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CRITICAL REVIEW

Cognitive Function and Assistive Technology for Cognition: A Systematic Review

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Abstract

The relationship between assistive technology for cognition (ATC) and cognitive function was examined using a systematic review. A literature search identified 89 publications reporting 91 studies of an ATC intervention in a clinical population. The WHO International Classification of Functioning, Disability and Health (ICF) was used to categorize the cognitive domains being assisted and the tasks being performed. Results show that ATC have been used to effectively support cognitive functions relating to attention, calculation, emotion, experience of self, higher level cognitive functions (planning and time management) and memory. The review makes three contributions: (1) It reviews existing ATC in terms of cognitive function, thus providing a framework for ATC prescription on the basis of a profile of cognitive deficits, (2) it introduces a new classification of ATC based on cognitive function, and (3) it identifies areas for future ATC research and development. (*JINS*, 2012, *18*, 1–19)

Keywords: Self-help devices, Delirium, Dementia, Amnestic, Cognitive disorders, Neuropsychology, Review, Memory disorders, Rehabilitation

INTRODUCTION

Human history can be written as a history of technology (Aunger, 2010). The defining feature of technology, as opposed to natural objects or other human artifacts, is that it extends human ability (Lawson, 2010). Kapp (1877) defined technology as a direct morphological extension of human organs. Bows, catapults, and guns extend the ability to throw a projectile at a target. Chariots, bicycles, motorbikes, and cars extend the ability to ambulate. McLuhan (1964) refined this definition by focusing on technologies which extend cognitive function. For example, writing, printing and digitization extend the ability to remember. Assistive technologies for cognition (ATC) can be defined as any technology which assists cognitive function during task performance.

Humans are "natural born cyborgs" (Clark, 2003, p. 1), inextricably bound to their material and symbolic technologies (Gillespie & Zittoun, 2010). Cognitive supports are ubiquitous, being used to aid memory (e.g., notebooks, diaries, and ledgers), calculation (e.g., abacus, pen and paper, and electronic calculators), prospectively memory (e.g., diaries, alarm clocks, and notices), and sequencing complex behaviors (e.g., recipes and manuals). Historically, it is high functioning individuals who have used ATC to extend their ability. The present article reviews high-tech ATC which aim to augment impaired cognition.

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ATC & COGNITIVE IMPAIRMENT

Cognitive impairment is a defining feature of dementias, stroke, mental illness, acquired brain injury and intellectual disability. The global cost of care for those with cognitive impairment is becoming unsustainable (Pavolini & Ranci, 2008; Wimo & Prince, 2010). Care provision is required to support activities of daily living, such as dressing, mobility, personal hygiene, shopping, and food preparation (Williams, Fries, Foley, Schneider, & Gavazzi, 1994).

Cognitive impairment confers risks which are generally managed by containment, administration of medicines and contingency management (Wood, 2001). These interventions limit risky behavior, rather than extend or augment cognitive function (Winocur, Moscovitch, & Freedman, 1987).

Informal and formal carers often support people with cognitive impairment, acting as 'assistants for cognition' (O'Neill & Gillespie, 2008). These assistants prompt, remind and provide support for the performance of everyday activities. The interpersonal dynamics of providing cognitive support can create problems for carer-givers (Gillespie, Murphy, & Place, 2010) and care-receivers (Proot, Crebolder, Abu-Saad, Macor, & Ter Meulen, 2000). It has been argued that ATC has the potential to reduce interpersonal tensions between care-givers and care-receivers (de Joode, van Heugten, Verhey, & van Boxtel, 2010) while also increasing independent activity, self-confidence, and the cost efficiency of care (LoPresti, Mihailidis & Kirsch, 2004).

However, ATC have yet to achieve this potential. Problems include the novelty or complexity of ATC for people with cognitive impairment (LoPresti et al., 2004) and mismatch between the user's cognitive profile and the prescribed ATC (de Joode et al., 2010). This latter problem explains why the same ATC can be used with divergent results (Stapleton, Adams, & Atterton, 2007). In their recent review of mobile ATC, de Joode et al. (2010, p. 710) call for "matching user demands and suitable technology to optimize the therapeutic effect."

Underlying all research on ATC is the assumption that performance on a task arises out of the interaction between cognitive function and socio-technical support. Thus, declining cognitive function can be offset by suitable socio-technical support to maintain task performance (Baltes, 2003). However, to-date, there has been no systematic analysis of the relation between ATC and cognitive function. The conclusion of LoPresti et al. (2004, p. 25) to their review of the field remains valid: "very little is known about the relationship between, on the one hand, the clinical characteristics of persons with cognitive impairments, and on the other hand, the specific characteristics of ATC interventions that are most suitable for those individuals."

Modularity of Cognitive Function

Taking a modular view of human cognition (Fodor, 1983) enables differentiating ATC by the cognitive function being assisted. This would enable neuropsychologists and health professionals to prescribe ATC after assessment of cognitive strengths and weaknesses.

Neuropsychological functions predict outcomes. For example, the presence of dysexecutive function predicts return to work (Crepeau & Scherzer, 1993), memory, executive function and balance function appear to predict acquisition of the altered activities of daily living after amputations (O'Neill, 2008) and short-term verbal memory, orientation, abstract thinking, and judgment predict functional status following a stroke (Galski, Bruno, Zorowitz, & Walker, 1993). Amelioration of variables prognostic of poor outcome can improve outcome (Paolucci et al., 1996). It thus seems logical that prescription of appropriate ATC to assist a given profile of deficit may improve outcome.

THE INTERNATIONAL CLASSIFICATION OF FUNCTION (ICF)

The modular conceptualization of cognitive function and activity which is used in the present review is the International Classification of Function (Üstün, Chatterji, Bickenbach, Kostanjsek, & Schneider, 2003; World Health Organization, 2002). The ICF is a framework for measuring health and disability at individual and population levels. It was officially endorsed by all 191 WHO member states in 2001 as the agreed international standard for assessing health and disability. The ICF categorizes functions and structures, rather than etiology or diagnosis.

There have been several recommendations for ICF to be the basis for the prescription and/or outcome evaluation of assistive technology (Bauer, Elsaesser, & Arthanat, 2011; Scherer, Jutai, Fuhrer, Demers, & Deruyter, 2007; Steel, Gelderblom, & Witte, 2010), without specific detail about how the ICF maps on to the functions addressed by currently available assistive technology. The present review moves the field forward by implementing these recommendations.

Existing reviews have been organized in terms of specific user groups such as older adults (Pollack, 2005), and people with dementia (Bharucha et al., 2009), or efficacy (de Joode et al., 2010), or ATC used (LoPresti et al., 2004), or the rehabilitation or support aims of the technology (Cole, 1999). The present review not only includes more studies than previous reviews, but also systematically conceptualizes ATC in terms of the cognitive function being assisted.

METHODOLOGY: NARRATIVE SYNTHESIS WITH ASSESSMENT OF METHODOLOGICAL QUALITY

A narrative synthesis is a systematic review procedure, based upon textual synthesis. It is used when statistical meta-analytical synthesis is not possible due to study heterogeneity (Popay et al., 2006), as is the case with ATC (de Joode et al., 2010). According to Arai et al. (2007), a narrative synthesis has three parts: (1) A preliminary synthesis of the data, such as the presentation of tables, figures, and graphs or textual descriptions to summarize the data extracted. (2) Exploration of relationships in the data, which in the present case will entail relationships between ATC, cognitive function, and activity domain. (3) Assessment of the robustness of the synthesis. In addition, we include an analysis of the methodological quality of the studies reviewed using the Scottish Intercollegiate Guidelines Network (SIGN, 2008) levels of evidence.

Aim and Questions

The aim is to review ATC in terms of the ICF cognitive functions. Five derivative questions are addressed: (1) How has the field changed over time? (2) What is the relation between ATC and cognitive functions? (3) What is the relation between ATC and activity domains? (4) What is the relation between ATC and clinical populations? (5) What is the evidence for ATC supporting specific cognitive functions?

Inclusion and Exclusion Criteria

Following on from Cole (1999) and LoPresti et al. (2004), we define ATC as any technology which compensates for cognitive deficit during task performance.

Included studies investigated electronic technologies as compensations for cognitive impairment to enable or enhance task performance. Included participants were people with cognitive impairments of all ages and etiologies including: acquired brain injury, neurodevelopment disorder, psychiatric disorder, dementia and or intellectual disability.

Excluded studies included interventions to restore cognitive function through training exercises or other methods. Technologies designed to support or extend language function [augmentative and alternative communication (AAC)] were also excluded as this is a well-developed area of research that has been the target of several systematic reviews (e.g., Beukelman, Fager, Ball, & Dietz, 2007). In addition, we excluded educational interventions which targeted acquisition of reading and writing skills. Studies examining pharmacological interventions for cognitive impairment were also excluded. Study design or publication outlet were not exclusion criteria.

LITERATURE SEARCH PROCEDURE

The PsychINFO, MEDLINE, AMED, and Embase databases were searched on April 17, 2011 (in Ovid, from earliest to latest). The search included terms for cognitive functions combined with search terms for cognitive rehabilitation with a technological component. The search terms below were searched in all fields.

(Memory OR attention OR set shifting OR psychomotor OR emotion* OR thought OR experience of self OR experience of time OR body image OR sequencing OR calculation OR perception OR abstraction OR flexibility OR insight OR judgment OR problem solving OR language) AND ((Cognitive rehabilitation AND (technolog* OR computer OR digital)) OR cognitive orthos* OR cognitve prosth* OR assistive technolog*)

Figure 1 presents a flow diagram of the study identification process. Two papers reported clinical data on two distinct ATC (Kirsch, Shenton, Spirl et al., 2004; Robinson, Brittain, Lindsay, Jackson, & Olivier, 2009) so each was included as two separate studies. The majority of studies were identified through hand search of the reference lists of reviews and other research papers. The heterogeneity of study populations, technologies and methods and common absence of specific ATC keywords, meant that it was not possible to develop a search strategy based mainly on keywords. This undoubtedly reflects the fact that this is an emerging field of research that crosses traditional discipline boundaries.

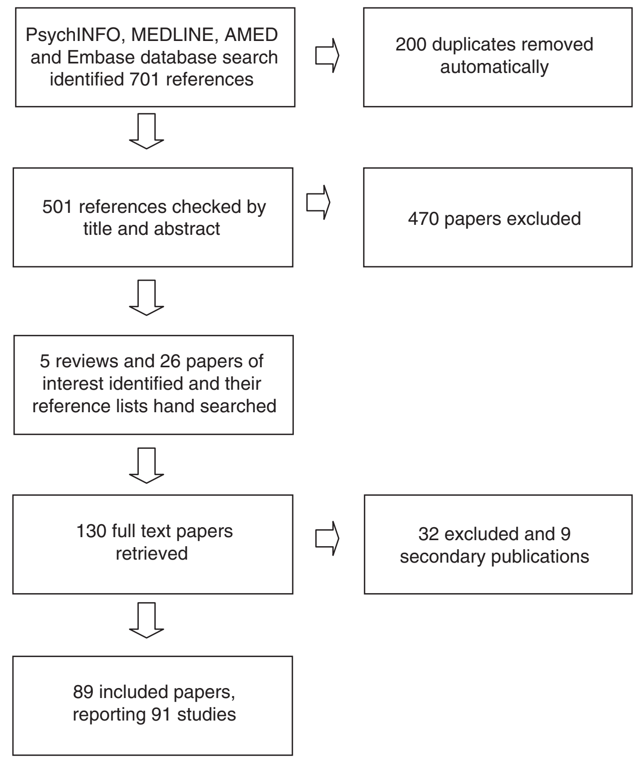

Fig. 1. Flow chart of study identification process.

Data Extraction and Categorization

Two authors extracted the following data: authorship, year of publication, intervention, outcomes, population, setting, publication type, design, number of participants, treatment effect, cognitive function (ICF), activity domain (ICF), technology (ISO 9999; International Organization for Standardization, 2007) and ATC function.

The cognitive functions were classified using the ICF classification of 'specific mental functions' (b140-b189). This comprises: attention functions, memory functions, psychomotor functions, emotional functions, perceptual functions, thought functions, higher-level cognitive functions, calculation functions, mental function of sequencing complex movements, and experience of self and time functions.

The activity domains in which ATC support was being provided were classified using the ICF classification of 'activities and participation' (d110-d999). This comprises: learning and applying knowledge, general tasks and demands, communication, mobility, self-care, domestic life, interpersonal interactions, major life areas, and community, social and civic life.

The ICF includes assistive products and technology for use in daily living (e1158), but does not differentiate the technologies in sufficient detail to be useful in the present review. Accordingly, we used the International Standardization Organization (ISO 9999; 2007) classification of assistive products for persons with disability. All of the technology came under the category 'assistive products for information and communication' within the ISO 9999. Applicable subcategories included the following: assistive products for calculation, assistive products for handling audio, visual and video information, assistive products for telephoning and messaging, assistive products for alarming indicating and signaling, and computers and terminals.

As the review will show, the ISO categories showed no useful relationship to cognitive function. Accordingly, we introduce the following five classifications of ATC based on the cognitive function being supported: (1) Alerting: Devices which draw attention to a stimulus that is present in the external or internal environment (e.g., a neglected limb or personal goal). (2) Reminding: Devices providing a one-way, usually one-off, time-dependent reminder about something not in the immediate environment which is intended to be an impetus to action (e.g., reminder about an appointment). (3) Micro-prompting: Devices using feedback to provide detailed step-by-step prompts guiding user through an immediately present task. (4) Storing and displaying: Devices which store and present episodic memories, without being a time-dependent impetus to action. (5) Distracting: Devices which distract users from anxiety provoking stimuli such as hallucinations.

The methodological quality of the studies was rated using the SIGN (2001) ratings of levels of evidence. The eight ratings are as follows: 1++: High quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias. 1+: Well-conducted meta-analyses, systematic reviews, or RCTs with a low risk of bias. 1−: Meta-analyses, systematic reviews, or RCTs with a high risk of bias. 2++: High quality systematic reviews of case control or cohort or studies or high quality case control or cohort studies with a very low risk of confounding or bias and a high probability that the relationship is causal. 2+: Well-conducted case control or cohort studies with a low risk of confounding or bias and a moderate probability that the relationship is causal. 2−: Case control or cohort studies with a high risk of confounding or bias and a significant risk that the relationship is not causal. 3: Non-analytic studies, such as case reports or case series. 4: Expert opinion.

The literature search yielded a large number of single subject experimental designs, in which subjects served as their own control. These studies were categorized between 2+ and 2−. Studies were reviewed by CB and BON independently with a resulting Cohen's kappa co-efficient of 0.80 demonstrating substantial inter-rater agreement.

Finally, treatment effect was defined in terms of statistically significant superiority of experimental condition either between groups or between conditions, or, in the case of weaker single subject experimental designs a visual inspection of data sufficient to conclude a positive treatment effect (Horner et al., 2005).

RESULTS

Table 1 presents the key data extracted from the 91 studies included in the review. The included studies consisted of 82 from journal articles, 6 from conference papers, 2 dissertations, and 1 book chapter. The majority of reported studies were small scale (mean $N = 8.5$; range, 1–143; *SD*, 16.4; and 31 (34.1%) of the 91 clinical tests were single N), and only three were randomized controlled trials (Robertson, McMillan, MacLeod, Edgeworth, & Brock, 2002; Wilson, Emslie, Quirk, & Evans, 2001; Zucker, Samuelson, Muench, Greenberg, & Gevirtz, 2009). The three randomized controlled trials had disparate outcome measures, the primary outcomes being completion of everyday tasks, autonomic function, and motoricity index, respectively.

The 91 studies targeted the following populations: traumatic brain injury (23.1%), acquired brain injury (including TBI, cerebral infectious diseases, space occupying lesions and hemorrhagic stroke, 22%), dementia and older people (14.3%), intellectual disability (12.1%), psychiatric (8.8%), stroke (7.7%), neurodevelopmental (3.3%), and mixed/other (8.8%).

Sixty-one studies (67.0%) reported a positive treatment effect. Four single subject experiments (4.4%) had mixed effects (Kirsch, Levine, Lajiness-O'Neill, & Schnyder, 1992; Stapleton et al., 2007; Van Hulle & Hux, 2006; Yasuda et al., 2002). Twenty-four usability trials did not contribute evidence on treatment effect as no experimental data was reported. Finally, two included studies (Sohlberg, Fickas, Hung, & Fortier, 2007; Wright et al., 2001), despite trialing ATC with a clinical population, did not address treatment effect.

No study was given a 1++, 1+, or 1 SIGN (2001) rating because each of the three randomized control trials had limited blind assessment. Five studies were rated 2++, 18 were rated 2+, 42 were rated 2−, and 26 were rated 3.

Preliminary Synthesis: ATC and Cognitive Function

The following sub-sections implement our aim to review ATC in terms of the ICF cognitive functions being assisted. Sub-headings correspond to ICF specific cognitive function categories.

Attention Functions (B140, 12 Studies)

ICF defines attention as specific mental function of focusing on an external stimulus or internal experience for the required period. The review revealed 12 clinical trials, which have used ATC to shift attention to neglected areas of personal space and to internally represented goal states.

Unilateral neglect is a common consequence of stroke. The Neglect Alert Alarm shifts attention to neglected areas of the body (O'Neill & McMillan, 2004). This device emits tones when the user has not moved their neglected limb within a prescribed period of time causing the user to attend to neglected space to terminate the alarm. Robertson and colleagues investigated the effectiveness of the device, first, through single case designs (Robertson, North, & Geggie, 1992; Robertson, Hogg, & McMillan 1998) and then progressed to a single blind randomized controlled trial (Robertson et al., 2002; SIGN rating 2++) where the device was found to produce improved motor function 24 months post-treatment.

ATCs can also shift attention to internally represented goals states. Content free cueing in the form of a simple text saying "stop" was examined by Fish et al. (2007, SIGN rating 2+). These messages were a cue for participants to reflect on their internal goal states and resulted in improved performance of scheduled tasks. Manly et al. (2004) also used content free cueing (an auditory tone) to improve performance on a test of sustained attention. Rich (2009, SIGN rating 2−) also provides another example of content free cueing, this time of the use of a tactile cue to redirect attention back to the task in hand. These ATC can all be construed as redirecting attention to a supervisory mode or engaging the supervisory attentional system.

Table 1. Included studies

Author	Year	ISO Technology Category	ATC Function	ICF Cognitive Function	ICF Activity Domain	Population	SIGN Study Quality Rating	*N*	Treatment Effect
Culley & Evans	2010	Alarm	Alerting	Attention—Shifting	Self-care—Personal health	TBI	2+	11	Yes
Fish et al.	2007	Telephone	Alerting	Attention—Shifting	Communicating—Using devices	ABI-other	2+	20	Yes
Hart, Hawkey, & Whyte	2002	Audio visual	Alerting	Attention—Shifting	Self-care—Personal health	TBI	2+	10	Yes
Kirsch, Shenton, Spirl, Simpson, LoPresti, & Schreckenghost	2004	Audio visual	Alerting	Attention—Shifting	Communicating—Conversing	TBI	2+	1	Yes
Manly et al.	2004	Alarm	Alerting	Attention—Shifting	General tasks—Daily routine	Stroke	2++	7	Yes
O'Neill & McMillan	2004	Alarm	Alerting	Attention—Shifting	Mobility—Walking and moving	Stroke	2−	1	Yes
Rich	2009	Alarm	Alerting	Attention—Shifting	Major life area—Education	Neurodevelopmental	2−	3	Yes
Robertson, Hogg, & McMillan	1998	Alarm	Alerting	Attention—Shifting	Mobility—Walking and moving	Stroke	2−	7	Yes
Robertson et al.	2002	Alarm	Alerting	Attention—Shifting	Mobility—Walking and moving	Stroke	2++	36	Yes
Robertson et al.	1992	Alarm	Alerting	Attention—Shifting	Mobility—Walking and moving	Stroke	2−	1	Yes
Taber et al.	1999	Audio visual	Alerting	Attention—Shifting	Major life area—Education	Neurodevelopmental	2−	1	Yes
Yeates et al.	2008	Telephone	Alerting	Attention—Shifting	Interpersonal interactions—Basic	Mixed & other	2−	2	Yes
Martins et al.	1999	Other	Mixed & Other	Calculation—Simple	Learning and applying knowledge	ABI-other	3	1	Qualitative
Feder	1982	Audio visual	Distraction	Emotion—Regulation	General tasks—Handling stress	Psychiatric	3	1	Qualitative
Johnston et al.	2002	Audio visual	Distraction	Emotion—Regulation	General tasks—Handling stress	Psychiatric	2+	1	Yes
McInnis & Marks	1990	Audio visual	Distraction	Emotion—Regulation	General tasks—Handling stress	Psychiatric	2−	1	Yes
Nelson et al.	1991	Audio visual	Distraction	Emotion—Regulation	General tasks—Handling stress	Psychiatric	2+	20	Yes
Reiner	2008	Other	Mixed & Other	Emotion—Regulation	General tasks—Handling stress	Psychiatric	2−	20	Yes
Zucker et al.	2009	Other	Mixed & Other	Emotion—Regulation	General tasks—Handling stress	Psychiatric	2++	38	Yes
Chang et al.	2008	Alarm	Navigation	Experience of self	Mobility—Different locations	Mixed & other	2−	6	Yes
Kirsch, Shenton, Spirl, Rowan Simpson & Lo Presti	2004	Alarm	Navigation	Experience of self	Mobility—Walking and moving	TBI	2−	1	Yes
Liu et al.	2008	Alarm	Navigation	Experience of self	Mobility—Different locations	Mixed & other	3	7	Qualitative
Morris et al.	2003	Alarm	Navigation	Experience of self	Mobility—Different locations	Dementia & older people	3	4	Qualitative
Robinson et al.	2009	Alarm	Navigation	Experience of self	Mobility—Different locations	Dementia & older people	3	1	Qualitative
Robinson et al.	2009	Alarm	Navigation	Experience of self	Mobility—Different locations	Dementia & older people	3	1	Qualitative
Sohlberg et al.	2007	Computer	Navigation	Experience of self	Mobility—Different locations	ABI-other	2−	20	N/A
Bergman	2002	Computer	Micro prompting	Higher level—Organisation and planning	Economic self-sufficiency	TBI	3	1	Qualitative
Boman, Tham, Granqvist, Bartfai, & Hemmingsson	2007	Alarm	Mixed & Other	Higher level—Organisation and planning	General tasks—Daily routine	TBI	3	8	Qualitative
Carmien	2005	Alarm	Micro prompting	Higher level—Organisation and planning	Social & civic—Leisure	Intellectual disability	3	7	Qualitative
Cihak, Kessler, & Alberto,	2008	Computer	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	2−	4	Yes
Davies et al.	2002	Alarm	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	2−	12	Yes
Ferguson et al.	2005	Alarm	Micro prompting	Higher level—Organisation and planning	Major life area—Education	Neurodevelopmental	2−	1	Yes
Ferreras et al.	2010	Alarm	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	3	8	Qualitative

(Continued)

Table 1. Continued

Author	Year	ISO Technology Category	ATC Function	ICF Cognitive Function	ICF Activity Domain	Population	SIGN Study Quality Rating	*N*	Treatment Effect
Fish, Manly, & Wilson	2008	Alarm	Micro prompting	Higher level—Organisation and planning	General tasks—Daily routine	ABI-other	2−	1	Yes
Furniss et al.	1999	Computer	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	2−	6	Yes
Gorman, Dayle, Hood, & Rumrell	2003	Computer	Micro prompting	Higher level—Organisation and planning	General tasks—Daily routine	ABI-other	3	2	Qualitative
Kirsch, Levine, Fallon-Krueger, & Jaros	1987	Computer	Micro prompting	Higher level—Organisation and planning	Domestic life—Household tasks	ABI-other	2+	1	Yes
Kirsch et al.	1992	Computer	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	TBI	2+	4	Mixed
Kirsch et al.	2004	Computer	Micro prompting	Higher level—Organisation and planning	Domestic life—Household tasks	TBI	2−	1	Yes
Lancioni et al.	2006	Audio visual	Micro prompting	Higher level—Organisation and planning	Self-care—Dressing	Intellectual disability	2+	2	Yes
Lancioni et al.	2000	Computer	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	2−	6	Yes
Lancioni et al.	1999	Computer	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	2−	4	Yes
Lancioni, van den Hof, Boelens, Rocha, & Seedhouse	1998	Computer	Micro prompting	Higher level—Organisation and planning	Major life area—Employment	Intellectual disability	2−	3	Yes
Lancioni, Van den Hof, Furniss, O'Reilly, & Cunha	1999	Computer	Micro prompting	Higher level—Organisation and planning	Domestic life—Household tasks	Intellectual disability	2+	4	Yes
Lemoncello	2009	Other	Micro prompting	Higher level—Organisation and planning	Self-care—Personal health	Stroke	2−	3	Yes
Mihailidis, Barbenel, & Fernie	2004	Computer	Micro prompting	Higher level—Organisation and planning	Self-care—Washing	Dementia & older people	2+	9	Yes
Mihailidis et al.	2008	Computer	Micro prompting	Higher level—Organisation and planning	Self-care—Washing	Dementia & older people	2+	6	Yes
O'Neill & Gillespie	2008	Computer	Micro prompting	Higher level—Organisation and planning	Self-care—Personal health	ABI-other	2+	1	Yes
O'Neill et al.	2010	Computer	Micro prompting	Higher level—Organisation and planning	Self-care—Personal health	ABI-other	2+	8	Yes
Starkhammar & Nygard	2008	Alarm	Mixed & Other	Higher level—Organisation and planning	Domestic life—Preparing meals	Dementia & older people	3	9	Qualitative
Stock, Davies, Wehmeyer, & Palmer	2008	Telephone	Mixed & Other	Higher level—Organisation and planning	Communicating—Using devices	Intellectual disability	2+	22	Yes
Cole, Dehdashti, Petti, & Angert	1994	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	3	3	Qualitative
Evans, Emslie, & Wilson	1998	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	2−	1	Yes

(Continued)

Table 1. Continued

Author	Year	ISO Technology Category	ATC Function	ICF Cognitive Function	ICF Activity Domain	Population	SIGN Study Quality Rating	*N*	Treatment Effect
Flannery et al.	1997	Alarm	Reminding	Higher level—Time management	Self-care—Personal health	ABI-other	2−	1	Yes
Fowler, Hart, & Sheehan	1972	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	3	1	Qualitative
Gentry	2008	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	Mixed & other	2−	20	Yes
Gentry, Wallace, Kvarfordt, & Lynch	2008	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	2−	23	Yes
Giles & Shore	1989	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	Stroke	2−	1	Yes
Gillette & DePompei	2008	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	Mixed & other	2+	35	Yes
Inglis, Szymkowiak, Gregor, Newell, Hine, Wilson, Evans	2003	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	3	9	Yes
Kapur	1995	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	Mixed & other	3	5	Qualitative
Kim, Burke, Dowds, & George	1999	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	3	1	Yes
Kim, Burke, Dowds, Boone, & Park	2000	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	2−	12	Yes
Kime, Lamb & Wilson	1996	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	3	1	Qualitative
Kirsch, Shenton, & Rowan	2004	Alarm	Reminding	Higher level—Time management	Learning and applying knowledge	TBI	2−	1	Yes
Leirer et al.	1991	Telephone	Reminding	Higher level—Time management	Self-care—Personal health	Dementia & older people	2+	8	Yes
Naugle, Naugle, Prevey, & Delany	1988	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	3	1	Qualitative
Oriani et al.	2003	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	Dementia & older people	2−	5	Yes
Pastrana, Wurst, & Zeiner	2009	Computer	Reminding	Higher level—Time management	General tasks—Handling stress	TBI	3	1	Qualitative
Pijnenborg et al.	2007	Telephone	Reminding	Higher level—Time management	Self-care—Personal health	Psychiatric	2−	5	Yes
Sablier et al.	2010	Computer	Reminding	Higher level—Time management	General tasks—Daily routine	Psychiatric	2−	9	Yes
Schmitter-Edgecombe, Fahy, Whelan, & Long	1995	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	2++	8	Yes
Stapleton et al.	2007	Telephone	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	2−	5	Mixed

(Continued)

Table 1. Continued

Author	Year	ISO Technology Category	ATC Function	ICF Cognitive Function	ICF Activity Domain	Population	SIGN Study Quality Rating	*N*	Treatment Effect
Svoboda & Richards	2009	Telephone	Reminding	Higher level—Time management	Communicating—Using devices	ABI-other	2+	1	Yes
Svoboda, Richards, Polsinelli, & Guger.	2010	Telephone	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	2−	1	Yes
Thöne-Otto & Walther	2003	Telephone	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	2−	12	Yes
van den Broek et al.	2000	Audio visual	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	2−	5	Yes
Van Hulle & Hux	2005	Alarm	Reminding	Higher level—Time management	Self-care—Personal health	TBI	2−	3	Mixed
Wade & Troy	2001	Telephone	Reminding	Higher level—Time management	General tasks—Daily routine	Mixed & other	2−	5	Yes
Wilson & Hughes	1997	Alarm	Reminding	Higher level—Time management	Major life area—Employment	ABI-other	3	1	Qualitative
Wilson, Emslie, Quirk & Evans	2001	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	Mixed & other	2++	143	Yes
Wilson, Evans, Emslie & Malinek	1997	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	2−	15	Yes
Wright et al.	2001	Alarm	Reminding	Higher level—Time management	General tasks—Daily routine	TBI	2−	12	N/A
Yasuda et al.	2002	Audio visual	Reminding	Higher level—Time management	General tasks—Daily routine	ABI-other	2−	8	Mixed
Alm et al.	2004	Computer	Storing and displaying	Memory—Retrieval	Interpersonal interactions—Basic	Dementia & older people	3	15	Qualitative
Berry et al.	2007	Audio visual	Storing and displaying	Memory—Retrieval	Interpersonal interactions—Intimate	ABI-other	2−	1	Yes
Cohene, Baecker, & Marziali	2005	Computer	Storing and displaying	Memory—Retrieval	Interpersonal interactions—Basic	Dementia & older people	3	1	Qualitative
Damianakis, Crete-Nishihata, Smith, Baecker, & Marziali	2010	Computer	Storing and displaying	Memory—Retrieval	Interpersonal interactions—Basic	Dementia & older people	3	12	Qualitative
Goldstein, Beers, Shemansky & Longmore	1998	Computer	Storing and displaying	Memory—Retrieval	Learning and applying knowledge	ABI-other	2−	5	Yes
Sarne-Fleischmann & Tractinsky	2008	Computer	Storing and displaying	Memory—Retrieval	Interpersonal interactions—Basic	Dementia & older people	3	5	Qualitative
Topo et al.	2004	Computer	Storing and displaying	Memory—Retrieval	Interpersonal interactions—Basic	Dementia & older people	3	23	Qualitative

Other ATCs redirect attention by sending participants messages with content that calls attention to their goals. This has been achieved through text messaging (Culley & Evans, 2010; Yeates et al., 2008) and voice messaging (Hart, Hawkey, & Whyte, 2002; Kirsch, Shenton, Spirl, Simpson, et al., 2004; Taber, Seltzer, Heflin, & Alberto, 1999). The messages include cues to pre-agreed goals and thus redirect attention to the participants' internal goal representations. They have been shown to improve on-task behavior and memory for therapy goals.

Overall, the evidence for the effectiveness of devices that shift attention is good. The best evidence is for the neglect alert device's effect on mobility (one 2++ single blind RCT and three 2− SIGN rated studies). There is also good evidence for the effectiveness of content free cueing in improving task performance (from one 2++, one 2+, and one 2− study). The evidence for the effectiveness of content that calls attention to goals is slightly weaker (three 2+ and two 2−), with studies tending to examine memory for goals not actual goal directed behavior.

Calculation Functions (B172, 1 Study)

The ICF divides calculation functions into simple and complex. While no ATC has aimed to assist complex calculations in clinical populations, there is a single case report of ATC successfully assisting with subtraction in a participant with dyscalculia (Martins, Ferreira, & Borges, 1999, SIGN rating 3).

Emotional Functions (B152, 6 Studies)

The ICF defines emotional functions as specific mental functions related to the feeling and affective components of the processes of the mind, such as the cognitive regulation of emotion. Two types of ATC have been used to regulate emotions. First, personal stereos have been used to manage the distressing effects of auditory hallucinations in people with schizophrenia (Feder, 1982; Johnston, Gallagher, Mcmahon, & King, 2002; McInnis & Marks, 1990; Nelson, Thrasher, & Barnes, 1991). Overall the evidence for the effectiveness of personal stereos on reducing distress caused by auditory hallucinations is positive but most of the studies are of low methodological quality (one 3, one 2−, and two 2+ SIGN rated study). For example the largest study (Nelson et al., 1991) included 20 participants but relied on self-report of perceived benefit as the main outcome measure.

Second, biofeedback devices have been used for people with anxiety-related conditions (Reiner, 2008, SIGN rating 2−). Biofeedback allows participants to reduce autonomic arousal and, thereby, levels of subjective anxiety. There is good evidence that biofeedback can reduce depressive symptoms and measures of autonomic arousal (Zucker et al. 2009, SIGN rating 2++). Thirty eight participants were randomized to the biofeedback or a progressive relaxation intervention and outcome measures were obtained with standardized instruments.

Experience of Self and Time Functions (B180, 7 studies)

The ICF defines experience of self and time functions as specific mental functions related to the awareness of one's identity, one's body, one's position in the reality of one's environment and of time. The only ATC found supporting this cognitive function pertained to awareness of self in relation to location (i.e., navigation).

Robinson et al. (2009) describe the development of two devices which use GPS to locate the user. Other ATCs use information in the environment to provide the user with context dependent directions. For example, Chang, Tsai, and Wang, (2008) used a series of tags, and Kirsch, Shenton, Spirl et al. (2004) symbols in the environment to provide the basis for context dependent navigation using a PDA. Morris et al. (2003) developed an intelligent mobility platform that generates a representation of location using sensors and guides the user on this basis. Finally, Liu et al. (2008) also developed an ATC that guides the user based on an internal (pre-programmed) map of the environment. Overall, evidence for the effectiveness of these navigation devices is limited with only two 2− rated studies and four 3 (qualitative) studies in this area. Although Chang et al. (2008, SIGN rating 2−) recruited six participants they did not use either an experimental design or statistical analysis.

Higher-Level Cognitive Functions (B164, 58 studies)

According to the ICF, higher-level cognitive functions are dependent upon the frontal lobes of the brain and correspond with what is often called executive function. The ICF divides higher-level cognitive functions into those which enable abstraction, organization and planning (including carrying out plans), time management, cognitive flexibility, insight, judgment, and problem-solving. A large proportion of ATC have been used to assist time management (33 studies) and organization and planning (25 studies).

Time management functions are prospective memory functions that ensure that one behavior stops and another begins at a specific time. For example, reminding the user to leave to go to a doctor's appointment at a specific time. Time management is the most common ICF specific mental function targeted by ATC. It also contains the largest study in the ATC field which is the Neuropage randomized controlled trial (Wilson et al., 2001; SIGN rating 2++), $N = 143$, which demonstrated the efficacy of using a paging system to deliver reminders for the performance of everyday tasks in people with cognitive impairments.

Aural or visual reminders to perform a given task at a particular time included: Voice recorders with a timer function (van den Broek, Downes, Johnson, Dayus, & Hilton, 2000; Yasuda et al., 2002); text messaging to mobile phones (Pijnenborg, Withaar, Evans, van den Bosch, & Brouwer, 2007), voice messages to phones (Leirer, Morrow, Tanke, & Pariante, 1991), reminder functions on a smartphone (Svoboda & Richards, 2009) or schedule software on a PC

(Flannery, Butterbaugh, Rice, & Rice, 1997; Kim, Burke, Dowds, & George, 1999; Kim, Burke, Dowds, Boone, & Park, 2000) and PDA (Davies, Stock, & Wehmeyer, 2002; Ferguson, Myles, & Hagiwara, 2005; Giles & Shore, 1989; Gillette & Depompei, 2008; Inglis et al., 2003; Sablier, Stip, Franck, & Mobus Group, 2010).

The evidence for the effectiveness of ATC devices that support time management functions is strong (two 2++, three 2+, eighteen 2−, and nine 3 SIGN rated studies). However there have been some mixed or negative results. Yasuda et al. (2002), Van Hulle and Hux (2006), and Stapleton, Adams, and Atterton (2007) all speculate about specific cognitive deficits interfering with the intervention.

ATC which assist higher level organization and planning provide step-by-step support during task performance. Mihailidis, Boger, Craig, and Hoey (2008, SIGN rating 2+) have developed the COACH system to prompt users with dementia through processes such as hand washing. The latest version of the device uses a camera to capture visual data on the position of the users' hands to gain feedback on progress through the task and to guide selection of the appropriate auditory prompt.

Lancioni, O'Reilly, Seedhouse, Furniss, & Cunha (2000, SIGN rating 2−) have developed the VICAID system which is used by people with intellectual disability to guide them through domestic and, primarily, vocational tasks. The VICAID system is a palm top computer with a simplified user interface consisting of a single button, providing visual and auditory prompts through tasks. Users provide feedback to the system by pressing the button. VICAID also rewards successful task completion through minimal feedback to the user.

Finally, O'Neill, Moran, and Gillespie (2010, SIGN rating 2+) examined the use of computer enabled auditory verbal prompting to aid a complex rehabilitation sequence (donning a prosthetic limb) in a sample of eight older adults with cognitive impairment of vascular origin. The system investigated, Guide, offers variable depth support which is bidirectional. The user provides verbal feedback to the system on task progress.

In summary, the 25 studies (nine 2+, ten 2−, and six 3 SIGN rated) indicate that there is currently moderate support for the effectiveness of ATC devices in supporting organization and planning functions.

Memory Functions (B144, 7 Studies)

Memory functions are the specific mental functions used in registering, storing and retrieving information. There are two main types of ATC supporting memory functions: these are cameras and multimedia reminiscence devices.

SenseCam (Vicon Revue) is a stills camera combined with a sensor which is worn around the neck and outward facing to augment long-term memory by taking regular photographs. It was designed to capture a digital record of the wearer's day, the wearer then reviews this information. This system has been investigated (Berry et al., 2007, SIGN rated 2−) in a subject with autobiographical memory impairment and found to result in improvement in episodic memory.

Alm et al. (2004, SIGN rated 3) report on the development and use of a touch screen interactive multimedia reminiscence tool. As the user interacts with the system they activate particular images or sound samples. These are found to trigger personal memories which the user then talks about. Trials with participants with dementia suggested that the system was tolerated and use enjoyed. Impact on rate of recall of memory or facilitation of conversation has yet to be reported.

Overall, the empirical support for ATC for memory functions is limited. Studies have been qualitative or single subject designs with high risk of bias (two −2 and five 3 SIGN rated studies).

Cognitive Functions Not Assisted

We did not find any ATC which primarily assisted the psychomotor functions (b147), perceptual functions (b156), thought functions (b160), mental functions of language (b167), or mental function of sequencing complex movements (b176). In the case of mental functions of language this is due to our exclusion of augmentative and alternative communication devices. Devices have been developed to support psychomotor functions (Kawamoto & Samkai, 2002; Kazerooni & Steger, 2006; Volpe et al., 2009), but these have not been tested with people with cognitive impairment.

Thought functions refer to the pace, form, and content of thought. It is difficult to imagine a device which mediates thought processes without primarily assisting attention, planning or memory. However, if one assumes a close relationship between thought and language (Vygotsky & Luria, 1994), then it might be possible to have a system which monitors verbal output and provides feedback to, for example, slow down, keep on track, or prompt general problem solving.

Regarding the cognitive functions associated with perception, it is surprising that no ATC assisting recognition or interpretation have been tested with clinical populations. Augmented reality systems fuse what users perceive with digital information, for example, using augmented reality glasses users perceive the environment as it is but also with a visual layer of digital information merged into their perceptual field (Haller, Billinghurst, & Thomas, 2007). Such technology should enable recognizing and interpreting visual stimuli, and even converting visual stimuli into, for example, auditory stimuli.

Evidence already shows that the visual perception of a word can be augmented by a computer routing the visual word into the auditory channel (Disseldorp & Chambers, 2002). In a non-clinical study Higgins and Raskind (2000) found that students reading with the aid of text to speech software had improved comprehension. Using more advanced technology it would be possible to have a mobile eye tracking system feeding into a text-recognition and text-to-speech system, such that text seen becomes words heard. Equally, ATC which could verbally prompt users, via an unobtrusive ear-piece, the names of faces seen (or heard) could have clinical application. A system which used object recognition to either verbally identify objects gazed upon or search the visual field for an object required by the user could

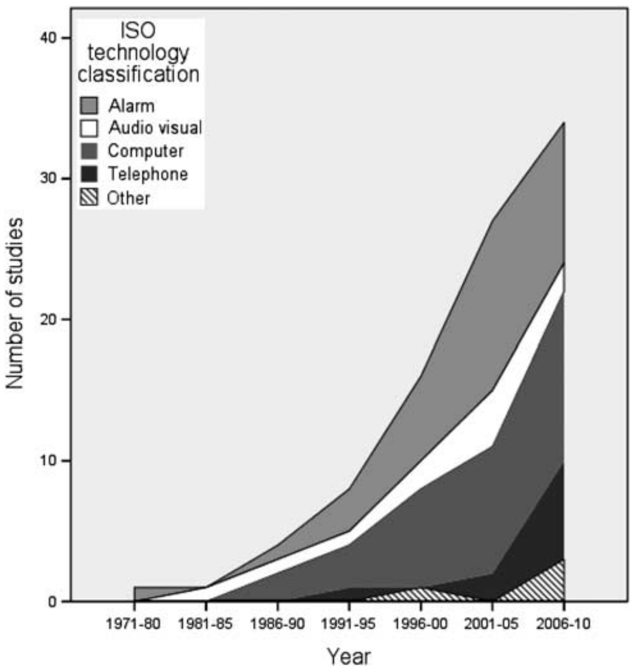

Fig. 2. Number of studies published in each ISO technology category by year.

also be beneficial. El Kaliouby and Robinson (2005) report on an ATC which assists with the recognition of emotions in other people, but it has not been clinically tested.

Exploring Relationships

Figure 2 addresses question 1, showing how the field has changed. Thirty-four studies were published between 2006 and 2010 compared to just 16 published between 1996 and 2000. The figure also shows the technology (ISO 9999) by year, suggesting that the use of technology platforms is not changing. However, the ISO classification conceals a large shift toward mobile platforms.

Figure 3 addresses question 2, revealing a poor fit between the ISO 9999 classification and the ICF cognitive functions. Multi-functional technologies, such as computers and smart phones can assist many different cognitive functions thus obscuring the relationship. Accordingly, the rest of our review uses our functional classification of the technologies used (see Table 1).

Figure 4 reveals clear relationships between ATC function and ICF cognitive function. Attention is assisted by alerting devices. Over half of the emotion regulation interventions use distraction (mainly personal stereos). The experience of self in relation to place, is assisted through GPS feedback devices and related navigation devices. The majority of studies targeted the higher level cognitive functions: organizing & planning and time management. The interesting pattern here is that organization and planning is assisted using interactive micro (step-by-step) prompting devices, while time management is assisted using reminding (single prompt) devices. Finally, episodic memory is exclusively augmented using devices which store and display information.

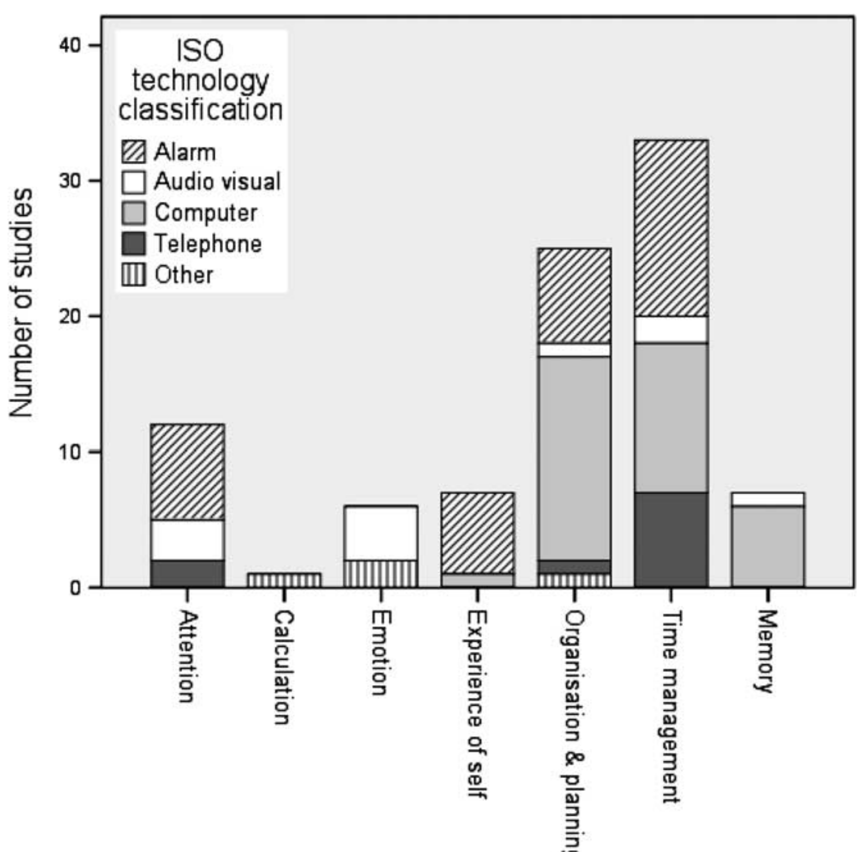

Fig. 3. Number of studies in each ICF cognitive function category by ISO technology category.

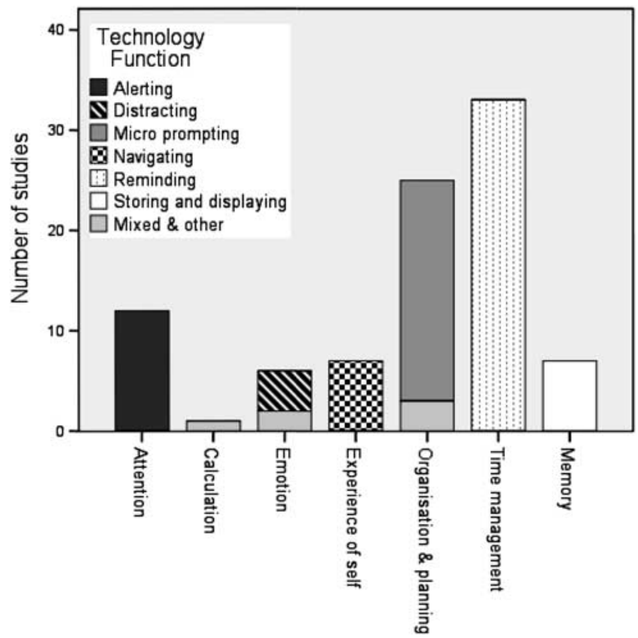

Fig. 4. Number of studies in each ICF cognitive function by assistive technology function.

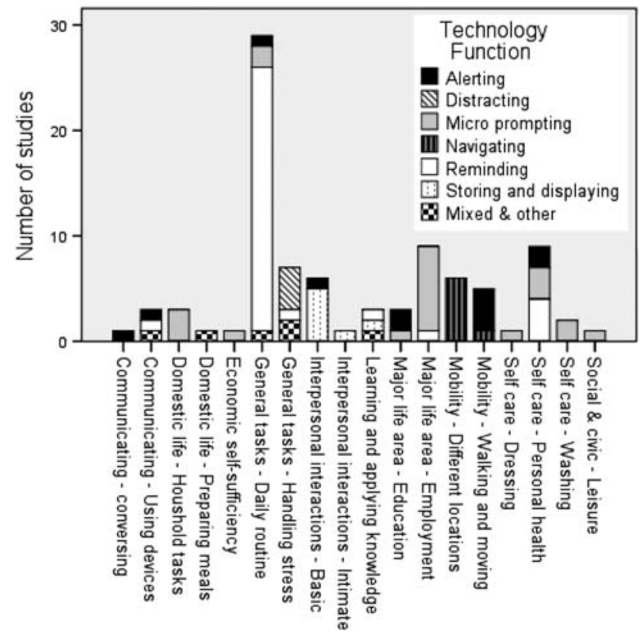

Fig. 5. Number of studies in each ICF activity domain by assistive technology function.

One problem with this mapping is that ATC may support more than one cognitive function. Navigation devices usually entail some interactive step-by-step prompting. Storing and display devices might also be used to distract. Moreover, ATC such as COACH and Guide, which provide step-by-step prompting through hand washing and prosthetic limb donning, arguably assist with attention, memory and executive function simultaneously. Future reporting of the neuropsychological deficits of participants in studies would allow a closer analysis of the relation between ATC and cognitive function.

Figure 5 addresses question 3, showing the ICF activity domains assisted by ATC function. ATC are being used to support a wide range of activities, from communication to social participation. ATC are most frequently used to support daily routines (personal hygiene, food preparation, and movement within and outside of the home), and in this regard, macro prompting devices (usually reminders to perform a task) are the most frequently used ATC function. Micro prompting is commonly used to support use of technology, household tasks, employment, travel, self-care and social participation.

Figure 6 addresses question 4, showing the relationship between ATC function and clinical populations. Distraction devices have been used exclusively with psychiatric populations, and all the interventions targeting people with intellectual disability have been micro prompters. But, it is also clear that both reminding and micro-prompting devices are used with the majority of the populations targeted.

Figure 7 addresses question 5, showing treatment efficacy for each ATC function in terms of number of participants (to ensure that large studies are fully weighted). The bulk of the evidence for efficacy is for ATC which issue reminders. This efficacy is accounted for by the large Neuropage RCT ($N = 143$; Wilson et al., 2001) and over 30 smaller between subject and within subject studies. Taken together there is, as de Joode et al. (2010) concluded, substantial evidence for the efficacy of reminding devices. There is also strong evidence for alerting, distracting and prompting devices. However, the absence of evidence for the other ATC functions should not be taken as negative evidence. The evidence base for navigating, storing and other (especially feedback) devices is promising.

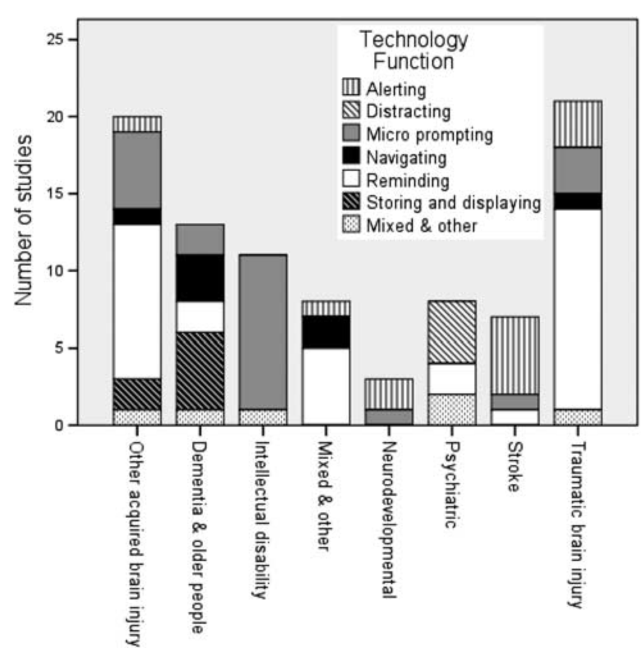

Fig. 6. Number of studies in each clinical population by assistive technology function.

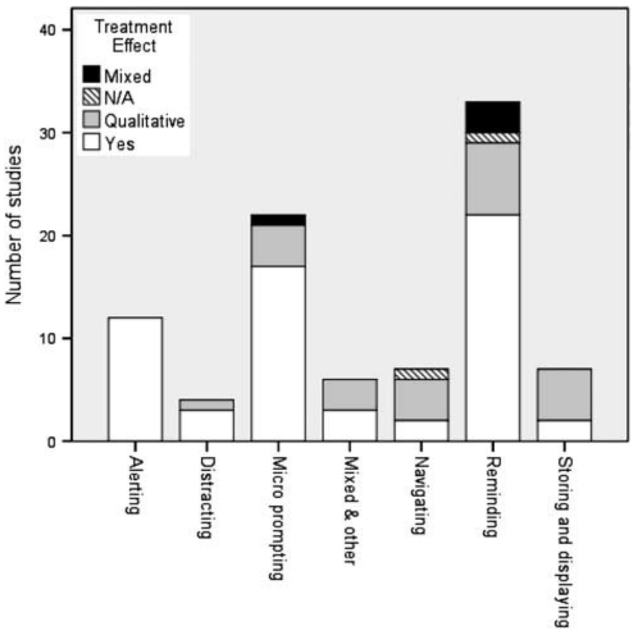

Fig. 7. Number of studies in each assistive technology function group subdivided by treatment effect.

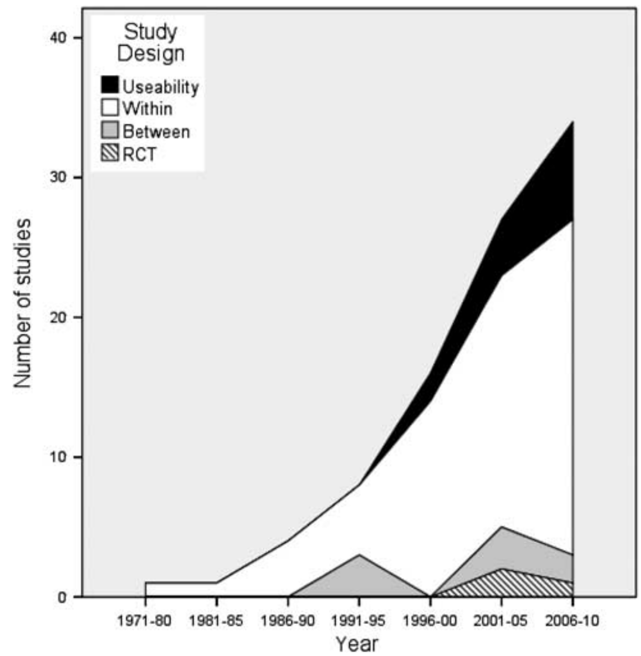

Fig. 8. Study design category by year.

Figure 7 collapses results across a range of diverse outcome measures. Outcome measures included, reducing the number of caregiver interventions, keeping appointments, performing daily chores, and mobility (e.g., after an ATC intervention for neglect). Therefore, although these studies show evidence of effect, what they show effect *for* varies. Given the heterogeneity of ATC, the diverse cognitive functions supported and the diverse outcomes, assessing overall ATC efficacy is problematic. Moreover, with so few studies showing a negative effect, it is possible that there is a bias toward publication of positive results.

One important outcome is duration of use. The nine studies reporting on this found that the devices continued to be used by participants. Two studies reported whether there were continued treatment effects after a discrete period of device use (Robertson et al., 2002; Wilson et al., 2001) and both found some continued improvement in function over baseline after device use terminated.

Assessing the Robustness of the Synthesis

The robustness of a narrative synthesis can be assessed by (1) examining the quality of the studies included in the review and (2) comparing the findings to those of previous reviews (Arai et al., 2007; Jackson & Waters, 2005).

In terms of quality, only three of the 91 studies reviewed were randomized control trials (RCTs). We categorized the other designs into "between subjects" designs which includes non-randomized controlled trials, "within subjects" designs which include multiple baseline case series and 'usability' trials which have no quantitative outcome measures. Figure 8 illustrates the number of studies in each design, as this has changed over time. Most studies, 56 of 91 (61.5%) were within subjects designs, 8 of the 91 studies (8.8%) were between groups designs, 3 of 91 (3.2%) were randomized controlled trials and 24 of 91 (26.4%) were usability trials. However, although RCTs account for a very small number of studies, they account for 28% of the total number of participants involved in the studies (total $N = 777$; RCT $N = 217$).

The quality of included studies was assessed using SIGN (2001) levels of evidence on an eight-point scale from 1++ (highest methodological quality) to 4 (lowest, namely, expert opinion). Five were rated 2++, 18 were rated 2+, 42 were rated 2−, and 26 were rated 3. The proportion of studies rated above 2+ has remained low: 36% (1991–1995), 6% (1996–2000), 22% (2001–2005), and 29% (2006–2010). Arguably, this pattern of research is consistent with a rapidly developing field where new devices are briefly tested and then superseded.

The large proportion (73.6%) of single subject designs is consistent with the variable nature of cognitive impairment which makes obtaining large homogenous samples difficult (Tate et al., 2008). Future research should improve the quality of single subject designs (up to a 2+ SIGN rating) by having multiple data points at baseline and intervention, using standardized outcome measures or at least inter-rater reliability and raters blind to the experimental hypothesis, and providing clear contextual data about the extent of support required for ATC operation. Nine of the single subject designs relied solely on visual inspection of the data, and, as has been recommended previously (Morley & Adams, 1991; Tate et al., 2008), these should be accompanied by statistical analysis. Although a single subject design provides limited basis for generalization (Wilson, 1987) this can partly be addressed by replication (Horner et al., 2005). For example, the large number and diversity of single case studies examining

ATC for time management and organization and planning makes a compelling case for efficacy.

In relation to previous reviews, the present article is the most systematic and extensive review of clinically tested ATC to date. Previous reviews have either not been systematic; that is they have not aimed to identify all studies based on an explicit inclusion, exclusion criteria and search methodology (e.g., Cole, 1999; Kapur, Glisky, & Wilson, 2004; LoPresti et al., 2004; Pollack, 2005); or have limited their scope to a subsection of ATC, focusing on portable ATC (de Joode et al., 2010; 25 studies), ATC for dementia (Bharucha et al., 2009; 58 technologies), or ATC for dementia during the hours of darkness (Carswell et al., 2009; 4 studies).

Our results concur with previous reviews (Bharucha et al., 2009; de Joode et al., 2010; Kapur et al., 2004; LoPresti et al., 2004), although a large number of ATC have been tested, very few studies have been large scale. Only three RCTs were included in the present review. However, rather than calling for more RCTs in general, we call for large scale studies to examine the efficacy of ATC functions rather than specific devices.

Our results concur with the reviews of LoPresti et al. (2004) and de Joode et al. (2010) in finding many devices to support prospective memory (reminder ATC functions in our terminology) and that devices such as Neuropage are those with the greatest evidence for efficacy. However, while de Joode et al. (2010) see little evidence for the use of voice recorders, text messaging systems, and mobile phones as prospective memory aids we see the efficacy of prospective memory aids (reminding devices) established in principle. In our view the established efficacy of Neuropage-like devices generalizes to the basic idea of using reminding devices to assist prospective memory. Generalizing to the underlying ATC functions is necessary to surmount an overly narrow empiricism that can lead to a fragmentation of evidence (Cornish & Gillespie, 2009).

CONCLUSION

The present review makes three contributions. First, it responds to calls to use the ICF as the basis for the evaluation and prescription of assistive technology for cognition (Bauer et al., 2011; Scherer, 2005; Steel et al., 2010). Scherer (2005) states that this neglect "is unfortunate because a common language and structure within which to convey a shared understanding would be of tremendous benefit to the international community of assistive technology researchers, practitioners, and users" (p. 738). The present review uses the ICF to advance a common language and structure for conceptualizing ATC function. Clinicians can use the present review to identify and prescribe suitable ATC to clients on the basis of the identified deficit in cognitive function.

Second, the review contributes a way of classifying ATC based on cognitive function. No relationship was found between the standardized classification of ATC (ISO 9999; 2007) and the ICF classification of cognitive function. However, re-categorizing ATC in terms of function (i.e., alerting, distracting, prompting, navigating, reminding and storing and displaying) reveals a systematic relation to the ICF cognitive functions. This new classification enables generalizing results from trials of specific ATC devices toward general ATC functions. Given the proliferation of unique ATC devices, it is not practical to conduct large scale studies of efficacy for each new device. For example, based on the present review we should conclude that there is most evidence for pager systems given the robust RCT of Neuropage (Wilson et al., 2001). But, pagers are a dated technology. Reminding can be more effectively provided using mobile phones or smart phones. If ATC are conceptualized functionally, then the evidence for Neuropage can be interpreted as basic evidence for reminding ATC.

The final contribution is to focus attention beyond reminding and prompting ATC. Sixty three percent of the reviewed studies reported reminding and prompting interventions. This focus supports Hart, O'Neil-Pirozzi, and Morita's (2003) finding that clinicians saw most potential for such devices. However, the preponderance these devices should not obscure the potential of ATC to support additional cognitive functions. There is increasing evidence for the efficacy of ATC to support attention, emotion-regulation, experience of self in relation to place, and memory. No ATC which augment the cognitive functions of perception, thought, recognition, or identification have been tested in a clinical context. Inability to recognize faces or objects can cause significant disability (Damasio, Tranel, & Damasio, 1990). Technology has been developed to recognize faces, voices, and objects and present that information to users in various ways. Augmented reality systems allow for information to be embedded in the visual and auditory field and we expect greater use of these technologies in future ATC.

Further growth is also expected in mobile systems. ATC have been used to address a wide range of tasks occurring in a wide variety of locations, in and outside of the home (Figure 5). For ATC to achieve their potential, they need to be available at the point of need. It is likely that smartphones will be the platform that provides this much needed portability. Smartphones are becoming ubiquitous and increasingly powerful, hosting a range of sensors, and supported by development kits and online stores which can easily distribute specialist 'apps.' As a technology platform, smart phones can support the ATC functions of alerting, distracting, navigating, reminding, prompting and storing and displaying information. Such diverse functionality from a single technology platform underscores our argument that research should focus on the generalizable level of ATC function, conceptualized in cognitive terms, rather than specific devices or even technology platform.

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