Efficacy and usability of assistive technology for patients with cognitive deficits

Clinical Rehabilitation 2010; **24:** 701–714

Efficacy and usability of assistive technology for patients with cognitive deficits: a systematic review

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Received 13th July 2009; returned for revisions 19th November 2009; revised manuscript accepted 12th January 2010.

Objective: To determine the efficacy of portable electronic aids such as personal digital assistants (PDAs), pagers or mobile phones for patients with cognitive deficits by means of a systematic review. The usability of these aids is also briefly discussed.
Data sources: PubMed, CINAHL, PsychINFO, EMBASE and MEDLINE were searched up to February 2009. The references of identified and relevant articles were scanned to find additional relevant titles.
Review methods: Papers referring to 'electronic aids', 'cognition' and 'brain injury' were included. The population had to be adult and have cognitive impairments as a result of acquired brain injury. Outcome measures were change in cognitive or occupational performance or the level of participation in daily life. The criteria of Cicerone *et al.* were used to evaluate the quality of the retrieved studies.
Results: Twenty-eight papers presenting 25 studies were reviewed. The total number of participants was 423. Most identified papers described case reports or non-randomized clinical trials. Only one randomized controlled trial was identified, in which the NeuroPage proved effective in supporting prospective memory. Other kinds of assistive technology such as PDAs and voice recorders showed positive results in supporting retrospective and prospective memory.
Conclusion: The efficacy of assistive technology in general is not yet sufficiently studied in randomized controlled trials, although promising results has been reported. Furthermore, several survey studies established that both potential users and clinicians have optimistic expectations about the usability of assistive technology.

Introduction

Nowadays, almost everyone uses electronic aids in daily life, such as personal computers, cell phones, smart phones or personal digital assistants (PDAs). These devices support our cognitive activities by helping us to manage our daily lives, plan our day or week, remember appointments, keep our contact information organized and keep track of our notes. For these reasons, people with cognitive deficits such as memory, planning, attention and motivation problems may also benefit from this type of cognitive support.[1,2] Important questions in that respect are whether people with cognitive deficits are capable of using these devices in their daily lives and whether this is effective in enhancing independent functioning.

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10.1177/0269215510367551

External aids to support cognitive functioning and thereby improve independence and quality of life are frequently used as cognitive aids and are often referred to as assistive technology. Indeed, many researchers and clinicians have suggested that assistive technology, such as pagers and PDAs, can also be used in a therapeutic setting.[3] Several studies have investigated the usability and efficacy of electronic cognitive aids for this purpose.

Five years ago, two reviews provided an overview of research on available technological cognitive aids.[4,5] They concluded that assistive technology is a promising tool for clinicians who work in the field of cognitive rehabilitation, especially because of the broad application of these devices. According to Lopresti and colleagues, technological aids such as PDAs should be viewed as necessary adjuncts for the treatment of patients who have sustained a traumatic brain injury, and can be used together with (or even instead of) non-technological interventions such as ‘memory books’. However, Kapur *et al.* were less convinced and concluded that computer-related memory rehabilitation strategies remain largely task-specific in their benefit, although the use of cues could prove to be beneficial to people with memory deficits.[4] According to these authors it remains unclear whether these developments will have a major impact in clinical settings such as rehabilitation centres.

Other well-known reviews[6–9] on the efficacy of cognitive rehabilitation do not explicitly differentiate on technological interventions and only mention a few studies investigating assistive technology. Even so, these authors conclude that these devices appear to benefit people with moderate to severe memory impairments. Training in the use of external compensations (including assistive technology) with direct application to functional activities is recommended as a practice guideline in subjects with moderate or severe memory impairment after traumatic brain injury or stroke.[8]

In order to determine the efficacy and usability of portable electronic devices as cognitive aids and to provide specific recommendations for their clinical use, it is necessary to evaluate the findings and quality of studies performed so far. The first two reviews[4,5] gave a thorough overview of assistive technology and the ways it is used in clinical practice, but they did not critically evaluate the methodological quality of studies such as the ecological validity of the outcome measures used, or the presence of adequate follow-up assessment. In addition, these reviews were published in 2004, while technological development is proceeding extremely fast and up to date information is currently needed. The other reviews[6–9] did evaluate the quality of the studies, but only mentioned a few of the available studies on assistive technology and did not address the subject in particular. Moreover, these reviews also included studies up to 2002. We therefore reviewed all existing literature up to date on the efficacy and usability of assistive technology interventions as cognitive aids for individuals with cognitive deficits due to brain injury. Furthermore, we will add to this discussion more specific recommendations for future research and clinical implications.

Methods

Literature search and study selection

Papers referring to ‘electronic aids’, ‘cognition’ and ‘brain injury’ were identified by searching the PubMed, CINAHL, PsychINFO, EMBASE and MEDLINE computerized databases up to February 2009. Both thesaurus terms and free text words in title, abstract or keywords were combined in our search. Details of the search are shown in Appendix 1. A flowchart for the literature search and paper selection is shown in Figure 1.

Participants had to be adult and cognitively impaired as a result of acquired brain injury (e.g. traumatic brain injury, stroke, multiple sclerosis, radiation treatment for cancer). Cognitive impairment was defined as having difficulties with cognitive abilities, such as memory, executive function or attention. Aphasia and apraxia are also common after brain injury but often impair the use of assistive technology and therefore require a very specific kind of technological aid. These patient populations were excluded.

We included only papers describing interventions with portable assistive technology that provide continuous support throughout the day (e.g. cell phone, pager or PDA). For the same reason, we excluded studies that reported on the

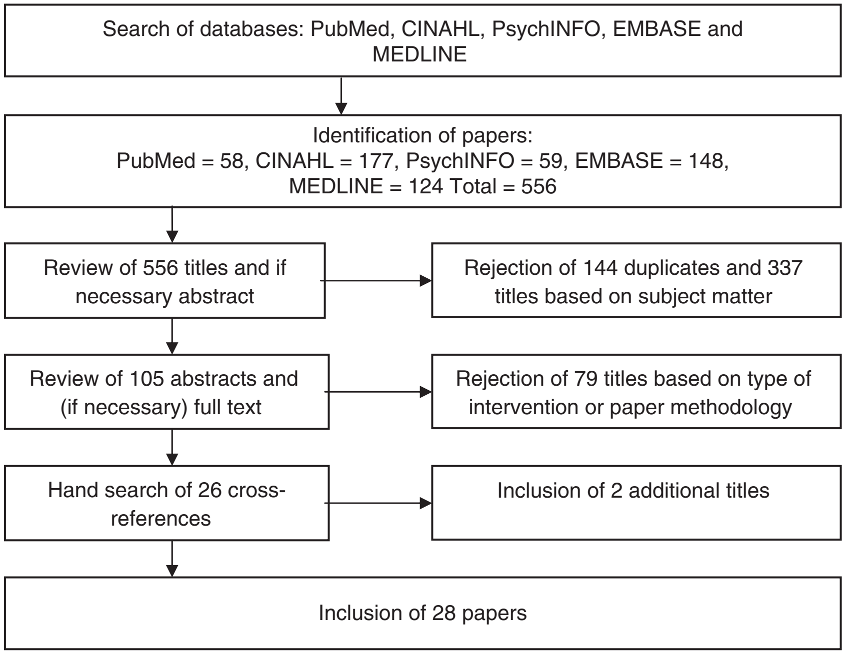

Figure 1 Flowchart of the literature search and paper selection.

use of personal computers or focused on domotics (i.e. household automation: the application of intelligent technology to make a home safer, more comfortable or convenient). However, there were no restrictions on study design or the number of participants. Outcome measures had to assess change in cognitive or occupational performance or the level of participation in daily life. Thus, (survey) studies with qualitative or descriptive outcome measures, such as willingness to continue use of the electronic aid, were excluded from the systematic review. These studies were used to describe the usability of assistive technology for cognitively impaired individuals in a separate paragraph (see 'Usability' section in Results).

The initial search resulted in 556 papers, of which 422 remained after the exclusion of duplicates. We assessed the subject matter of these articles based on title and abstract. This resulted in 105 potentially relevant papers, and further selection based on design (see 'Quality assessment' below) and outcome measures led to the final inclusion of 26 quantitative papers with efficacy assessment. The references of these articles were scanned to find additional relevant titles and another two papers were included.

Quality assessment

We used the criteria of Cicerone *et al.*[6] to evaluate the quality of the retrieved studies. These authors outlined evidence-based recommendations for cognitive rehabilitation in clinical practice. The reviewed studies were classified according to the strength of their research design. Class I studies were defined as prospective randomized controlled trials. Within this category, studies with 'quasi-randomized' assignment to intervention conditions, such as prospective assignment of subjects to alternating conditions were labelled class Ia studies. Class II studies consisted of prospective non-randomized cohort studies, retrospective non-randomized case–control studies or clinical series with well-designed controls that permitted between-subject comparisons of treatment conditions, such as multiple baseline across subjects. Class III studies were clinical series without concurrent controls, or studies with results from one or more single cases that used appropriate single-subject methods, such as multiple baselines across interventions with adequate quantification and analysis of results. Studies that did not meet these classification criteria were rated as unclassified.

Results

Study characteristics

Twenty-eight papers describing 25 studies met the inclusion criteria. Table 1 presents the main study characteristics. These papers consisted of one class I study, two class II studies, 18 class III studies and four papers were not classified because they did not meet the classification criteria.

Twenty-three papers included 23 or fewer participants, and 11 papers used a single-case design. In 12 papers no statistical analyses were reported. Follow-up (two months to one year) data were available in five papers, but in four of these papers these data were only about continued use of the device. Seventeen papers used pre and post measurements for comparison with the experimental intervention; five papers used single baseline measurements. Two papers used a control intervention, three papers used both baseline and control measurements, and one paper did not use any control measurement.

Patient characteristics

The total number of participants was 423, with a male/female ratio of 3:2. Mean age was 38.1 years. Time since brain injury is reported per paper in Table 1. Most included patients suffered from traumatic brain injury or stroke, but also patients with subarachnoidal haemorrhage, intellectual disability or multiple sclerosis were included in the reviewed papers.

Interventions

Ten papers evaluated the efficacy of a PDA but the device was used in very different ways in these studies. Some studies used a standard PDA primarily as a memory aid,[10] while others customized a standard PDA for use as a navigational aid[11] or a conversational aid.[12]

Four studies assessed the efficacy of one specific device: the NeuroPage.[13–19] This is a pager linked to a message service that sends personally composed messages at predetermined times to remind the user of tasks or appointments. The schedule of reminders or cues is entered into the computer, resulting in an audible cue for the user on the appropriate date and time.

Three papers assessed the use of cell phones and another five papers assessed voice recorders as a memory aid. Two papers assessed the use of a combination of two devices: one used a cell phone and a PDA,[10] and yet another used a standard pager and a customized navigational device.[11]

The way in which the devices were used differed considerably between studies. For example, with devices used to support planning and memory, not only did the mode of cue presentation differ (visual and auditory, both beeps and voice messages), but also the content of the cues. Both content-free cueing (messages reading STOP) at random intervals during the day[20] and explicit personal text messages at set times[13] were used to improve performance on prospective memory tasks.

Another important aspect of interventions with assistive technology is the amount of time spent on training subjects to learn how to use the cognitive aid. A few studies fail to mention this at all,[21] and others only mention the amount of training sessions, but not the exact number of hours.[22–25] The ones that do describe the exact time spent on training show a substantial amount of variation (from 30 minutes[20] up to 9 hours[26]). Furthermore, also the setting and the person assisting the subjects in the use of a new device differed between studies. Some devices were used at home,[13,14,18] others only within a clinic[22] and some were only used in the research lab.[25,27] Training was in most cases provided by the researchers,[28,29] sometimes by clinicians[22] and support from a caregiver was essential in the applications of most devices.[18,23,29]

Goals for use

The main use of these cognitive aids was to support prospective memory functioning. Most studies investigated whether the device improved

Table 1 Paper and participant characteristics

First author, year	Study type	Class	N	Male	Aetiology and time since injury (>)	Mean age (years)	Intervention type	Control condition	1st outcome	Follow-up	Results	Remarks
Wilson, 2001[15]	Randomized controlled cross-over paper design ABA	I	143	105	TBI, CVA, developmental difficulties, other conditions > mean 4.9 years	38.6	NeuroPage	Multiple baseline	% Successful task achievement Self-care, self-medication, and keeping appointments	No	80% were more successful in daily tasks With pager more achieved target behaviours ($P<0.001$)	Large sample with heterogeneous patient group, large age range leads to generalization!
Wilson, 2005[13]			63	53	TBI >mean 5.3 years	Age range 8–65					Without NeuroPage 47%, with 72% achieved target behaviour ($P<0.001$)	Group was part of 2001 paper
Emslie, 2007[14]			4	3	Encephalitic patients >6 months–20 years	39					2–81% success without pager 45–96% with pager	Group was part of 2001 paper. Results case-wise presented: no statistical analyses
Fish, 2008[16]			36	24	18 CVA 18 SAH >mean 3.3 years	46.7					CVA: 45%75% Compared with TBI, CVA showed less post pager maintenance.	Group was part of 2001 paper CVA: older, shorter post injury and poorer exec. funct. In TBI: maintenance associated with exec. function
			50	38	30 TBI 20 CVA	–						
DePompei, 2008[23]	ABCDABCD	II	35	21	Youth >2–7 years	15.3	Paper planner, 2 kinds of PDA	Pre and post measurements	On-time response rate to cue (%)	Partial, $n=6$ for 1 year	Adult TBI: 23%67% Youth: 42%78% Adult ID: 20%29%	No statistical analyses Youth gained most from Palm PDA
			36	17	Adult TBI >mean 2 years	45.5						
			35	18	Adult ID	41.2						
Thone-Otto, 2003[10]	ABAC	II	12	All M	ABI >mean 46 months	46 (28–58)	PDA and cell phone with calendar function	Pre and post measurements	Execution of tasks Forgotten everyday intensions Usefulness	No	Using devices-> decrease in forgotten intentions for daily and experimental tasks	Slow and fast learners and their preferences Developers of MEMOS
van den Broek, 2000[29]	Single case ABA	III	5	4	ABI >1.5–4.5 years	42.6	Voice organizer	Pre and post measurements	Recall of message passing task and domestic task	No	All improved on message passing, 4 improved on domestic task	Did not affect their mood. No statistical analysis
Davies, 2002[27]	Prospective Within-subject	III	12	8	Intellectual disability	34.2	PDA	Paper schedule	Completion of an 8-item schedule	No	Less assistance Fewer schedule errors Timely completion	Laboratory paper: generalization? IQ <70

(continued)

Table 1 Continued

First author, year	Study type	Class	*N*	Male	Aetiology and time since injury (>)	Mean age (years)	Intervention type	Control condition	1st outcome	Follow-up	Results	Remarks
Evans, 1998[17]	Single case ABAB	III	1	0	CVA > 7 years	50	NeuroPage	Pre and post measurements	Target behaviours: medication, watering plants, washing underwear	No	Increase in timely achieved target behaviours	No statistical analyses
Giles, 1989[44]	Single case ABAC	III	1	0	CVA >18 months	25	Psion organizer	Pre and post measurements and pocket diary	10 normal household activities	Yes, 3 months	Baseline: 0/10 Diary: 8/10, 6 on time Psion: 9/10. All on time	No statistical analyses
Hart, 2002[33]	Prospective Within-subject	III	10	8	TBI >3 months–18 years	31,5	Portable voice organizer	Unrecorded goals	Remembering goals, follow through with therapy objectives	No	Recorded goals were remembered better and associated with better outcome	
Fish, 2007[20]	Prospective Within-subject	III	20	15	14 TBI, 4 CVA, 2 other median >27.5 months	40,8	Text messages reading STOP	Uncued days	Prospective memory tasks: phoning a voice-mail at set times	No	Significantly better performance on cued days	Content-free cueing
Fish, 2008[18]	Single case ABABACAD	III	1	0	SAH >18 years	60	NeuroPage vs. checklist	Baseline, and checklist only	Behavioural goals: medication, morning/evening routine	Yes, 6 months	NeuroPage increased performance on all 3 goals. NeuroPage + checklist reduced time spent on morning routine even further	Continued use at follow-up plus GMT messages
Gentry, 2008[26]	Quasi-experimental pre- and post-assessment design	III	23	16	TBI >1 year	Age range: 18–66	PDA with training 8 weeks	Baseline	Occupational performance COPM Everyday participation CHART-R	No	Performance+ Satisfaction+ Cognitive independence+ Mobility+ Occupation +	Self-ratings/sign. Other Volunteers
Kirsch, 2004[22]	Single case ABA	III	1	1	TBI	Mid-30s	Pager	Pre- and post measurements	% entries in memory log about prior therapy appointments	No	Substantial increase of entries during intervention. Decrease in second A-condition.	No statistical analyses
Kirsch, 2004[11]	Single case ABA	III	1	1	TBI	19	Web-based PDA	Pre- and post measurements	Accuracy in route finding	No	Substantial improvement in task performance Decreased number of errors per route (3.2–0.9)	No statistical analyses Only 3 intervention days between 8 baseline days, chance results?

(continued)

Table 1 Continued

First author, year	Study type	Class	*N*	Male	Aetiology and time since injury (>)	Mean age (years)	Intervention type	Control condition	1st outcome	Follow-up	Results	Remarks
Oriani, 2003[25]	Within subjects ABC	III	5	3	Alzheimer's	68.4	Voice recorder	Baseline and checklist	Remembering tasks at specified times	No	Voice recorder increased performance dramatically	Laboratory paper with occupational therapist
Sohlberg, 2007[32]	Within-subject	III	20	15	ABI >4–37 years	45.9	4 kinds of navigation prompt modes	Between modes	Accuracy and confidence during navigation	No	Best performance when cued via speech-based audio directions	Interpretation using the resource allocation theory
Stapleton, 2007[28]	Single case ABAB	III	5	5	TBI	34	Cell phone: individual reminder messages	Pre- and post measurements	Individual memory target behaviours	No	2/5 success: 50–90%	No statistical analyses Success dependent of severity memory impairment
Wilson, 1997[19]	Within-subject ABA	III	15	11	ABI >6 months–13 years	40.1	NeuroPage	Pre- and post measurements	Memory failures for daily life tasks	No	All benefited from the pager, more tasks achieved, even after withdrawal of NeuroPage	
Van Hulle, 2006[24]	Single case ABA(CA)	III	3	3	TBI >14 months–14 years	29.3	Wristwatch alarm and/or digital voice recorder	Pre- and post measurements	% independent medication requests	No	D.G.: no effect of intervention J.W.: slow but continuous improvement across interventions	1 participant dropped out prior to intervention No statistical analyses
(21)	Single case ABA	III	8	4	ABI >2–25 months	46.3	Voice recorder	Pre- and post measurements	Successful completion of daily task	No	Completion without voice recorder 5.1%, with voice recorder 57%	No statistical analyses But totally unsuccessful for 3/8 patients and others benefited dramatically
Gentry, 2008[30]	ABC	III	20	4	MS patients with cognitive impairment >median 9 years	Median 50	PDA with 5-hour training by occupational therapist	Baseline	Occupational performance COPM Everyday participation CHART-R	Yes, 8 weeks	Significant improvement on all subscales of the COPM and on cognitive independence and mobility of the CHART-R	Effects remained significant after 8-week follow-up
Gorman, 2003[31]	Single case AB	–	2	2	Anoxic brain injury >18 months traumatic brain injury >3 months	31	ISAAC	Baseline	Functional Independence Measure (FIM)	No	Both cases increased FIM score. From needing assistance to modified independence.	On demand user-initiated access Sufficient training necessary No statistical analyses

(continued)

Table 1 Continued

First author, year	Study type	Class	*N*	Male	Aetiology and time since injury (>)	Mean age (years)	Intervention type	Control condition	1st outcome	Follow-up	Results	Remarks
Kim, 1999[45]	Single case	–	1	1	TBI inpatient needing max. cueing >2 months	22	PDA	No	Arrive on time Ask for medication	No	Punctual without assistance Asked for all medication	
Kirsch, 2004[12]	Single case BAB	–	1	1	TBI with history of alcohol abuse	Mid-30s	PDA with voice recording 'be brief'	Baseline	Decrease in verbose communication	No	Decrease in number of lengthy utterances.	No statistical analyses No baseline prior to intervention
Wade, 2001[46]	Single case AB	–	5	4	ABI >1–15 years	34.6	Cell phone: reminder voice messages	Baseline	Individual target behaviours	No	In all 5 cases increased in achieved target behaviours	No new learning necessary No statistical analyses

TBI, traumatic brain injury; CVA, cerebrovascular accident; SAH, subarachnoid haemorrhage; ID, infectious disease; ABI, acquired brain injury; MS, multiple sclerosis; COPM, Canadian Occupational Performance Measure; CHART-R, Craig Handicap Assessment and Rating Technique-Revised; Poorer exec. funct., Poorer executive functioning.

specific target behaviours, such as remembering to take medication on time. Two papers investigated the use of the device on participation in everyday life[26,30] and one investigated independent functioning.[31] Kirsch and colleagues[11,12,22] used a customized PDA in different ways: as a reminder to write entries in a memory log, to improve accuracy in route finding, and as a conversational aid to decrease verbose speech. Route finding was promoted by using coloured circles as landmarks inside the treatment facility and corresponding coloured circles on the PDA to guide the user from landmark to landmark. Verbose speech was reduced by using a PDA with a voice-recording saying: 'be brief' delivered at fixed intervals, which reduced the number of lengthy utterances.

Outcome measures

The main outcome measure and its ecological validity also varied widely between studies. For example, most of the NeuroPage papers focused on individual memory target behaviours, such as taking medication, watering plants and keeping appointments. This type of outcome measure was chosen for their high ecological validity. Other papers evaluated performance on experimental laboratory tasks, such as remembering therapy goals or the number of relevant entries in a memory journal. Three papers used questionnaires to measure outcome: first, the Canadian Occupational Performance Measure (COPM) to assess occupation performance, second, the Craig Handicap Assessment and Rating Technique-Revised (CHART) to assess participation in everyday life[26,30] and third, the Functional Independence Measure (FIM) to assess level of independent functioning in daily life.[31]

Efficacy

Of the seven papers of the NeuroPage, four class I papers assessed the effect on achieving memory target behaviours in daily life as part of one randomized trial. These papers all reported improvement relative to baseline (achievement of target behaviours increased significantly from 45% at baseline to 72% post treatment) and a return to baseline after the intervention ended. Three class

III papers reported improvement with the NeuroPage. Another class III paper in which a standard pager was used reported a substantial increase in journal entries about prior therapy appointments (93% post treatment versus 22% at baseline).

Of the 10 papers in which a standard PDA was used, two class II papers investigated the effect on the timely execution of tasks.[10,23] DePompei *et al.* reported an increase in the number of executed tasks in patients with acquired brain injury: 23% with a paper planner versus 67% with a PDA. Thone-Otto *et al.* reported a significant decrease from 2.5 forgotten intentions per week without a memory aid to 0.7 forgotten intentions per week with a PDA or cell phone. Four class III papers and one unclassified paper described an intervention paper using a standard PDA. One unclassified paper described the use of a customized PDA.[31] All these papers aimed to improve prospective memory tasks, and all papers reported a positive effect on remembering to do specific tasks on time, such as household tasks. A customized PDA to diminish verbose speech decreased the number of lengthy utterances.[12] Furthermore, a customized navigational aid used in a class III paper improved accuracy and confidence during navigation when the user was cued through speech-based audio directions.[32] Another class III paper used a customized PDA to assist in navigation and showed substantial improvement in the accuracy of route finding.[11]

Five papers, all class III, investigated a digital voice recorder. Four reported an improvement of prospective memory functioning (e.g. independent medication requests, remembering therapy goals, message passing task) and one reported contradictory results.[24] Only one of three participants in this paper clearly benefited from the use of a voice recorder. One paper aimed to improve memory for therapy goals.[33] Recorded goals were remembered better than unrecorded goals. Two papers used a cell phone to improve performance of target behaviours, such as doing housework or feeding a pet. The first, a class III paper in which text messages were used as reminders, reported success in two of five patients. The second, an unclassified paper in which voice messages were used as reminders, reported an increase in achieved target behaviours in all five patients studied.

Usability of assistive technology

Only a few papers described the potential use of portable electronic devices as cognitive aids.[4,34–37] A survey completed by 81 traumatic brain injury professionals that was executed in 2001 showed that about half of the respondents reported prior experience with clients with traumatic brain injury who had been using portable electronic aids.[4,37] Twenty-nine respondents (36%) reported using portable electronic memory devices with patients with traumatic brain injury. Respondents saw most potential for assistive technology in the areas of learning and memory, planning and organization and initiation; less potential was seen for social, interpersonal or behavioural difficulties. Learning and memory abilities were identified as essential client characteristics associated with successful use. Cost was identified as a significant barrier to use portable devices in rehabilitation. Respondents expressed low confidence in their ability to assist clients in the use of such devices; those who reported personal experience with assistive technology were significantly more confident than those who did not. Confidence in their ability to assist clients was statistically associated with respondents' use of such devices in traumatic brain injury rehabilitation.

To assess the opinion of potential users of assistive technology, 80 persons with moderate to severe traumatic brain injury were interviewed (median: 3.7 years post injury).[35] Two thirds of participants reported regular use of computers, but less than one third had experience with handheld computers or similar devices. Seventy-five per cent of respondents not currently using assistive technology showed interest in using portable devices for everyday memory and organizational tasks. Respondents expressed preferences for simplicity of use, technical support and long-lasting battery power. Preferred functions included keeping track of money spent, remembering things to do, and remembering conversations. The authors therefore conclude that portable electronic devices are acceptable or desirable by consumers with moderate to severe traumatic brain injury for use as compensatory aids.

A study by Kim *et al.*[36] showed that 75% of the participants found the aid useful and more than half of the participants continued the use of an electronic aid after the initial trial usage.

Children and teenagers with cognitive deficits seem even more than any other age group prone to use assistive technology. A survey of 53 youth–parent–teacher triads probing their views regarding the youth's relationship with technology indicate that they use a variety of technologies and are more likely to be exposed to computers than cell phones or PDAs.[38] They value many varied features of technology, but rated most highly good technical support, simple learning requirements, capacity to store information and long battery life. These results show clear similarities with the opinion of adult patients on assistive technology described in the study by Hart *et al.*[35]

Discussion

We reviewed the literature on the efficacy of electronic cognitive aids, using the classification of Cicerone *et al.*[6] We identified 28 relevant papers describing 25 studies; one class I study, two class II studies and 17 class III studies; four papers did not meet the classification criteria.

One class I study and three class II studies found the NeuroPage to increase the number of achieved target behaviours, such as remembering to feed the pets or taking medication on time. Thus NeuroPage is effective in supporting prospective memory in individuals who have sustained brain injury. Less convincing evidence exists for the efficacy of other electronic aids, such as PDAs or voice recorders. Two class II studies and several class III studies reported standard and customized PDAs to have a positive effect on prospective memory function, and thus we consider the use of PDAs as a prospective memory aid a promising intervention. There is currently insufficient evidence to draw conclusions about the value of other uses of PDAs (e.g. as a navigational or communication aid).

Voice recorders were found to have a beneficial effect in five class III studies, but the available evidence is inconclusive with respect to their efficacy. If, for instance, reading or writing is impaired, a voice recorder could be used as a prospective memory aid, but further research is needed. Cell phones or smartphones should only be considered as a memory aid if a user is reluctant to learn to use a new device and rather wants to use their own phone. Disadvantages of phones are their small screen and buttons compared to PDAs. In any case, when deciding which memory aid should be used, the relation between the demands of the user and the characteristics of an electronic cognitive aid should always be borne in mind.

Several authors[6,39,40] have stressed that the relationship between the clinical characteristics of brain-injured individuals and the characteristics of appropriate technological interventions has not been sufficiently studied. Evans *et al.*[41] described important determinants of the successful use of memory aids, such as prior experience with a cognitive aid, age, and the level of cognitive functioning. In the reviewed papers, these determinants were not always taken into account. While mean age of the subjects and neuropsychological functioning was reported, none reported whether the subjects had previously used a computer or other device, which could influence how well a person could use a device.

Some authors did discuss the relationship between user characteristics and optimal use of the device, and the influence of the level of cognitive functioning on the success of an intervention with an electronic aid. Maintenance of the effect of the NeuroPage after returning the device was associated with higher level of executive functioning.[16] Individuals who learned to use a PDA quickly, used their cognitive aid more frequently and showed a larger decrease in forgotten intentions compared with slow learners.[10] Furthermore, in a paper with divergent results for the five participants, it appeared that the effect of reminder messages on target behaviours depended on the severity of memory impairments.[28] Future research should therefore focus more on matching user demands and suitable technology to optimize the therapeutic effect of a cognitive electronic aid.

Although all papers included in this review expand our knowledge about the application of assistive technology for individuals with cognitive deficits, some limitations of these studies should be discussed. Most of the papers used baseline measurements as the control condition, instead of comparing assistive technology with paper-and-pen aids such as a 'memory book', which are commonly used in cognitive rehabilitation. Therefore it is not possible to evaluate the additional effect of electronic cognitive aids compared to care-as-usual (i.e. paper-and-pen aids).

Only four papers mentioned the use of a follow-up assessment, hence little is known about the long-term effects of assistive technology. Moreover, potentially important factors that could influence the outcome of the use of cognitive aids[40] were not sufficiently described or assessed, such as premorbid or actual cognitive functioning or prior use of this kind of technology, such as personal computers. Lastly, the external and ecological validity of outcome measures should be assessed. Checking the next therapy appointment in an inpatient setting is very different from making one's own appointments with friends and rescheduling them because of unexpected changes during the day or week.

A few possible limitations of this review itself should also be mentioned. Because only papers in English were included, papers in other languages were not part of this review. Although five large databases were searched for relevant papers, it is possible that not all relevant papers were identified.

The reviewed papers contain important information on which we can base future research. Given the fact that in almost all studies positive effects have been found of the use of assistive technology, further research into promising interventions with PDAs should be pursued. Furthermore, several survey studies established that both potential users and clinicians have optimistic expectations about the use of assistive technology as cognitive aids. For example Hart *et al.*[35] concluded that portable electronic devices were acceptable and desirable by consumers with moderate to severe traumatic brain injury for use as compensatory aids.

The use of PDAs and smartphones in our daily life is becoming more common every day and these survey studies were all performed before 2004. Therefore the opinion of both clinicians and patients could possibly be even more positive if they were asked the same questions today.

Assistive technology could also be used by individuals with a range of other cognitive impairments, such as mild cognitive impairment (MCI), or psychotic patients with cognitive difficulties.[42] Furthermore, Gillette and DePompei[38,43] showed the potential of PDAs for children and teenagers with cognitive impairments.

In this review the efficacy of assistive technology to support memory deficits has been shown, however, deficits in other cognitive domains could also be supported. Multipurpose devices, such as PDAs or smartphones could target cognitive domains such as executive functioning and attention. Planning daily activities and dealing with changes in one's schedule could also be supported by assistive technology. Many cognitively impaired individuals are easily distracted from a current activity; assistive technology can remind users what they were doing. Furthermore, a lack of initiative can be counteracted by cueing the user to start activities. The opposite problem, an inability to stop a current activity due to perseveration, can be counteracted by cueing the user after a set amount of time to end the activity. Lastly, use of assistive technology will be facilitated when it can be individually adjusted to the needs and abilities of a specific patient.

Future research should focus on the application of such devices in a large-scale randomized controlled trial, in which the control condition consists of care-as-usual treatment. Outcome measures should be ecologically valid and should include valid measures of both cognitive and social functioning. Finally, also long-term functioning and the level of functioning of the caregiver should be assessed as a measure of patient independence.

Clinical messages

- Assistive technology, such as pagers, PDAs and digital voice recorders can be used as a cognitive aid, especially to support prospective memory.
- Both potential users and clinicians have optimistic expectations about the use of assistive technology as a cognitive aid.
- Multipurpose devices, such as PDAs or smartphones may also be used to target other cognitive domains such as executive functioning and attention.

Competing interests

None declared.

Source of funding

This work was supported by ZonMw, The Netherlands Organization for Health Research and Development, without having any influence over the analyses, interpretation or reporting of data (grant number 143500552).

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Appendix 1 – Literature search terms

Combination of search terms used

'Computers, Handheld'[MeSH] OR 'Handheld computer*' OR 'Reminder System*' OR 'Reminder Systems'[MeSH] OR 'pocket pc' OR 'memory aid' OR 'memory device' OR 'palm top' OR pager OR 'paging system' OR 'Personal Digital Assistant' OR 'pocket computer' OR 'Assistive Technology Devices'

AND

'Cognition'[Mesh] OR 'Attention'[Mesh] OR 'Memory'[Mesh] OR 'Thinking'[Mesh] OR 'executive dysfunction*'[All Fields] OR 'executive function*'[All Fields] OR 'planning'[All Fields] OR 'Delirium, Dementia, Amnestic, Cognitive Disorders'[Mesh] OR 'Memory Disorders'[Mesh] OR 'Cognitive Therapy'[Mesh] OR 'Cognition Disorders'[Mesh] or 'Thought Disorder' OR 'Cogniti*' OR 'Attention' OR 'Memory' OR 'Thinking' OR 'Amnes*'

AND

'Brain Damage, Chronic'[Mesh] OR 'Stroke'[Mesh] OR 'Brain Diseases'[MeSH] OR 'Brain Injuries'[MeSH Terms] OR 'Brain Damage' OR 'Stroke' OR 'Brain Disease*' OR 'Brain Injury' OR 'brain injuries'