</i> ] (3)	PPD – static (TAP)	9 (SCED)	0.86, 0.89 and 0.49 (NAP)
Mihailidis et al. (2000)	Degenerative disease [ <i>Alcoholic dementia</i> ] (1)	MPD (Computerised cueing device; prototype of COACH)	4 (SCED)	n/a [not enough data reported]
Mihailidis et al. (2004)	Degenerative disease [ <i>Dementia</i> ] (10)	MPD (COACH)	7 (SCED)	0.97 (NAP)* and n/a [individual results not reported for other participants]
Mihailidis, Boger, Craig, and Hoey (2008)	Degenerative disease [ <i>Dementia</i> ] (6)	MPD (updated version of COACH)	6 (SCED)	n/a [individual results not reported]
O'Neill and Gillespie (2008)	Degenerative disease [ <i>Vascular Dementia</i> ] (1)	MPD (Guide)	4 (SCED)	n/a [not enough data reported]
O'Neill et al. (2010)	Degenerative disease [ <i>Peripheral vascular disease</i> ] (8)	MPD (Guide)	4 (SCED)	n/a [not enough data reported]
O'Neill et al. (2013)	ABI [ <i>Haemorrhage</i> ] (1)	MPD (Guide)	7(SCED)	0.78 In home phase [0.8 in care setting, not included in review analysis] (NAP)
Oriani et al. (2003)	Degenerative disease [ <i>AD</i> ] (5)	PPD – portable (EMA)	4 (SCED)	n/a [not enough data reported]
Stapleton, Adams, and Appleton (2007)	ABI [ <i>TBI</i> ] (5)	PPD – portable (Siemens C45 mobile)	7 (SCED)	0.8, 0.52, 0.67, 0.66, 0.69 (NAP)*
Svoboda and Richards (2009)	ABI [ <i>complications with cyst removal surgery</i> ] (1)	PPD – portable (Treo 680 smartphone)	5 (SCED)	n/a [not enough data reported]

Svoboda et al. (2012)	ABI [ <i>aneurysm (3), anoxia (2), TB I(1), cyst (1), germinoma (1), glioma (1) and CVA (1)</i> ] (10)	PPD – portable (Unnamed)	9 (SCED)	n/a [not enough data reported]
Van den Broek et al. (2000)	ABI [ <i>encephalitis (2), haemorrhage (2) and TBI (1)</i> ] (5)	PPD – portable (IQ Voice Organiser Model No. 5300 manufactured by Voice Powered Technology International Inc.)	3 (SCED)	n/a [not enough data reported]
Van Hulle and Hux (2006)	ABI [ <i>TBI</i> ] (2)	PPD – portable (WatchMinder and Voice Craft)	6 (SCED)	0.54 and 0.45 (NAP)
Wade and Troy (2001)	ABI [ <i>TBI (4), haemorrhage (1)</i> ] (5)	PPD – portable (Mobile phone reminder system)	4 (SCED)	n/a [not enough data reported]
Waldron et al. (2012)	ABI [ <i>TBI (3), CVA (1), tumour (1)</i> ] (5)	PPD – portable (Palm IIIe)	5 (SCED)	1, 1, 0.83, 1 and 0.92 (NAP)
Wilson, Evans, Emslie, and Malinek (1997)	ABI [ <i>TBI (10), haemorrhage (2), cyst (1), CVA (1) and tumour (1)</i> ] (15)	PPD – portable (NeuroPage)	6 (SCED)	n/a [not enough data reported]
Wilson, Emslie, Quirk, and Evans (1999)	ABI [ <i>TBI</i> ] (1)	PPD – portable (NeuroPage)	5 (SCED)	n/a [not enough data reported]
Yasuda et al. (2002)	ABI [ <i>TBI (4), haemorrhage(s) (3) and tumour (1)</i> ] (8)	PPD – portable (Sony IC Recorder (ICD-50))	5 (SCED)	n/a [not enough data reported]

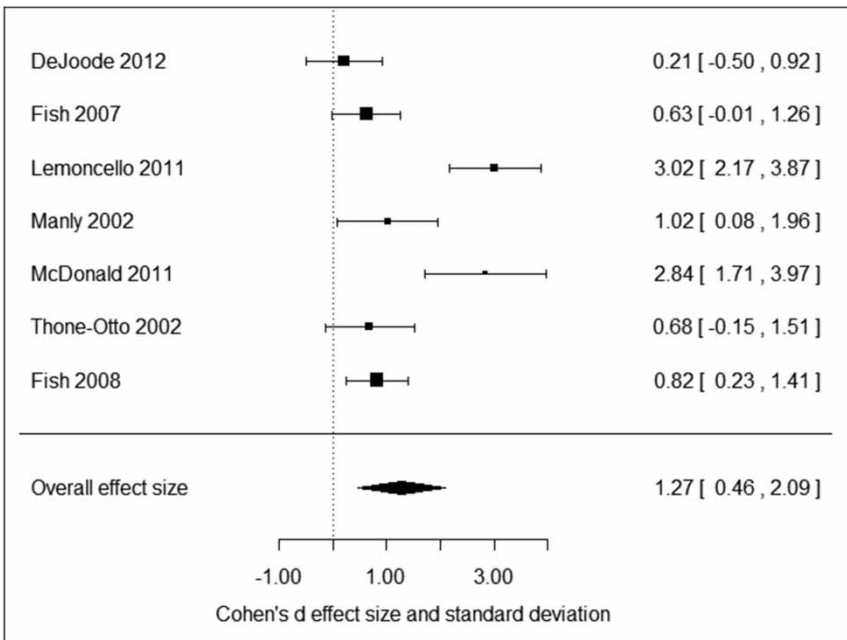
### Key

\*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).

ABI = Acquired brain injury; AD = Alzheimer's disease; COACH = Cognitive orthosis for assisting activities in the home; CVA = Cerebrovascular accident; EMA = Electronic memory aid; ISA = Intelligent speed adaptation; ITG = Interactive guidance system; MPD = micro-prompting device; MS = Multiple sclerosis; PEAT = Planning and Execution Assistant and Trainer; PEDro-P = reliability of data obtained within the Physiotherapy Evidence Database – PsycBITE adaptation ([www.psycbite.com](http://www.psycbite.com)); PPD – portable = personal (portable) digital assistant (prospective prompting device); PPD – static = static prompting device (in-home, care environment or vehicle) (prospective prompting device); SCED = Single case experimental design; TAP = Television assisted prompting; TBI = Traumatic brain injury

## Group studies

All of the devices that were tested in the group studies were prospective 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., 2011a). The rest of the papers looked at some form of PDA. The studies predominantly tested technology with people with ABI from traumatic injury or cerebrovascular accident. Many studies also included people with a degenerative disease (e.g., dementia; Mihailidis et al., 2000) or people who acquired a brain injury from some other illness or disease (e.g., encephalitis; Wilson et al., 2001) and one study specifically focused on people with multiple sclerosis (Gentry, 2008). The mean PEDro-P rating for all group studies was 4.45 (median = 5, range = 1–7). 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 = 3–7). After studies were weighted in



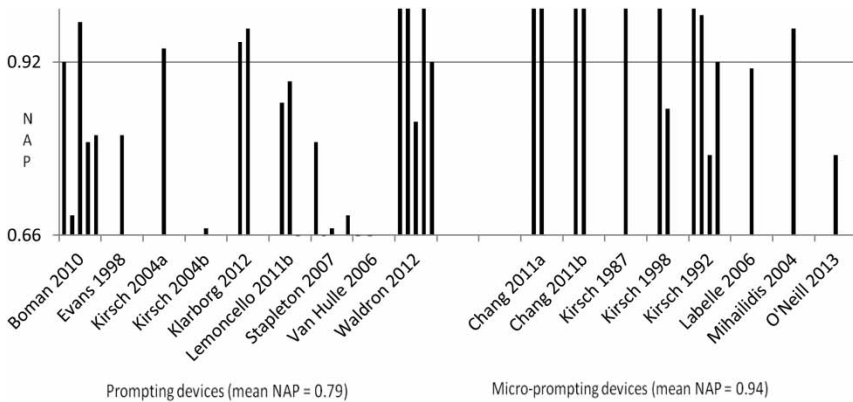
**Figure 2.** Meta-analysis results with effect sizes, confidence intervals and weightings for each individual study.



accordance with sample sizes, a significant, large positive overall effect size (Cohen's  $d = 1.27$ ,  $p < .01$ ) was found. Figure 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  $d = 0.398$ ,  $p < .05$ ). 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).

### SCED studies

Within the SCED papers the most commonly tested technology was prospective prompting devices (PPDs) (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 = 3–9). 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% of participants (Parker et al., 2009). Figure 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 PPDs (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 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 & Vannest, 2009).

## DISCUSSION

### 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 et al., 2012; 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 in Manly et al., 2002) to participant set everyday tasks (Wilson et al., 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 may be biased towards pleasing 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 & Hux, 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 (Kirsch et al., 2004b; Lemoncello et al., 2011b). Around half of the SCED studies did not accumulate or provide enough raw data to perform a 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.

### 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 above 0.8 indicates a large effect size (Cohen, 1988). The results of the meta-analysis therefore offer very convincing evidence for the efficacy of prospective memory prompting devices which are portable (McDonald et al., 2011; Fish, Manly, Emslie, Evans, & Wilson, 2008) or fixed in a home environment (Lemoncello et al., 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, & 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, it seems more likely to indicate long-term improvement in remembering the specific tasks measured in the study because prospective prompting technology allows associations to be formed (e.g., between taking pills and dinner time). Alternatively, it may reflect differences in cognitive impairment between participants recruited to PPD studies and MPD studies.

### 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 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 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 (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 utilised. 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.

Smartphone devices are becoming increasingly more easily 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, & 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. 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.

### 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 et al., 1988), food preparation (Chang et al., 2011a) 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 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 (Cognitive orthosis for assisting activities in the home) 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 guides participants through a prosthetic limb-donning task (O'Neill & Gillespie, 2008) and a participant's morning routine (O'Neill et al., 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 & Mihailidis, 2006; O'Neill, Moran, & Gillespie, 2010). Future research could attempt to show the efficacy of such devices in a group study design.

### 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.

### 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, 2008). While the means and standard deviations for some sub-groups of the participants included in the Wilson et al. (2001) study were reported in the study by Fish et al. (2008), these data were used by Fish et al. to analyse the extent to which beneficial effects of the NeuroPage were maintained once the pager was removed. This meant that participants who had *not*

benefited from use of the pager were excluded from that aspect of the analysis. This meant that these data could not be included in our meta-analysis of primary efficacy as the sample would have been biased.

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 been 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 robust.

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 et al., 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 lead to the formation of a habit (Fish et al., 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 the 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.

## 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 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 not readily available but the evidence from the studies in this review suggests that it should be.

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## APPENDIX

### 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*