NEUROPSYCHOLOGICAL REHABILITATION, 2004, *14* (1/2), 5–39

Assistive technology for cognitive rehabilitation: State of the art

Edmund Frank LoPresti
AT Sciences, Pittsburgh, PA, USA

Alex Mihailidis
Simon Fraser University, Vancouver, Canada

Ned Kirsch
University of Michigan Health Systems, Ann Arbor, MI, USA

For close to 20 years, clinicians and researchers have been developing and assessing technological interventions for individuals with either acquired impairments or developmental disorders. This paper offers a comprehensive review of literature in that field, which we refer to collectively as assistive technology for cognition (ATC). ATC interventions address a range of functional activities requiring cognitive skills as diverse as complex attention, executive reasoning, prospective memory, self-monitoring for either the enhancement or inhibition of specific behaviours and sequential processing. ATC interventions have also been developed to address the needs of individuals with information processing impairments that may affect visual, auditory and language ability, or the understanding of social cues. The literature reviewed indicates that ATC interventions can increase the efficiency of traditional rehabilitation practices by enhancing a person's ability to engage in therapeutic tasks independently and by broadening the range of contexts in which those tasks can be exercised. More importantly, for many types of impairments, ATC interventions represent entirely new methods of treatment that can reinforce a person's residual intrinsic abilities, provide alternative means by which activities can be completed or provide extrinsic supports so that functional activities can be performed that might otherwise not be possible.

Correspondence should be addressed to E. F. LoPresti, AT Sciences, 160 N. Craig St., Suite 117, Pittsburgh, PA 15213, USA (Email: edlopresti@acm.org).

http://www.tandf.co.uk/journals/pp/09602011.html DOI:10.1080/09602010343000101

Although the major focus of research in this field will continue to be the development of new ATC interventions, over the coming years it will also be critical for researchers, clinicians, and developers to examine the multi-system factors that affect usability over time, generalisability across home and community settings, and the impact of sustained, patterned technological interventions on recovery of function.

As clinicians and researchers seek new ways to serve people with cognitive and neuropsychological disabilities, many have incorporated computers and other advanced technologies into clinical interventions (Bergman, 1998). These technological interventions, often referred to as "cognitive orthoses" or "cognitive prostheses" (and to which we will refer collectively in this paper as assistive technology for cognition or ATC), range from alarms to remind people of their medication schedules to interactive robotic caregivers. Some draw on technology designed for the mainstream population, while others are designed for the unique needs of people with disabilities, but all are typically designed to provide extrinsic supports for individuals with compromised cognitive ability.

ATC interventions can aid people with a variety of disabilities, including traumatic brain injury (NIH, 1998; Wilson, Evans, Emslie, & Malinek, 1997), cerebrovascular accident (Evans, Emslie, & Wilson, 1998; Wright et al., 2001), learning disabilities (Higgins & Raskind, 1995; Raskind & Higgins 1995; MacArthur, Ferretti, Okolo, & Cavalier 2001), and multiple sclerosis (Allen, Goldstein, Heyman, & Rondinelli, 1998); and have shown some potential to aid people with dementia (Zanetti et al., 2000), autism spectrum disorders (Strickland, Marcus, Mesibov, & Hogan, 1996; Imamura, Wiess, & Parham, 1990; Werry, Dautenhahn, Ogden, & Harwin, 2001), and mental retardation (LoPresti, Friedman, & Hages, 1997).

Depending on the specific needs of the person, these technologies may be used in a number of ways. One approach capitalises on those of a person's skills that have *not* been compromised so that tasks can be accomplished using alternative strategies or information characteristics. For example, an ATC intervention may include a computer that allows speech recognition rather than typing for a person with poor visual letter recognition but strong verbal language skills. Similarly, a personal digital assistant (PDA) may be used for daily planning by a person with memory impairments but relatively intact executive skills or a software interface may be designed that accommodates visual–perceptual or information processing impairments.

For more severely impaired individuals, an alternative approach has been to develop extrinsic interventions that assume greater responsibility for initiation, cueing, activity guidance, and maintenance of daily information. For example, an ATC intervention may be designed that, in addition to providing simple alarms about when medications are to be taken, also provides step-by-step guidance about how to recognise the medication, how to recognise how much of the medication to take, how much water to drink, and how to refill a dispensing container to prepare for the next dose. For all of these interventions, the goal is to achieve a way of performing tasks that compensate for existing impairments by using a device that either partially takes the place of a person's impaired ability, or translates a problem into one that matches the client's strengths.

More specifically, "cognitive orthoses" or "cognitive prosthetics", collectively referred to as ATC, have been defined as compensatory strategies that alter the patient's environment and are directed to an individual's functional skills (Kirsch, Levine, Fallon-Kreuger, & Jaros, 1987). Cole expanded this definition in his 1999 review of the field to include the following attributes of a cognitive prosthetic:

- Uses computer technology;
- Is designed specifically for rehabilitation purposes;
- Directly assists the individual in performing some of their everyday activities;
- Is highly customizable to the needs of the individual (Cole, 1999).

Lynch defines a "cognitive prosthetic" as "any computer-based system that has been designed for a specific individual to accomplish one or more designated tasks related to activities of daily living (ADL), including work (Lynch, 2002)".

In keeping with these definitions, this paper will focus on interventions that provide compensatory methods and strategies for task performance. However, not all of the cognitive assistive technologies described in this article will qualify as cognitive orthoses according to all aspects of these definitions. While most attention will be given to computer-based devices, low-tech solutions will also briefly be discussed. Devices designed for both mainstream and rehabilitation applications will be reviewed, with some discussion of the advantages and disadvantages of using mainstream technology for people with cognitive impairment. Not all ATC interventions described below are designed for a specific individual, but all cognitive orthoses must indeed be customised to the individual user's needs, to varying degrees.

Scope of this article

This article reviews the state of research in cognitive orthoses through the following topics:

1. Cognitive disabilities and the human-technology interface.
2. Technology for memory and executive function impairments.
    - Compensation technologies for memory.

- Compensation technologies for planning and problem solving.
- Context-aware cognitive orthoses.

3. Technology for information processing impairments.
   - Compensation technologies for sensory processing.
   - Technologies for social and behavioral issues.
4. Conclusion

Since the purpose of this article is to introduce the reader to the breadth of research that has been conducted in this area, we will not review all areas of "cognitive rehabilitation" that utilise technology. For example, technology for communication deficits will not be addressed. Augmentative and alternative communication is an active field with an extensive literature of its own, addressing the technological needs of people with communication impairments, including neurologically based aphasias (Beukelman & Mirenda, 1998). This review will also not address educational software, although there are a number of software products that are directed to teaching reading, maths, and other skills to people with cognitive disabilities (Gillette, 2001). Finally, this paper will not review the use of technology for "restorative" interventions. This is a large field, with a robust history, that has been reviewed extensively. (Lynch, 1982, 2002; NIH, 1998). Most importantly, in our judgement, the literature in the area of "restorative" technological interventions is essentially indistinguishable from the more general literature addressing cognitive rehabilitation (Cicerone et al., 2000), and is subject to the same issues of efficacy that are faced by non-technological interventions, including domain specificity and limited ecological validity (Lynch, 2002). Having said this, however, we will return to the issue of restorative intervention in the concluding section, where new developments in neurorehabilitation and their implications for ATC will be addressed briefly.

COGNITIVE DISABILITIES AND THE HUMAN–TECHNOLOGY INTERFACE

Any assistive technology for people with cognitive disabilities must accommodate the individual user's skills and deficits. This is complicated by the fact that each person will have a unique combination of strengths and weaknesses. A prospective memory aid that requires a great deal of self-initiation and problem solving skills will be useful for some clients, but will only exacerbate difficulties for others. Similarly, while mainstream computer software has great potential to assist people with cognitive disabilities (for example, software for time and money management), existing software is often either too complex or not age appropriate for adults (Lynch, 2002; Wehmeyer, 1998). Therefore, accommodations for people with mental retardation and other cognitive disabilities to use computers typically need to include visual displays with reduced clutter, provision of information in non-text formats (e.g., graphics, video, audio), minimisation of the number and complexity of decision making points, presentation of information sequentially, and reduced reliance on memory (Wehmeyer, 1998).

People with cognitive disabilities will often have physical and sensory limitations, as well. In designing and prescribing cognitive aids, it is important to consider how well the technology matches the individual's physical and sensory abilities, including:

- Vision.
- Hearing.
- Tactile sense (e.g., ability to feel and touch buttons).
- Fine motor control (e.g., ability to operate small controls, ability to write).
- Ability to speak.
- Co-ordination (e.g., ability to accurately select small buttons).

All aspects of a person's cognitive, physical, and sensory capabilities must be taken into account in prescribing technology (LoPresti & Willkomm, 1997). Features that make a device more "user-friendly" for one group of users may make it less so for another group (Cole, Dehdashti, Petti, & Angert, 1994). Technology design and prescription also require consideration of all the people who will be affected by the technology, including clinicians and caregivers as well as people with the disabilities (Cole et al., 2000; Magnusson & Larsson, 1994).

Designers can better understand users' needs by referring to models of typical user needs (user modelling) or by involving the user in the design process (user-centred or participatory design). Since existing user models largely rely on data collected for individuals without disabilities, some researchers are now beginning to develop models which incorporate data for people with disabilities (Keates, Clarkson, & Robinson, 2000) or which encourage "thought" experiments in which the designer tries to put him- or herself in the position of a person with a disability (Svensk, 1997). In user-centred design, technology development is guided by frequent interactions with representatives of the user populations to discuss general needs and possible features, and to review prototypes (Cole, Dehdashti, Petti, & Angert, 1993). In participatory design, members of the user population are continually involved as members of the design team, suggesting features and pointing out possible difficulties with the design (Cole et al., 1994). Newell et al. (2000) have suggested the concept of "user sensitive inclusive design" which extends the concept of user-centred design, specifically to include users with disabilities.

High customisation is often needed for a cognitive device to be effective. Each device may need to be customised for a specific individual, and revised on a regular basis as the user's capabilities change. This customisation needs to reflect a number of factors including user priorities, functional deficits, and the environment where the activity is performed, such as home, community, school, and work (Cole, 1999; Cole & Dehdashti, 1998). Different devices approach this need for customisation in different ways.

TECHNOLOGY FOR MEMORY AND EXECUTIVE FUNCTION IMPAIRMENTS

Compensation technologies for memory

Individuals with cognitive disabilities are often unable to generalise from graded memory drills and exercises to independent completion of activities of daily living (Chute & Bliss, 1988; Middleton, Lambert, & Seggar, 1991). Therefore, interest has grown in using computers as compensatory tools in actual life situations—i.e., improving a person's performance by using the computer to support areas of cognitive weaknesses (Chute, Conn, DiPasquale, & Hoag, 1988; Rothi & Horner, 1983). Early attempts to use the computer for this purpose were limited, but growing evidence indicates that the computer has promise (Bergman, 1998).

Technological interventions can provide compensatory support for a number of executive function impairments and those complex memory deficits often associated with the integrity of executive functions. *Executive functions* are typically associated with effective adaptation and accommodation to changing environmental demands through the appropriate and efficient integration of more basic cognitive skills (Levine, Horstmann, & Kirsch, 1992; Luria 1973). This requires a range of cognitive skills, including:

- Planning.
- Task sequencing and prioritisation.
- Task switching.
- Self-monitoring.
- Problem solving.
- Self-initiation and adaptability (Cole & Dehdashti, 1998; Rubenstein, Meyer, & Evans, 2000).

Related memory skills include "prospective memory", that is, remembering tasks that need to be performed and carrying out these tasks at the appropriate time (Ellis, 1996).

Early work on prospective memory aids investigated the application of commonplace technologies, such as clocks and calendars (Harris, 1978) or timers and digital watches (Jones & Adams, 1979, Klein & Fowler, 1981, Wilson, 1984). These technologies are inexpensive, easy to use, and have no social stigma that might otherwise be attached to "rehabilitation" devices.

However, these devices have limitations in regard to the amount of information that can be stored, and how information can be presented to the user. More importantly, written lists and calendars provide no cues to the user as to when he or she needs to perform a task. For individuals with deficits in self-initiation, a device which can call itself to the person's attention will be better able to facilitate activity performance (Hersh & Treadgold, 1994, Kim, Burke, Dowds, & George, 1999, Kime, Lamb, & Wilson, 1995). However, while a standard alarm wristwatch or timer will provide an audible cue, it will not provide information about the task to be performed. An alarm wristwatch can be combined with a written list, so that whenever the watch alarm sounds the person refers to the list for information. However, this latter intervention requires that the client both associate the watch alarm with the need to refer to the list and remember to use (and carry) both the watch and the list. This can be inconvenient for people with mild memory impairments, and difficult or impossible for people with more severe memory or executive function deficits. Therefore, it is sometimes useful to have a single, easily portable device that provides both an external cue and relevant information.

Prospective memory aids are most effective when they can be customized for a specific user and his or her desired activities of daily living (ADLs) (Chute & Bliss, 1988). Chute and Bliss (1988) addressed this problem through the use of object-oriented programming, a programming approach which simplifies modification and adaptation of the properties of software "objects" or functions. Their ProsthesisWare software was designed for training and neuropsychological monitoring with four issues in mind: (1) the elderly need to be in control of their environments and ADLs; (2) the success of ProsthesisWare implementation depends on its ability to be customised to suit individual needs and abilities; (3) interconnectivity is required to provide a seamless environment among applications on the computer and other devices such as fax machines; and (4) the graphical user interface must be designed taking into account the cognitive and ergonomic capacities of its user (Chute & Bliss, 1994). ProthesisWare monitored the user, provided cues and reminders (via pictures of the user completing the required task), and supplied schedules and sequences of tasks. ProsthesisWare programs were evaluated and modified through an iterative customisation process that occurred on a case-by-case basis, and their effectiveness was measured by utility for each individual user. Outcome evaluation has been limited to qualitative analyses but the results were disappointing, in part because the subject was selected shortly after injury (Chute & Bliss, 1994).

The Institute for Cognitive Prosthetics (Bala Cynwyd, PA) has developed many ATC interventions customised to the specific needs of individual clients (Cole & Dehdashti, 1988; Cole et al., 2000). Their approach has been to meet with the individual client, identify specific functional needs, and develop a customised computer-based system designed to increase the

TABLE 1
Commercially available prospective memory aids

Device	*Manufacturer*	*Description*
IQ Voice Organizer™	Voice Powered Technology International Inc., Burlington, NJ, USA	Pocket-sized device that allows verbal messages to be recorded and played back audibly at a specified time
NeverMiss DigiPad™	ICP Inc., Montreal, Quebec, Canada	Pocket-sized device that allows verbal messages to be recorded and played back, but without an associated time function
Data Link watch	Timex™, Middlebury, CT, USA	System that includes a wristwatch and software program for a personal computer that stores the user's schedule and alerts him or her with an audible alarm when an item from the schedule is due
CellMinder	Institute for Cognitive Prosthetics, Bala Cynwyd, PA	System which utilises a cell phone as a reminder system. Software on the user's computer keeps track of a schedule and calls the user on his or her cell phone at appointed times
ISAAC	Cogent Systems, Inc., Orlando, FL	Handheld cognitive device specifically designed for individuals with a wide range of cognitive disabilities
Planning and Executive Assistant and Trainer (PEAT)	Attention Control Systems, Inc., Mountain View, CA	Handheld reminding device with intelligent support for revising schedules

client's self-sufficiency for tasks of interest to the client (Cole 1999; Cole & Dehdashti, 1990).

In one case study, a system was developed for a 54-year-old woman who was 4 years post-traumatic brain injury. A computer-based system, including a text editor and home finance software, was customised in an iterative process to match the client's strengths and weaknesses. The client was able to use the final system reliably when unattended, and able to learn the software applications in three 30-min training sessions (Cole & Dehdashti, 1990). A system was developed for a 33-year-old woman who experienced neurological dysfunction of unknown etiology followed by a series of cerebrovascular accidents. A cognitive prosthetic system was customised to her needs. The client showed increased stamina for writing, the ability to produce a two-dimensional design using drawing software and showed improvements in visual scanning and in neuromotor skills related to activities of daily living (Cole, Petti, Matthews, & Dehdashti, 1994).

Three clients with traumatic brain injury, no expectation of spontaneous recovery, and lack of remediation from alternative compensatory strategies achieved a significant increase in function using a cognitive prosthetic system (Cole et al., 1994), which included following a daily schedule, initiation of a designated activity following a cue, and maintaining a prioritised to-do list. Subjects showed additional benefits including increased relaxation and self-confidence and improved planning, problem solving, and self-initiation (Cole et al., 1994). Similar results have been observed for numerous other cases (Cole, 1999; Cole & Dehdashti, 1998; Cole et al., 1993).

The Institute for Cognitive Prosthetics has provided distance rehabilitation services (Cole, 1999; Cole et al., 2000) and remote computer connections. An integrated treatment planning system co-ordinates activities of the therapist, client, and computer programmers responsible for software customisation (Cole et al., 1994, 2000). The work in the Institute for Cognitive Prosthetics indicates a growing acceptance of the efficacy of cognitive orthotic technology by service providers.

Mastery Rehabilitation Systems (Bala Cynwyd, PA) developed the Essential Steps software to support users in a variety of daily tasks through cues presented on-screen or using a computer-generated voice (Bergman, 1996, 2002). Fifty-four people with cognitive impairments demonstrated rapid skill acquisition in individual trials with the software. It was demonstrated that this tool could be integrated into ADL tasks at home, school, and vocational settings for as much as 10 years (Bergman, 1997).

Much of the work in this area has focused on clients with prospective memory deficits resulting from traumatic brain injury or cerebrovascular accident. Zanetti and colleagues (2000) studied the ability of individuals with mild to moderate Alzheimer's disease to appropriately use an electronic agenda. Seven memory tasks, such as finding a hidden personal object or putting a newspaper in the trash, had to be completed by each of five subjects at fixed hours. Performance with the device was compared on different days with control conditions. The results showed statistically significant improvements in completion of the required tasks, with two of the five subjects achieving perfect scores when allowed to use the electronic aid (Zanetti et al., 2000).

As an alternative to specially designed cognitive orthoses, Flannery and Rice (1997) studied the efficacy of calendar software designed for the mainstream population. A laptop Macintosh computer was equipped with Easy Alarms™ software (Nisus Software, Inc, Solana Beach, CA). The software was programmed with 15 tasks that were repeated on a daily basis. The system was evaluated for a 17-year-old male with short-term memory loss. The rate of needed reminders from a caregiver dropped from 75% to 8% when the computer system was used (Flannery & Rice, 1997).

Some work on reminder systems has focused on the specific task of medication compliance. Medication compliance devices range from plastic boxes divided into sections labelled by times and day, to electronic systems that provide auditory cues (Fernie & Fernie, 1996). Devices without external cues are not effective unless the user can first remember to take his medication at an appropriate time, locate the medication dispenser and figure out which day/time compartment to open. Until recently more complex electronic devices have tended not to be portable, and the person may not respond to the audible alarms (Fernie & Fernie, 1996).

A number of electronic memory aids and recording devices are commercially available. Examples of such devices are shown in Table 1 (Hersh & Treadgold, 1994; Levinson, 1997; LoPresti & Willkomm, 1997). These are only a few examples of available products, representing a range of products of this type.

The IQ Voice Organizer™ and Data Link Watch are two examples of prospective memory aids designed for and marketed to the mainstream population, rather than specifically for people with cognitive disabilities. Scheduling and reminder software are also available for standard palmtop computers, such as those running the Palm (Palm Inc, Mipitas, CA) and Windows CE (Microsoft, Redmond, WA) operating systems. These devices may be more readily available than devices designed for people with disabilities. Also they may be more acceptable to clients, since they are "normal" devices.

Other devices, such as ISAAC (Cogent Systems, Inc.), CellMinder (Institute for Cognitive Prosthetics, Bala Cynwyd, PA), and the Planning and Execution Assistant and Training System (PEAT, Attention Control Systems Inc, Mountain View, CA), have been designed specifically for individuals with cognitive disabilities. They provide more support for people who would have difficulty independently entering their schedules into more complex devices and are designed with physical and sensory limitations in mind.

A number of investigators have studied the efficacy of electronic prospective memory aids (Herrmann et al., 1999; Tackett, Rice, Rice, & Butterbaugh, 2001). Studies have shown that older adults with memory impairments can perform as well as younger adults in prospective memory tasks if they are able to use external memory aids (Maylor, 1996). Kime et al. (1995) demonstrated improved performance of complex functional tasks by using an alarm system with a personal organiser. Subjects with attention deficit disorder have been observed to improve in punctuality for prospective memory tasks when using a Voice Organizer™ personal organiser (Willkomm & LoPresti, 1997). Hersch and Treadgold (1994) have shown that NeuroPage, a specialised paging system, can be used to facilitate prospective performance of functional tasks. Similarly, Hart, Hawkey, and Whyte (2002) have demonstrated that a portable voice organiser (Parrot Voice Mate III) can promote the retention and performance of behavioural goals (e.g., utilising relaxation techniques when episodes of anxiety occur) as well as simple prospective tasks (e.g., remembering to get the mail).

The most central work in this area has been reported by Wilson and colleagues (Evans et al., 1998; Wilson, Emslie, Quirk, & Evans 2001; Wilson et al., 1997; Wright et al., 2001) who have demonstrated that an alphanumeric paging system can facilitate the performance of functional activities for adults with a variety of neurological impairments including cerebrovascular accident and traumatic brain injury, thereby supporting independence in the home and community. In one study, Wilson and colleagues performed an ABA single case experimental design with 15 subjects who had experienced traumatic brain injuries using an alphanumeric pager to provide reminder messages at predetermined times. This intervention was associated with a significant reduction in incidents of memory failures ($p < .05$; Wilson et al., 1997).

In another study, Evans and colleagues conducted a single-subject ABAB design with a 50-year-old woman who had experienced a cerebrovascular accident resulting in impairments of planning, attention, and prospective memory. An alphanumeric paging system was compared to a paper-and-pencil checklist for efficacy as prospective memory aids. The alphanumeric paging system was able to prompt the subject to perform intended activities, to perform activities in a timely manner, and to initiate planning of future activities. For example, the subject took medication with a mean delay of 1.9 min with the pager, compared to a mean delay of 33.44 min with the checklist (Evans et al., 1998). A randomised control trial was conducted with 143 people having memory, planning, attention, or organisation problems, usually following a traumatic head injury or a stroke. More than 80% of those who completed the 16 week trial were significantly more successful in carrying out everyday activities (such as self-care, self-medication, and keeping appointments) when using the pager in comparison with the baseline period; for most of these, significant improvement was maintained when they were monitored 7 weeks after returning the pager (Wilson et al., 2001). The MemoJog project at Dundee (Inglis et al., 2002) is extending this research to develop an interactive memory aid using PDA's with data transmission via the mobile phone network. This system extends the Neuropage functionality to enable communication with the carers' computer system so that, for example, an alarm can be raised if certain critical messages are not acknowledged by a button press on the PDA.

Research has been conducted on the use of technology to support interaction with a human assistant. Videoconferencing is being explored to provide job coach services remotely to workers with cognitive disabilities in a vocational setting (Rosen et al., 2000). Telerehabilitation features were included in the Isaac and TASC projects (Fagerberg, 1999; Jonsson & Svensk, 1995). Isaac included cognitive orthotic software together with a cellular phone, a digital camera and GPS satellite navigation receiver to provide support centre staff with information about the client's needs (Jonsson & Svensk, 1995).

The Jogger system includes a portable memory aid and a home docking station, to assist caregivers and clinicians in preparing a person's schedule and monitoring performance (Jinks & Robson-Brandi, 1997). The docking station enables communication with a clinician's computer for reviewing the user's compliance with previous cues and editing his or her schedule. Researchers at the Coleman Institute are developing a Memory Aiding Prompting System (MAPS) which incorporates a PDA with a docking system, wireless communication, and data logging (Carmien, 2002). The docking system will allow a caregiver to programme the user's schedule on a stationary computer, which will download the schedule to the user's PDA. The wireless communication will allow the user or the system to contact a caregiver when problems arise that the system cannot automatically handle. Data logging facilitates evaluation of the effectiveness and appropriateness of the system.

Compensation technologies for planning and problem solving

Some ATC interventions seek to provide support with planning and problem solving as well as prospective memory. The Planning and Execution Assistant and Training System (PEAT, Attention Control Systems Inc, Mountain View, CA) uses artificial intelligence to automatically generate daily plans and re-plans in response to unexpected events (Levinson, 1997). Using manually entered appointments in conjunction with a library of ADL scripts, PEAT generates the best plan to complete all of the required steps, and assists with plan execution by using visual and audible cues. The user provides input to the device when a step has been completed, or if more time is required to complete the step (Levinson, 1997).

Most existing memory aids are designed to present scheduled, one-step tasks (e.g., "At 5:00, cook dinner"), but people may want to remember tasks that are not precisely scheduled. For example, a person might want to bake a pie sometime before 5:00, but not at any particular time. Further, many tasks are not limited to one step, e.g., cooking dinner involves a number of sub-tasks related to preparing kitchen utensils and following a recipe. People can be assisted in multi-step tasks by low-tech aids such as a series of cards with pictures which illustrate the steps of the task. Some research has shown that a system which combines automatic presentation of such pictorial instructions with auditory or tactile cues can improve performance (Lancioni et al., 1999, 2000).

Levine and Kirsch (1985), developed a specialised computer language called COGORTH (COGnitive ORTHotic) to support guidance through multi-step tasks. This language provided a highly structured environment for programming sequential messages, such as steps in a task. These messages could be presented as text on a video display, an audio signal, or a visual cue (Levine & Kirsch, 1985). COGORTH program could display directions at any level of specificity. COGORTH provided programming capabilities for instructional modules (IM) which could check a user's performance for errors, branch to error correcting or help procedures, manage interruptions of a task when a higher priority task must be completed, and manage a user's environment through control of electric appliances, telephone, and audio signals (Levine & Kirsch, 1985). Keyboard input from the user was required to obtain feedback regarding his or her performance. An inappropriate response, or lack of response within a certain amount of time, would cause COGORTH to conclude that assistance was required (Levine & Kirsch, 1985).

A computerised task guidance system utilising COGORTH was used in a series of efficacy studies with a wide range of patient types and cognitive disabilities. In one study, a subject with difficulty in planning and problem-solving following an anoxic episode experienced improved performance in a cooking task when using a computerised task guidance system instead of only written instructions (Kirsch et al., 1988). Four head-injured individuals used a COGORTH-based ATC intervention to perform janitorial tasks. Two subjects showed substantial improvements in accuracy when using the intervention. A third subject experienced only mild difficulty in performing the janitorial tasks with written directions and did not benefit from the introduction of the orthotic. The final subject appeared to benefit from the orthotic, but her level of motivation changed dramatically during the course of the study (Kirsch, Levine, Lajiness-O'Neill, & Schneider, 1992). More recently, the underlying concepts of COGORTH are being modified to take advantage of wireless, web-based technology (Kirsch et al., 2002) and current artificial intelligence methods (Simpson, Schreckenghost, & Kirsch, 2002).

Steele, Weinrich, and Carlson (1989) developed an ATC intervention which used a series of dynamic icons and illustrations to communicate the steps to a simple recipe. Fourteen trials were conducted for one subject with severe aphasia using six different recipes. The subject was able to accurately prepare the food during 11 of 14 trials when the device was used (Steele et al., 1989). Performance without the device was not reported.

Napper and Narayan (1994) developed a computerised ATC system to help therapists and caregivers create customised task guidance systems for people with cognitive impairments. The device guided a person through each required step of a task. The device was evaluated by assisting a subject with a head injury while shaving. With the device, the number of cues and interactions required with the caregiver was reduced compared to baseline data, and the number of errors made by the subject was reduced to zero (Napper & Narayan, 1994).

Context-aware cognitive orthoses

Many of the ATC interventions described thus far require input from the user to provide feedback to the device (e.g., pushing a button after the cued tasks has been completed). However, a person with a cognitive disability may not remember what step they had just been asked to perform and/or the need to indicate that the step had been completed (Vanderheiden, 1998). Even for those people capable of providing this input, the additional requirement increases the cognitive load on a person, and can result in the user becoming further frustrated and agitated. In addition, users who lack initiation and planning skills may not be able to actively retrieve the messages or information stored in these devices (Friedman, Kostraba, Henry, & Coltellaro, 1991). Manual re-programming is also required to customise these devices for an individual user, which can be time-consuming and difficult (especially if a caregiver or family member is expected to perform this function).

This could be remedied if a device was able to recognise the user's context; that is, his or her physical and social environment. If the device was aware of the user's location, for example, it could give reminders relevant to that location. Information about the user's environment might also provide cues to the device on what reminders might be important (handwashing if the person is in the washroom) or unnecessary (a reminder to go to the cafeteria if the person is already there). Social cues might allow the device to know when a reminder would be inappropriate; such as when the user is talking with another person and might not want to be interrupted.

Context-sensitive reminding requires a person's environment and activities to be monitored. Several researchers have used sensors and switches attached to various objects in the user's environment to detect which task the person is completing. If these devices detect an unexplainable change in the person's normal routine, then external assistance is called. Trials with several subjects indicate that this method of tracking a person's actions is a good way of monitoring the state of a person's health and independence (Bai, Zhang, Cui, & Zhang, 2000; Nambu, Nakajima, Kawarada, & Tamura, 2000; Ogawa et al., 2000).

Friedman (1993) developed an ATC device with sensing capabilities. A wearable microcomputer used a combination of radio and ultrasound to communicate with stationary ultrasound transmitters throughout the user's environment, allowing the computer to determine the person's location. Additional sensors provided task-related information. The computer provided voice prompts only as needed to help the user maintain his or her schedule. Continued evidence of difficulty adhering to the schedule would cause the computer to automatically call for human assistance (Friedman, 1993). By only providing prompts as needed, the system could "fade" cues and therefore decrease the user's dependence on them.

Cavalier and Ferretti (1993) evaluated the efficacy of this system to assist two high school students with severe learning disabilities in wiring a switch box. The task consisted of 47 component steps. If a step was completed correctly, the device waited 3 s then, if the student was not continuing to make progress, it prompted the user to start the next step using a verbal cue. If a step was incorrectly performed, the computer corrected the actions of the user using a verbal cue. If the user ignored the cues provided by the device, the teacher provided assistance. With the cognitive orthotic the subject was able to self-initiate 11% of the steps, and verbal prompts from the cognitive device were required 89% of the time (Cavalier & Ferretti, 1993). Interactions with the teacher during this phase were not required. Results from the second student were similar.

LoPresti, Friedman, and Hages (1997) instrumented a workspace with sensors to detect progress through a vocational task. A palm-top computer offered programmed advice, reminders, and praise audibly through a set of headphones. Using the device, two subjects with mental retardation were able to maintain levels of productivity comparable to those obtained when a job coach closely guided each subject (LoPresti et al., 1997).

Mihailidis, Fernie, and Cleghorn (2000) conducted a pilot study, and observed that a person with severe dementia would complete an activity of daily living in response to a computerised device that used a recorded voice for cueing. The computerised device monitored and prompted a subject through handwashing. The hardware consisted of several switches and motion sensors installed inside a fibreglass overlay, on top of a sink. The subject was independently able to complete (i.e., without a caregiver) approximately 22% more steps in the handwashing activity when the device was used. These results showed that a computerised cueing device can be effective. The current prototype however was too rigid in the way that it provided assistance to the users, and it only allowed the users to complete the ADL in one set sequence. This inflexibility in the device's algorithms resulted in several errors to occur, and for the subjects to sometimes become frustrated because the device was trying to force them to complete handwashing in a way that was different from their familiar sequence (Mihailidis et al., 2000).

Mihailidis et al. (2001) therefore used artificial intelligence to develop a new cognitive orthotic. The COACH (Cognitive Orthosis for Assisting aCtivities in the Home) was a prototype of an adaptable device to help people with dementia complete handwashing with less dependence on a caregiver. The device used artificial neural networks, plan recognition, and a single video camera connected to a computer to automatically monitor progress and provide pre-recorded verbal prompts. It was able to automatically adapt its cueing strategies according to a user's preferences and past performance of the ADL, and play multiple levels of cue detail (Mihailidis, Fernie, & Barbenel, 2001). Results from clinical trials conducted using this new device can be found in the paper by Mihailidis, Barbenel, and Fernie in this issue.

Mynatt, Essa, and Rogers (2000) are developing an instrumented environment in which an entire house will function as a cognitive orthotic. The system will have information about the user's activities through a daily schedule (e.g., a medicine regimen) and sensors (e.g., detecting that the stove is on to infer that the person is cooking). Sensors will be used to detect disruptions in a task. Auditory and visual cues will be used to both remind the person to perform a task and cue the person about the next step in a multi-step task. These sensors will be used not only to determine when the resident might need reminders or cues from a cognitive orthotic, but also when the person may need emergency assistance from a caregiver or medical professional (Mynatt et al., 2000).

Bonasso (1996) has investigated a system which would receive information from sensors in an elderly user's home and also monitor the user's vital signs. It would then incorporate this sensed information with knowledge of the user's goals and of tasks which are needed to achieve those goals. These tasks would be considered in a step-by-step fashion, with the system either prompting the user to perform tasks or assisting the user in needed tasks (Bonasso, 1996). Other researchers are developing a mobile robot assistant to monitor the needs of elderly users. The robot possesses information about the user's daily activities, monitors performance, and provides reminders when needed (Ramakrishnan & Pollack, 2000).

Sensor-based cognitive orthoses are also being developed for the mainstream population. Beigl (2000) has developed the MemoClip, a device that communicates with LocationBeacons at places of interest in the environment in order to determine the user's location. MemoClip provides an audible cue and a text message on a 4×5 cm display (Beigl, 2000). DeVaul (2000) has developed Memory Glasses that detect objects, locations, or people by sensing transmitters or "tags" in the environment. The Memory Glasses associate each tag with an image and/or a text description, and display this information on the glasses in a small part of the visual field. The developers plan to investigate the efficacy of this system as a memory aid for both people with normal cognitive function and people with memory impairments (DeVaul, 2000).

In addition to supporting prospective memory aids, a device which can determine a person's location, such as those developed by Friedman (1993) and Beigl (2000), could provide navigation support, providing directions to guide someone through a building. Location sensors can also help in providing care for people who are prone to wandering. Sensors can detect when someone is leaving a building or other defined area, and alert caregivers, and can assist in tracking someone who has wandered and may have become lost.

TECHNOLOGY FOR INFORMATION PROCESSING IMPAIRMENTS

Compensation technologies for sensory processing

Cognitive disabilities often result in an inability of the brain to properly process and integrate sensory information (Kielhofner, 1997). This can lead to deficits in a number of skill areas, including:

- Visual–spatial processing.
- Auditory processing.
- Sensory–motor processing.
- Language processing.
- Understanding of social cues.

Populations affected include people with learning disabilities, traumatic brain injuries, and autism spectrum disorders. By allowing information to be presented in different ways, computers can provide people with the flexibility to utilise their strengths and accommodate information-processing deficits. For example, computers can translate information between printed text and audible speech, or between audible alerts and tactile (e.g., vibrating) alarms. Adjustments to the interface between human and computer, made with attention to a particular client's needs and strengths, can greatly improve a client's performance on desired tasks (Gregor & Newell, 2000).

One area that has received considerable attention is the understanding and production of written text by people with dyslexia. Dyslexia has been defined by the World Federation of Neurology as "a disorder manifested by difficulty in learning to read despite conventional instruction, adequate intelligence, and sociocultural opportunity". It is marked by a number of possible characteristics:

1. Difficulties with visual recognition of letters, numbers, punctuation, and entire words; especially, confusion of characters or words with similar shapes (Willows & Terepocki, 1993).
2. Letter reversal (for example, interpreting a "b" as a "d"; Willows & Terepocki, 1993).
3. Poor visual memory, leading to problems with letter and word recollection (Arkell, 1997).

4. Spelling problems, often reflecting a phonic strategy with words like "of" and "all" being spelled "ov" and "olh" (Willows & Terepocki, 1993).
5. Fixation problems (Meares-Irlen Syndrome) resulting in an inability to scan text without losing one's place (Wilkins & Lewis, 1999).
6. Tendency to add duplicate or extra words, omit words, or reverse word order (Willows & Terepocki, 1993).
7. Difficulty viewing patterns of stripes, such as those produced by black text on a white background; such patterns can cause headaches or perceptions that the lines are moving or bending (Wilkins, 1995).

These problems lead to poor comprehension, since the text which is perceived may be significantly different from the actual text. They also lead to difficulties in producing original text or copying text (Gregor & Newell, 2000; Willows, Kruk, & Corcos, 1993). These difficulties are further exacerbated by motor control difficulties for some people with dyslexia, who may have hand–eye co-ordination difficulties which impede handwriting, and ocular motor control difficulties which impede smooth eye movements between lines of text (Everatt, Bradshaw, & Hibbard, 1999).

In compensating for dyslexia and related disorders, computers offer many advantages over traditional media. The computer allows variation of the appearance of text. Once text is committed to paper and ink, its appearance is permanent. Computers offer options such as changing text size and contrast (Keates, 2000). Computers also allow a user to change the colour of the text and/or the background, similar to the practice of placing coloured screens over text to increase readability (Wilkins & Lewis, 1999).

In addition to changing the appearance of printed text, computers can augment visible text using speech, so that a person with good verbal skills and aural information processing can acquire the information without the need to process printed text (Higgins & Raskind, 1997; Raskind & Higgins, 1995). Speech synthesis software can provide speech output to match text on the computer screen in a word processor or on the computer desktop. Text from books or worksheets can be scanned into the computer and read using optical character recognition software and many books are now available directly in electronic formats. In addition to using speech output as an alternative to text, it is possible to use auditory feedback while viewing the printed text. This software can therefore act as a reading assistant; the person reads most of the text, but has the computer speak unrecognisable words.

Espin and Sindelar (1988) studied the value of auditory feedback for people with learning disabilities. Ninety students took part in the study, including one group with learning disabilities, a control group matched for reading level, and a second control group matched for age. Within each group, half the subjects simply read a text passage and half the subjects listened to a recording of the passage while also having access to the printed text. Subjects were asked to identify and correct errors of grammar and syntax. For all subject groups, subjects listening to the text identified more errors than those who simply read the text (Espin & Sinclair, 1988).

More recent studies have investigated the effects of auditory feedback using speech synthesis while reading on the computer (Borgh & Dickson, 1992; Swanson & Trahan, 1992; Leong, 1995; Lundberg, 1995). In one study, subjects without learning disabilities did more editing when writing original stories on a word processor with speech synthesis compared to the word processor without speech synthesis, and preferred writing using the speech synthesis (Borgh & Dickson, 1992). In another series of studies, subjects with learning disabilities exhibited better reading and spelling performance following training with computer-generated speech feedback (Lundberg, 1995). Other studies have shown more mixed results for subjects with and without learning disabilities, with individual differences between subjects exceeding any clear effect of auditory feedback (Leong, 1995; Swanson & Trahan, 1992). These studies indicated that the value of speech synthesis depends on characteristics of the subject and of the learning goals (Leong, 1995).

MacArthur (1998) studied the use of speech synthesis and word prediction for students with learning disabilities. Five students with learning disabilities wrote in dialogue journals using a standard word processor during baseline phases and a word processor with speech synthesis and word prediction features during treatment phases. For four of five students, percentage of legible words increased from 55% to 85% during the baseline phase to 90–100% during the treatment phase, and the percentage of correctly spelled words increased from 42% to 75% to 90 to 100% (MacArthur, 1998).

Raskind, Higgins, and colleagues have conducted a number of studies on the efficacy of assistive technologies for people with learning disabilities (Higgins & Raskind, 1995, 1997; Raskind & Higgins, 1995). In one study, 33 post-secondary students with learning disabilities proofread self-generated written language samples under three conditions: (1) using a speech synthesis program that simultaneously highlighted words on a monitor and audibly “spoke” them; (2) having text read aloud by another person; and (3) receiving no assistance. Subjects detected a significantly higher percentage of errors when using speech synthesis compared to either of the other conditions. In particular, subjects detected a significantly higher percentage of capitalisation, spelling, usage, and typographical errors with speech synthesis. Subjects may have detected more errors with computer assistance than with human assistance because a person reading the text aloud may subconsciously correct errors when reading aloud; the novelty of the computer may have increased motivation in that condition; and the visual highlighting may have provided an additional benefit unavailable with the human assistant (Raskind & Higgins, 1995).

Thirty-seven post-secondary students with learning disabilities were given reading comprehension exams under three conditions: (1) using an optical character recognition/speech synthesis system; (2) having text read aloud by a human reader; and (3) reading silently without assistance. There was a significant inverse correlation between comprehension scores in silent reading and speech synthesis conditions. Subjects who had the lowest scores without assistance achieved a greater improvement with speech synthesis, but those with high scores without assistance received lower scores when using speech synthesis (Higgins & Raskind, 1997).

Computers also offer alternatives for text production. Some people have difficulty with handwriting due to motor co-ordination difficulties, or have more difficulty comprehending handwritten text compared to printed text. A keyboard can provide assistance for these individuals, since typing may be easier than handwriting. Typing is also helpful because all letters are visible on the keyboard, compensating for letter recollection difficulties. The position of the characters on the keyboard can also be used to aid recognition; if the person can remember the position of the letter he or she wants on the keyboard, he or she does not need to recall the letter's shape (Gregor & Newell, 2000).

For individuals who have difficulty typing as well as writing, speech recognition is an option for text entry in the computer. People who have good verbal skills can compose material directly through speech, and the computer will take on the task of translating the words into printed text. In one study of voice recognition, 29 post-secondary students with learning disabilities wrote essays under three conditions: (1) using speech recognition software; (2) using a human transcriber; and (3) receiving no assistance. Essays were scored according to a standardised scoring guide. Subjects received higher scores when using speech recognition than when receiving no assistance ($p < .05$). Essays written using speech recognition were longer and had a higher proportion of words with seven or more letters (Higgins & Raskind, 1995).

Whether a person is entering text through typing or speech, computer word processors have other features such as spell checkers and grammar checkers which can help compensate for spelling difficulties or a tendency to reverse word order. Word prediction software is also available, which will predict the word which a person is typing based on the letters typed thus far, or on the basis of preceding words. These features have been shown to be beneficial for people with dyslexia (Newell & Booth, 1991; Newell, Booth, Arnott, & Beattie, 1992). However, they have drawbacks. First, the unique spelling and grammar errors which are often produced by people with disabilities can confound automated spelling and grammar checkers, so that they are unable to offer appropriate assistance. Also, spelling and grammar checkers and word prediction software generally function by providing the user with a list of word to choose from (e.g., a list of possible "correct spellings" or a list of predicted words). If the user has difficulty with letter or word recognition, he or she may be unable to select the appropriate word from a list (Gregor & Newell, 2000). To alleviate this problem, students need strategies to use spell checkers effectively (Gillette, 2001), or additional tools such as talking spell checkers.

To expand upon available technologies, Gregor and Newell (2000) developed a highly configurable word processing environment, SeeWord, to assist people with dyslexia in reading and composing text. SeeWord was developed within the context of the University of Dundee's overall research programme on human–computer interaction for extraordinary users and users in extraordinary situations (Gregor, Alm, Arnott, & Newell, 1999). This software provides a variety of options related to the visual appearance of the text and of the software interface, and the means for each user to customize these settings to his or her particular preferences. Users could adjust the text font and size; spacing between characters, words, and paragraphs; and the foreground and background colours. Twelve computer-literate individuals with dyslexia evaluated the software, provided feedback during the development process, and were observed using the software after being asked to think aloud about their decisions and impressions. Subjects' preferred selections were highly individualised. They tended to prefer larger font and increased spacing between characters, words, and lines compared to typical word processor settings (Gregor & Newell, 2000). Although subjects varied in regard to their favourite colour combination, most subjects liked low contrast colour combination, such as brown text on a dark green background (Gregor & Newell, 2000), a colour combination which would be highly unusual in software for the mainstream population. These findings highlight the importance of attempting a variety of solutions and eliciting client input.

These features were implemented in a modified word processor which allows a person to set the appearance of text on the screen separately from the appearance of text produced on the printer, so that the person can compose text with his or her preferred visibility settings but print text in a standard format to share with others (Gregor & Newell, 2000). This version of the software included three additional features:

1. Users could specify a pair of characters which they have difficulty distinguishing, and have the computer increase the distinctiveness of the two characters by presenting one in a different colour, font, or size.
2. Users could reduce the width of a page to assist with fixation.
3. Users could request that selected text be read aloud.

This software was evaluated by seven people with dyslexia. Each of the users found the system easy and intuitive to use, and reported that each of the options had an effect on her or his ability to read. The option to distinguish pairs of characters (option 1 above) was reported to have a negative effect on readability by one evaluator and a positive effect by the remaining six evaluators. The reported reason for this improvement was not assistance in distinguishing characters, as intended. Rather, the occasional appearance of a character with different font, size, or colour helped in fixation by reducing the monotonous appearance of the text (Gregor & Newell, 2000).

This SeeWord software was further evaluated in a study with six students with dyslexia (Dickinson, Gregor, & Newell, 2002). Each subject was given the opportunity to select word processor settings within SeeWord. Two days later the subject was presented with a series of texts displayed with either the subject's selected settings or default word processor settings. Five out of six subjects made fewer errors when reading with their preferred settings and the mean number of errors across texts was significantly lower for the condition in which subject-selected settings were used (Dickinson et al., 2002). Following this pilot study, SeeWord was modified to allow the user to alter line spacing and more easily modify settings, and to improve users' ability to focus on a desired section of text (Dickinson et al., 2002).

In addition to difficulties with visual processing and motor co-ordination, individuals with learning disabilities often have difficulty organising their thoughts for written compositions (Newcomer & Barenbaum, 1991). Computer software can aid in this organizational process by helping the user create concept maps. Concept mapping is the process of categorizing information into a graphic form, known as a "concept map" or "semantic network". This visual representation of information can then be used to organise concepts and provide a basis for the structure of written text. Concept mapping has been shown to support more organised and detailed written texts (Ruddell & Boyle, 1989; Zipprich, 1995). Software such as Inspiration (Inspiration Software Inc, Portland, OR) provides a means to easily create and edit concept maps.

In a study of 12 eighth-grade students with learning disabilities, subjects were observed to write compositions with greater length (number of words) and quality (holistic writing scores) when using either hand-drawn or computer-supported concept maps compared to writing without maps (Sturm & Rankin-Erikson, 2002). Carry-over effects were also observed which indicate that training in concept mapping strategies improved subjects' writing performance in the no-mapping condition. Results showed that subjects' attitude toward writing was significantly more positive in the computer-supported mapping condition compared to hand-drawn mapping and no mapping (Sturm & Rankin-Erikson, 2002).

Technologies for social and behavioural issues

Sensory processing impairments can also lead to social and behavioural difficulties. If an individual is easily overwhelmed by environmental stimuli, he or she may have difficulties with concentration and social engagement (Strickland et al., 1996). Difficulties in processing visual information about faces, or auditory information about a person's tone of voice can also impair a person's ability to recognise social cues. For example, pilot data indicate that adults with autism spend much less time looking at a person's eyes compared to adults without autism (Trepagnier, 1996; Trepagnier, Gupta, Sebrechts, & Rosen, 2000). Some technological interventions have been developed to address these behavioural and social problems.

One application of such ATC is to modify speech so that individuals can more easily comprehend speech and its auditory cues. Some language learning-impaired individuals need longer neural processing times in order to process speech, making it difficult to distinguish speech sounds that have durations in the range of 10–50 ms. People may, for example, have difficulty distinguishing the speech syllables /ba/ and /da/ due to rapid frequency transitions in the initial syllables (Nagarajan et al., 1998; Tallal, Miller, & Fitch, 1993). Nagarajan and colleagues have developed software which alters the characteristics of a speech sample in a two-step process. First, the speech is prolonged, allowing more time for auditory processing. Second, sounds that are marked by high frequency or rapid transitions are made louder, so that they will be easier to comprehend (Nagarajan et al., 1998). This process has been incorporated into training software which aims to foster a reorganisation of the neural structures responsible for processing rapid speech sounds (Habib, Espresser, Rey, Giraud, Braus, & Gres, 1999; Merzenich et al., 1996; Tallal et al., 1996; Turner & Pearson, 1999;). A real-time version of this software could compensate for auditory processing difficulties and help an individual better understand a conversational partner's speech.

Technology is also being applied to allow people with dementia to communicate by augmenting their short-term memory capabilities. A multidisciplinary team of designers, software engineers, and psychologists has developed an approach to helping older people with dementia to communicate, by using an easily accessible multimedia reminiscence aid. With the age profile of most societies shifting towards a larger and larger proportion of older people, the challenges presented by dementia will increase. A significant problem with this condition is the exclusion from everyday interaction it can cause due to the person's inability to communicate effectively because of the loss of short-term memory. To address this problem a conversation support system is being developed based on touch screen access to multimedia material. The system is designed in such a way as to help users to be able to use it easily, and to be able again to enjoy holding conversations with relatives, friends, and carers. The conversations are based on reminiscence about the past, since long-term memories can remain relatively intact with dementia, even where short-term memory is ineffective (Astell et al., 2002).

A first prototype has been tested in the field with people with dementia and their carers. Both care staff and people with dementia responded positively to the system and report enjoyment in using it. People with dementia were able to use the touch screen and the multimedia presentation successfully acted as a prompt for satisfying conversation. Staff reported finding out more new information and getting to know the people with dementia better. Given the disempowerment which communication impairment can cause, an important early finding is that using this system, as compared to traditional methods of supporting reminiscence sessions, gave the people with dementia more control over the interaction (Alm et al., 2004 this issue).

Human and animal studies indicate that deep pressure is calming and reduces arousal in the nervous system (Ayers, 1979; King, 1989; Kumazawa, 1963). This research has inspired the development of tactile interventions to compensate for difficulty independently managing sensory input. Grandin developed a "squeeze machine" that provides deep pressure automatically (Grandin, 1992, 1995). Unlike other forms of deep pressure stimulation, such as rolling in mats, the squeeze machine can apply greater amounts of pressure over larger areas of the body. Also, the user has complete control over the amount of pressure applied and can enter and leave the machine at will (Grandin, 1995). Some research has shown that deep pressure administered by the squeeze machine has a relaxing effect on normal adults and may have an effect on auditory threshold (Grandin, 1992).

Beneficial effects of the squeeze machine have been described anecdotally for children with autistic disorder, attention-deficit hyperactivity disorder, learning disabilities, pervasive developmental disorder (PDD) and Tourette's syndrome. However, there is a lack of formal research data pertaining to the clinical treatment of children (Grandin, 1992). One study (Imamura et al., 1990) examined behavioural effects of the squeeze machine on nine children, aged 3–7 years, with autistic disorder or PDD. Hyperactivity was found to be reduced in four subjects, and the machine had no effect on five children. There appeared to be a relationship between longer duration of squeeze machine usage and beneficial effects (Imamura et al., 1990).

Vibration also appears to have a calming effect on individuals with sensory processing impairments, and non-contingent vibration has been found to reduce stereotypical behaviour (Grandin, 1992). One case study explored the use of automatic vibration in a seating system for an individual with developmental disability. Initially, the subject showed a reduction in stereotypical behaviours, including self-injuring behaviours. However, these behaviours increased over time, indicating that the subject acclimated to the vibration (Kelm & Pawley, 1998).

CONCLUSION

Over the past 20 years, technology has played an increasing role in the rehabilitation of persons with cognitive impairments. The literature reviewed in this paper represents a body of research which demonstrates that technological interventions can effectively facilitate participation in many activities that would otherwise not be possible. Technological interventions have been developed to assist with tasks requiring cognitive skills as diverse as complex attention, prospective memory, self-monitoring for the performance of specific desirable behaviours, inhibition of undesirable behaviours, sequential processing, and understanding of social cues. These assistive technologies can facilitate improved functioning in a number of ways. One approach has been to provide cues, reminders and sequential guidance when task completion would otherwise not be possible—in effect, serving as a "supervisory attendant" or "aide" for the person. A related approach has been to develop interventions that restructure task demands so that residual abilities can be used in place of those that are most impaired. More recently, researchers have been exploring the applications of artificial intelligence, virtual reality, and other advanced technologies to ATC systems, so that a broader range of complex tasks can be addressed and the likelihood of generalisation enhanced.

Although it can be argued that ATC interventions are still not commonplace in clinical practice, their efficacy and broad applicability clearly confirms their general importance in cognitive rehabilitation. In fact, for some types of clinical conditions, such as traumatic brain injury, technological aides such as personal digital assistants (PDA) are now viewed, at very least, as necessary therapeutic considerations, supplementing and sometimes supplanting the use of non-technological interventions such as "memory books."

Our perspective is that interventions based on ATC will continue to grow in importance as technological developments increase their ease of use, portability, and intelligence. However, this field has now grown beyond its infancy and the research approaches adopted over the past 20 years must be broadened. In the paragraphs that follow, we will briefly discuss areas that we believe constitute an ambitious, but necessary, research agenda.

First, very little is known about the relationship between, on one hand, the clinical characteristics of persons with cognitive impairments and, on the other, the specific characteristics of ATC interventions that are most suitable for those individuals. This area, sometimes referred to as "matching persons and technology" (Scherer, 2002), has received most attention for physical disabilities. The complexities of "matching persons and technology" for those with cognitive impairments is only beginning to be recognised.

Clinical experience suggests that there are many factors that influence the appropriate choice of technological cognitive interventions (and their ultimate acceptance by the user), in addition to technological considerations themselves. These factors include (but are not limited to):

1. A person's specific pattern of cognitive strengths and weaknesses (which may determine the intensity of intervention required, the person's ability to learn, or the specific cognitive skills that are to be "capitalised on" in order to promote compensation).
2. Unique issues associated with the natural history of the disorder responsible for the person's acquired cognitive profile (which may determine, for example, whether or not modifications to the intervention will be required over time or whether other considerations, such as sensory-motor adaptations will be required).
3. Specific emotional and behavioural changes associated with the disorder (which may influence motivation or the ability to sustain effort over time, despite persisting motivation).
4. The person's pre-morbid and current personality characteristics and "attitudes", (which may affect the degree to which unobtrusive or "transparent" interventions are required that do not appear to the user to be technological in nature).
5. The person's attitudes in regard to interventions that appear to exert "external control" (which will determine the degree to which participatory consultation with the user will be advantageous).
6. The person's pre-morbid and current system of psychosocial support (which will determine whether caretakers can be relied upon to rehearse and reinforce the use of the ATC intervention in the home and community).

A person's status in any one of the above areas can result in a prescribed device being used ineffectively or even abandoned, even if the intervention itself can be shown to be highly effective in a controlled setting. In order to avoid this type of disappointing outcome, our recommendation is that ATC interventions be developed and prescribed within the context of a conceptual framework that accounts for all of these "systems". Our perspective is that these types of questions must be addressed by multi-disciplinary research teams that include a broad range of rehabilitation disciplines and that represent an understanding of the technological, cognitive, emotional, behavioural, family and social factors that can influence the use of prescribed devices.

It is also crucial that clients themselves be participants in this process. Over the past several years, the National Institute of Disability and Rehabilitation Research has emphasised the importance of participatory action research (PAR) as a critical strategy for assuring that consumer input and review will be incorporated into the design and testing of new interventions. Our recommendation is that the intended consumers for new ATC interventions be incorporated into every phase of research. As an example of this approach, Cole (1999) has described a strong commitment to consumer participation during the design, feedback and implementation stages of device development. Wilson (2000) has suggested that strong consumer involvement enhances acceptance of the device and, hopefully, promotes continuing use over time. White (2002) has suggested that implementation of PAR models may actually be an ethical issue requiring consideration by all researchers.

However, it must also be noted that ATC interventions are often developed for individuals whose cognitive impairments may limit the degree to which they can contribute to any stage of device design or testing. Research teams must therefore assess the cognitive abilities of the intended consumers so that an *appropriate level of participation can be devised*, including the involvement of caretakers who may be responsible for assuring that use of the ATC intervention is maintained over time.

Second, as ATC interventions begin to incorporate changes in technological infrastructure, such as wireless wide area networks, it is inevitable that ATC interventions will be increasingly used in the community. In this regard, the issue of “context generalisability” or, to borrow a phrase loosely, the “ecological validity” of ATC interventions will have to be established, since it is still unclear whether being able to perform a task in a controlled environment will generalise to performing the identical task in a community environment. To use a very simple example, checking a personal digital assistant (PDA) to determine one’s next therapy appointment may be a far different task than checking the same PDA to assure that one leaves the mall in order to return to home on time to eat supper. Our recommendation is that the generalisability of ATC devices across functional contexts cannot be assumed. As the portability of ATC devices increases, it will become increasingly important for research programmes to identify the factors that promote or hinder the effective use of ATC systems across the range of community settings in which they will be used and, most critically, to develop research programmes that actually test new interventions within those community settings.

Third, recent developments in physical neurorehabilitation suggest the very tentative hypothesis that ATC may offer a fruitful approach for attempting the “restoration” of neurocognitive functioning. For physical impairment, recent evidence suggests that sensory and motor functioning may be enhanced by “forcing” an affected limb to engage in functional activities using constraint induced therapy (CIT) or patterned neural activation (PNA) (McDonald et al., 2002; Morris & Taub, 2001). One of the critical features of this type of intervention appears to be that the affected limb is repeatedly engaged in functional activities during the course of everyday life. In regard to cognition, it is as yet unclear if there are interventions that will also qualify as PNA. However, the most likely candidates for analogous interventions would appear to be those that promote repeated, systematic and controlled performance of functional activities that require the intensive use of the cognitive skill being targeted. Potential therapeutic activities must be chosen to assure that they actually do promote activation of partially damaged neurological areas, or that they promote the activation of other neurological areas that are presumed to communicate with the damaged areas. Similarly, any functional activity chosen for this type of intervention will require that a clinically appropriate balance be achieved between demanding of the person too much of the impaired skill (making performance of the task simply impossible) or too little (making performance of the task, in effect, another compensatory intervention).

Clearly, there are many ways in which repeated, systematic and controlled performance of functional activities can be achieved. However, technological interventions seem particularly promising in this regard, because they can be used to guide a person through the stages of a functional task, in a manner analogous to the use of functional electrical stimulation for co-ordinating groups of muscles (McDonald et al., 2002). ATC interventions can be used for repeated and controlled rehearsal of activities, otherwise requiring skills that are impaired, with systematic variation of task parameters so that the level of challenge is carefully controlled. To our knowledge, this type of intervention has not yet been reported, but the implications are exciting and suggest a promising new line of research for ATC.

In conclusion, the literature reviewed in this paper establishes a 20-year history of increasingly successful technological interventions for cognition. Our perspective is that this literature serves as a strong foundation for continuing development of more sophisticated interventions that will, over time, parallel and incorporate broader technological and infrastructure changes. The “coming of age” of clinical intervention and research in this area requires that a broader perspective be adopted in regard to the development and assessment of ATC interventions. There are also many new opportunities in this area that suggest a central role for ATC in clinical and research programmes.

REFERENCES

Allen, D. N., Goldstein, G., Heyman, R. A., & Rondinelli, T. (1998). Teaching memory strategies to persons with multiple sclerosis. *Journal of Rehabilitation Research and Development*, *35*(4), 405–410.

Alm, N., Ellis, M., Astell, A., Dye, R., Gowans, G., & Campbell, J. (2004). A cognitive prosthesis and communication support for people with dementia. *Neuropsychological Rehabilitation*, *14*(1/2), 117–134.

Arkell, H. (1997). *An introduction to dyslexia: A dyslexic’s eye view*. Surrey, UK: Helen Arkell Dyslexia Centre.

Astell, A. J., Ellis, M., Alm, N., Dye, R, Gowans, G., & Campbell, J. (2002). Developing computer technology to assist communication for people with dementia: The CIRCA project. *Neurobiology of Aging*, *23* (1S), S543.

Ayers, J. A. (1979). *Sensory integration and the child*. Los Angeles: Western Psychology Service.

Bai, J., Zhang, Y., Cui, Z., & Zhang, J. (2000). Home telemonitoring framework based on integrated functional modules. *World Congress on Medical Physics and Biomedical Engineering*. Chicago, Illinois.

Beigl, M. (2000). Memoclip: A location based remembrance appliance. *Personal Technologies*, *4*(4), 230–234.

Bergman, M. (1996). Computer orthoses: Fostering self-sufficiency in people with cognitive challenges. *Disability Today*, *Fall*, 54–55.

Bergman, M. M. (1997). People with cognitive challenges can enjoy rapid success in acquiring skills and managing their lives: The exciting breakthrough of Cognitive Orthoses. *California State University, Northridge, Technology and Persons with Disabilities Conference (CSUN)*. Los Angeles, CA.

Bergman, M. M. (1998). A proposed resolution of the remediation-compensation controversy in brain injury rehabilitation. *Cognitive Technology*, *3*(1), 45–51.

Bergman, M. M. (2002). The benefits of a cognitive orthotic in brain injury rehabilitation. *Journal of Head Trauma Rehabilitation*, *17*(5), 432–445.

Beukelman, D., & Mirenda, P. (1998). *Augmentative and alternative communication: management of severe communication disorders in children and adults*. Baltimore, MD: Paul H. Brookes Publishing Co.

Bonasso, R. P. (1996). Using adjustable autonomy to extend the independence of the elderly. *Developing Assistive Technology for People with Disabilities, AAAI, Fall Symposium*.

Borgh, K., & Dickson, W. P. (1992). The effects on children's writing of adding speech synthesis to a word processor. *Journal of Research on Computing in Education*, *24*(4), 533–544.

Carmien, S. (2002). MAPS: PDA scaffolding for independence for persons with cognitive impairments. *2002 Human Computer Interaction Consortium*.

Cavalier, A. R., & Ferretti, R. P. (1993). The use of an intelligent cognitive aid to facilitate the self-management of vocational skills by high school students with severe learning disabilities. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 216–218). Arlington, VA: RESNA Press.

Chute, D. L., & Bliss, M. E. (1988). Prosthesis ware: Personal computer support for independent living (Vol. 2000). Retrieved December 16, 2002, from http://www.homemods.org/library/life-span/prosthesis.html

Chute, D. L., & Bliss, M. E. (1994). ProthesisWare. *Experimental Aging Research*, *20*, 229–238.

Chute, D., Conn, G., DiPasquale, M., & Hoag, M. (1988). Prosthesis ware: A new class of software supporting the activities of daily living. *Neuropsychology*, *2*(1), 41–57.

Cicerone, K. D., Dahlberg, C., Kalmar, K., Langenbahn, D. M., Malec, J.F., Bergquist, T. F., Felicetti, T. Giacino, J. T., Harley, J. P., Harrington, D. E., Herzog, J., Kneipp, S., Laatsch, L., & Morse, P. A. (2000). Evidence-based cognitive rehabilitation: Recommendations for clinical practice. *Archives of Physical Medicine & Rehabilitation*, *81*(12), 1596–1615.

Cole, E. (1999). Cognitive prosthetics: An overview to a method of treatment. *NeuroRehabilitation*, *12*, 39–51.

Cole, E., & Dehdashti, P. (1988). Increasing personal productivity of adults with brain injury through interface design [Abstract]. *SIGCHI Bulletin*, October.

Cole, E., & Dehdashti, P. (1990). Interface design as a prosthesis for an individual with a brain injury. *SIGCHI Bulletin*, *22*(1), 28–32.

Cole, E., & Dehdashti, P. (1998). Computer-based cognitive prosthetics: Assistive technology for treatment of cognitive disabilities. *Proceedings of the Third International ACM Conference on Assistive Technologies*. Los Angeles: ACM Press.

Cole, E., Dehdashti, P., Petti, L., & Angert, M. (1993). Design parameters and outcomes for cognitive prosthetic software with brain injury patients. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 426–428). Arlington, VA: RESNA Press.

Cole, E., Dehdashti, P., Petti, L., & Angert, M. (1994). Design and outcomes of computer-based cognitive prosthetics for brain injury: A field study of three subjects. *NeuroRehabilitation*, *4*(3), 174–186.

Cole, E., Petti, L., Matthews, M., & Dehdashti, P. (1994). Rapid functional improvement and generalization in a young stroke patient following computer-based cognitive prosthetic intervention. *NIH Neural Prosthesis Workshop*.

Cole, E., Ziegmann, M., Wu, Y., Yonker, V., Gustafson, C., & Cirwithen, S. (2000). Use of "therapist-friendly" tools in cognitive assistive technology and telerehabilitation. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 31–33). Arlington, VA: RESNA Press.

DeVaul, R.W. (2000). The Memory Glasses Project. http://www.media.mit.edu/wearables/mithril/memory-glasses.html. *MIT Media Lab*. Viewed December 16, 2002; last updated March 2, 2002.

Dickinson, A., Gregor, P., & Newell, A.F. (2002). Ongoing investigation of the ways in which some of the problems encountered by some dyslexics may be alleviated using computer techniques. *Proceedings of Assets 2002: The Fifth International ACM Conference on Assistive Technologies, Edinburgh, Scotland* (pp. 97–103). New York: ACM Press.

Ellis, J. (1996). Prospective memory or the realization of delayed intentions: A conceptual framework for research. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 1–22). Mahway, NJ: Lawrence Erlbaum Associates, Inc.

Espin, C.A., & Sindelar, P.T. (1988). Auditory feedback and writing: Learning disabled and nondisabled students. *Exceptional Children*, *55*(1), 45–51.

Evans, J. J., Emslie, H., & Wilson, B. A. (1998). External cueing systems in the rehabilitation of executive impairments of action. *Journal of the International Neuropsychological Society*. *4*(4), 399–408.

Everatt, J., Bradshaw, M. F., & Hibbard, P. (1999). Visual processing and dyslexia. *Perception*, *28*(2), 243–254.

Fagerberg, G. (1999). TASC: Telematics applications supporting cognition. In European Commission Directorate-General, *Telematics for the integration of the disabled and elderly* (pp. 102–103). Luxembourg: Office for Official Publications of the European Communities.

Fernie, G., & Fernie, B. (1996). The potential role of technology to provide help at home for persons with Alzheimer's disease. *The 18th Annual Conference of the Alzheimer's Society of Canada*, Ottawa, ON.

Flannery, M., & Rice, D. (1997). Using available technology for reminding. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 517–519). Arlington, VA: RESNA Press.

Friedman, M. (1993). A wearable computer that gives context-sensitive verbal guidance to people with memory or attention impairments. *Proceedings of the Rehabilitation Society of North America (RESNA)* (pp. 199–201). Arlington, VA: RESNA Press.

Friedman, M., Kostraba, J., Henry, K., & Coltellaro, J. (1991). Hardware description of a portable electronic device. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 333–334). Arlington, VA: RESNA Press.

Gillette, Y. (2001). Pictures to print: A software scaffold to written literacy. *Journal of Head Trauma Rehabilitation*, *16*(5), 484–497.

Grandin, T. (1992). Calming effects of deep touch pressure in patients with autistic disorder, college students and animals. *Journal of Child and Adolescent Psychopharmacology*, *2*(1), 63–70.

Grandin, T. (1995). *Thinking in pictures*. New York: Doubleday.

Gregor, P., Alm, N., Arnott, J., & Newell, A. F. (1999). The application of computing technology to interpersonal communication at the University of Dundee's department of applied computing. *Technology and Disability*, *10*, 107–113.

Gregor, P., & Newell, A. F. (2000). An empirical investigation of ways in which some of the problems encountered by some dyslexics may be alleviated using computer techniques. *Proceedings of Assets 2000: The Fourth International ACM Conference on Assistive Technologies, Washington, DC* (pp. 85–91). New York: ACM Press.

Habib, M., Espresser, R., Rey, V., Giraud, K., Braus, P., & Gres, C. (1999). Training dyslexics with acoustically modified speech: Evidence of improved phonological performance. *Brain and Cognition*, *40*(1), 143–146.

Harris, J. (1978). External memory aids. In M. Gruneberg, P. Morris, & R. Sykes (Eds.), *Practical aspects of memory*. London: Academic Press.

Hart, T., Hawkey, K, & Whyte, J. (2002). Use of a portable voice organizer to remember therapy goals in traumatic brain injury rehabilitation: A within-subjects trial. *Journal of Head Trauma Rehabilitation*, *17*(6), 556–570.

Herrmann, D., Brubaker, B., Yoder, C., Sheets, V., & Tio, A. (1999). Devices that remind. In F. T. Durso, R. S. Nickerson, R. W. Schvaneveldt, S. T. Dumais, D. S. Lindsay, & M. T. H. Chi (Eds.), *Handbook of applied cognition* (pp. 377–408). Chichester, UK: John Wiley and Sons.

Hersch, N. A., & Treadgold, L. G. (1994). NeuroPage: The rehabilitation of memory dysfunction by prosthetic memory and cueing. *NeuroRehabilitation, 4*(3), 187–197.

Higgins, E. L., & Raskind, M. H. (1995). Compensatory effectiveness of speech recognition on the written composition performance of postsecondary students with learning disabilities. *Learning Disability Quarterly*, *18*(Spring), 159–174.

Higgins, E. L., & Raskind, M. H. (1997). The compensatory effectiveness of optical character recognition/speech synthesis on reading comprehension of postsecondary students with learning disabilities. *Learning Disabilities*, *8*(2), 75–87.

Imamura, K. N., Wiess, T., & Parham, D. (1990). The effects of hug machine usage on behavioral organization of children with autism and autistic-like characteristics. *Sensory Integration Quarterly, 27*, 1–5.

Inglis, E., Szymkowiak, A., Gregor, P., Newell, A. F., Hine, N., Wilson, N. A., & Evans, J. (2002). Issues surrounding the user-centred development of a new interactive memory aid, In S. Keates, P. Langdon, P. J. Clarkson, & P. Robinson (Eds.), *Universal access and assistive technology* (pp.171–178). Proceedings of the Cambridge Workshop on UA and AT '02 2002.

Jinks, A., & Robson-Brandi, C. (1997). Designing an interactive prosthetic memory system. *Proceedings or the Rehabilitation Engineering Society of North America (RESNA)* (pp. 526–528). Arlington, VA: RESNA Press.

Jones, M., & Adams, J. (1979). Toward a prosthetic memory. *Bulletin of the British Psychological Society*, *32*, 165–167.

Jonsson, B., & Svensk, A. (1995). ISAAC—A personal digital assistant for the differently abled. *Proceedings of the 2nd TIDE Congress* (pp. 356–361). Paris, France.

Keates, A. (2000). *Dyslexia and information and communications technology: A guide for teachers and parents*. London: David Fulton Publishers.

Keates, S., Clarkson, J., & Robinson, P. (2000). Investigating the applicability of user models for motion-impaired users. *Proceedings of Assets 2000: The Fourth International ACM*

Conference on Assistive Technologies, Washington, DC (pp. 129–136). New York: ACM Press.

Kelm, K. & Pawley, R. (1998). Good vibrations. *TeamRehab Report*, *9*(9), 37–40.

Kielhofner, G. (1997). The sensory integration model. In G. Kielhofner (Ed.), *Conceptual foundations of occupational therapy* (pp. 251–269). Philadelphia, PA: F.A. Davis Company.

Kim, H., Burke, D., Dowds, M., & George, J. (1999). Utility of a microcomputer as an external memory aid for a memory-impaired head injury patient during inpatient rehabilitation. *Brain Injury*, *13*, 147–150.

Kime, S., Lamb, D., & Wilson, B. (1995). Use of a comprehensive program of external cueing to enhance procedural memory in a patient with dense amnesia. *Brain Injury*, *10*, 17–25.

King, L. (1989). Facilitating neurodevelopment. *Autism Society of America Conference Proceedings* (pp. 117–120). Seattle, WA.

Kirsch, N. L., Levine, S. P., Fallon-Kreuger, M., & Jaros, L. (1987). The microcomputer as an 'orthotic' device for patients with cognitive deficits. *Journal of Head Trauma Rehabilitation*, *2*(4), 77–86.

Kirsch, N. L., Levine, S. P., Lajiness, R., Mossaro, M., Schneider, M., & Donders, J. (1988). Improving functional performance with computerized task guidance systems. *ICAART '88 Annual Conference*, Arlington, VA: RESNA Press.

Kirsch, N. L., Levine, S. P., Lajiness-O'Neill, R., & Schneider, M. (1992). Computer-assisted interactive task guidance: Facilitating the performance of a simulated vocational task. *Journal of Head Trauma Rehabilitation*, *7*(3), 13–25.

Kirsch, N. L., Shenton, M., Spirl, E., Simpson, R., & Schreckenghost, D. (2002). Interactive wireless cueing facilitates performance of moderately complex functional tasks for persons having severe TBI. Poster presented at *Clinical Trials in Medical Rehabilitation: Enhancing Rigor and Relevance*, Kessler Medical Rehabilitation Research and Education Corporation, West Orange, NJ.

Klein, R., & Fowler, R. (1981). Pressure relief training device: The microcalculator. *Archives of Physical Medicine and Rehabilitation*, *62*, 500–501.

Kumazawa, T. (1963). "Deactivation" of the rabbit's brain by pressure application to the skin. *Electroencephalography and Clinical Neurophysiology*, *15*, 660–671.

Lancioni, G., O'Reilly, M., Seedhouse, P., Furniss, F., & Cunha, B. (2000). Promoting independent task performance by persons with severe developmental disabilities through a new computer-aided system. *Behavior Modification*, *24*(5), 700–718.

Lancioni, G., Van den Hof, E., Furniss, F., O'Reilly, M., & Cunha, B. (1999). Evaluation of a computer-aided system providing pictorial task instructions and prompts to people with severe intellectual disability. *Journal of Intellectual Disability Research*, *43*(1), 61–66.

Leong, C.K. (1995). Effects of on-line reading and simultaneous DECtalk auding in helping poor readers comprehend and summarize text. *Learning Disability Quarterly*, *18*, 101–116.

Levine, S. P., Horstmann, H. M., & Kirsch, N. L. (1992). Performance considerations for people with cognitive impairments in accessing assistive technologies. *Journal of Head Trauma Rehabilitation*, *7*(3), 46–58.

Levine, S. P., & Kirsch, N. L. (1985). COGORTH: A programming language for customized cognitive orthoses. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA*) (pp. 359–360). Arlington, VA: RESNA Press.

Levinson, R. (1997). PEAT: The planning and execution assistant and training system. *Journal of Head Trauma Rehabilitation, 12*(2), 769–775.

LoPresti, E. F., Friedman, M. B., & Hages, D. (1997). Electronic vocational aid for people with cognitive disabilities. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 514–526). Arlington, VA: RESNA Press.

LoPresti, E. F., & Willkomm, T. (1997). Comparison of commercially available electronic prospective memory aids. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 523–525). Arlington, VA: RESNA Press.

Lundberg, I. (1995). The computer as a tool of remediation in the education of students with learning disabilities: A theory-based approach. *Learning Disability Quarterly*, *18*, 89–99.

Luria, A. (1973). *The working brain: An introduction to neuropsychology*. New York: Basic Books.

Lynch, W. (1982). The use of videogames in cognitive rehabilitation. In: L. Trexler (Ed.), *Cognitive rehabilitation: Conceptualization and intervention*. New York: Plenum Press.

Lynch, W. (2002). Historical review of computer-assisted cognitive retraining. *Journal of Head Trauma Rehabilitation*, *17*(5), 446–457.

MacArthur, C. A. (1998). Word processing with speech synthesis and word prediction: Effects on the dialogue journal writing of students with learning disabilities. *Learning Disability Quarterly*, *21*(2), 151–166.

MacArthur, C. A., Ferretti, R. P., Okolo, C. M., & Cavalier, A. R. (2001). Technology applications for students with literacy problems: A critical review. *Elementary School Journal*, *101*(3), 273–301.

Magnusson, C., & Larsson, J. E. (1994). Svarne, an expert system to be used in the care of the mentally retarded. *SAIA '94 Workshop.*

Maylor, E. A. (1996). Does prospective memory decline with age? In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 173–197). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

McDonald, J. W., Becker, D., Sadowsky, C. L., Jane, J. A., Conturo, T. E., & Schultz, L. M. (2002). Late recovery following spinal cord injury: Case report and review of the literature. *Journal of Neurosurgery* (*Spine 2*), *97*, 252–265.

Merzenich, M., Jenkins, W., Johnston, P., Schreiner, C., Miller, S., & Tallal, P. (1996). Temporal processing deficits of language-learning impaired children ameliorated by training. *Science*, 271, 77–81.

Middleton, D., Lambert, M., & Seggar, L. (1991). Neuropsychological rehabilitation: Microcomputer-assisted treatment of brain-injured adults. *Perceptual Motor Skills*, *72*, 527–530.

Mihailidis, A., Fernie, G., & Barbenel, J. C. (2001). The use of artificial intelligence in the design of an intelligent cognitive orthotic for people with dementia. *Assistive Technology*, *13*, 23–39.

Mihailidis, A., Fernie, G. R., & Cleghorn, W. L. (2000). The development of a computerized cueing device to help people with dementia to be more independent. *Technology & Disability, 13*(1), 23–40.

Morris, D. M., & Taub, E. (2001). Constraint-induced therapy approach to restoring function after neurological injury. *Topics in Stroke Rehabilitation*, *8*(3), 16–30.

Mynatt, E. D., Essa, I., & Rogers, W. (2000). Increasing opportunities for aging in place. *ACM Conference on Universal Usability, Washington, DC* (pp. 65–71). New York: ACM Press.

Nagarajan, S. S., Wang, X., Merzenich, M. M., Schreiner, C. E., Johnston, P., Jenkins, P., Miller, S., & Tallal, P. (1998). Speech modifications algorithms used for training language learning-impaired children. *IEEE Trans on Rehabilitation Engineering*, *6*(3), 257–268.

Nambu, M., Nakajima, K., Kawarada, A., & Tamura, T. (2000). A system to monitor elderly people remotely, using the power line network. *World Congress on Medical Physics and Biomedical Engineering,* Chicago, Illinois.

Napper, S. A., & Narayan, S. (1994). Cognitive orthotic shell. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 423–425). Arlington, VA: RESNA Press.

Newcomer, P., & Barenbaum, E. (1991). The written composing problems of children with LD: A review. *Journal of Learning Disabilities*, *22*, 262–264.

Newell, A. F., & Booth, L. (1991). The use of lexical and spelling aids with dyslexics. In C. H. Singleton (Ed.), *Computers and Literacy* (pp. 35–44). Hull, UK: University of Hull.

Newell, A. F., Booth, J., Arnott, J. L., & Beattie, W (1992). Increasing literacy levels through the use of linguistic prediction. *Child Language Teaching and Therapy*, *8* (2), 138–187.

Newell, A. F., & Gregor, P. (2000). User sensitive inclusive design in search of a new paradigm. In J. Scholtz & J. Thomas (Eds.), *CUU 2000 First ACM Conference on Universal Usability* (pp. 39–44). New York: ACM Press.

NIH (United States National Institutes of Health) (1998). Rehabilitation of persons with traumatic brain injury. *NIH Consensus Statement*, *16*(1), 1–41.

Ogawa, M., Ochiai, S., Shoji, K., Nishihara, M., & Togawa, T. (2000). An attempt of monitoring daily activities at home. *World Congress on Medical Physics and Biomedical Engineering.* Chicago, Illinois.

Ramakrishnan, S., & Pollack, M. E. (2000). Intelligent monitoring in a robotic assistant for the elderly. *Proceedings of the 16th National Conference on Artificial Intelligence*. Orlando, FL: AAAI.

Raskind, M. H., & Higgins, E. L. (1995). Effects of speech synthesis on the proofreading efficiency of postsecondary students with learning disabilities. *Learning Disability Quarterly*, *18*(Spring), 141–158.

Rosen, M., Brennan, D., Trepagnier, C., Tran, B., Lauderdale, D., & Lathan, C. (2000). Dimensions of diversity in design of telerehabilitation systems for universal usability. *ACM Conference on Universal Usability* (pp. 61–62). Washington, DC.

Rothi, L., & Horner, I. (1983). Restitution and substitution: Two theories of recovery with application to neurobehavioral treatment. *Journal of Clinical Neuropsychology*, *5*, 73–81.

Rubinstein, J. S., Meyer, D. E., & Evans, J. E. (2000). Executive control of cognitive processes in task switching. *Journal of Experimental Psychology: Human Perception & Performance*, *27*(4), 763–797.

Ruddell, R. B., & Boyle, O. F. (1989). A study of cognitive mapping as a means to improve comprehension of expository text. *Reading Research and Instruction*, *29*(1), 12–22.

Scherer, M. J. (Ed.) (2002). *Assistive technology: Matching device and consumer for successful rehabilitation*. Washington, DC: American Psychological Association.

Simpson, R., Schreckenghost, D., & Kirsch, N. L. (2002). A task planning, scheduling and sequencing orthotic for the cognitively impaired. *Proceedings of the AAAI Workshop on Automation as Caregiver: The Role of Intelligent Technology in Elder Care*, Edmonton, Canada, July 2002.

Steele, R. D., Weinrich, M., & Carlson, G. S. (1989). Recipe preparation by a severely impaired aphasic using the VIC 2.0 interface. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 218–219). Arlington, VA: RESNA Press.

Strickland, D., Marcus, L., Mesibov, G.B., & Hogan, K. (1996). Brief report: Two case studies using virtual reality as a learning tool for autistic children. *Journal of Autism and Developmental Disorders*, *26*(6), 651–660.

Sturm, J., & Rankin-Erikson, J. L. (2002). Effects of hand-drawn and computer-generated concept mapping on the expository writing of middle school students with learning disabilities. *Learning Disabilities Research and Practice*, *17*(2), 124–139.

Svensk, A. (1997). Empathic modeling (The Sober Version). *Proceedings 4th European Conference for the Advancement of Assistive Technology, (AAATE), Thessaloniki, Greece*. (pp. 432–435). Amsterdam: IOS Press.

Swanson, H. L., & Trahan, M. F. (1992). Learning disabled readers' comprehension of computer-mediated text: The influence of working memory, metacognition, and attribution. *Learning Disabilities Research and Practice*, *7*, 74–86.

Tackett, S. L., Rice, D. A., Rice, J. C., & Butterbaugh, G. J. (2001). Using a palmtop PDA for reminding in prospective memory deficit. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 23–25). Arlington, VA: RESNA Press.

Tallal, P., Miller, S. L., Bedi, G., Byma, G., Wang, X., Nagarajan, S. S., Schreiner, C., Jenkins, W. M., & Merzenich, M. (1996). Language comprehension in language-learning impaired children improved with acoustically modified speech. *Science*, *271*, 81–83.

Tallal, P., Miller, S. L., & Fitch, R. (1993). Neurological basis of speech: A case for the preeminence of temporal processing. *Annual New York Academy of Science*, *682*, 27–47.

Trepagnier, C. (1996). A possible origin for the social and communicative deficits of autism. *Focus on autism and other developmental disabilities*, *11*(3), 170–182.

Trepagnier, C., Gupta, V., Sebrechts, M. M., & Rosen, M. J. (2000). How does he look: Tracking autistic gaze. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 28–30). Arlington, VA: RESNA Press.

Turner, S., & Pearson, D. W. (1999). Fast ForWord language intervention program: Four case studies. *Tejas—Texas Journal of Audiology and Speech Pathology*, 13.

Vanderheiden, G. (1998). *Assistive techniques & devices for persons with cognitive and language impairments*. Madison WI: Trace Research and Development Centre: Accessible Design, University of Wisconsin.

Wehmeyer, M. L. (1998). National survey of the use of assistive technology by adults with mental retardation. *Mental Retardation*, *36*(1), 44–51.

Werry, I., Dautenhahn, K., Ogden, B., & Harwin, W. (2001) Can social interaction skills be taught by a social agent? The role of a robotic mediator in autism therapy. *Proceedings CT2001, The Fourth International Conference on Cognitive Technology: Instruments of mind*, Warwick, UK.

White, G. W. (2002). Consumer participation in disability research: The golden rule as a guide for ethical practice. *Rehabilitation Psychology, 47*(4), 438–446.

Wilkins, A. (1995). *Visual stress*. Oxford: Oxford University Press.

Wilkins, A., & Lewis, E. (1999). Coloured overlays, text, and texture. *Perception*, *28*, 365–370.

Willkomm, T., & LoPresti, E. (1997). Evaluation of an electronic aid for prospective memory tasks. *Proceedings of the Rehabilitation Engineering Society of North America (RESNA)* (pp. 52–522). Arlington, VA: RESNA Press.

Willows, D. M., Kruk, R. S., & Corcos, E. (1993). *Visual processes in reading and reading disabilities*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Willows, D. M., & Terepocki, M. (1993). The relation of reversal errors to reading disabilities. In D. M. Willows, R. S. Kruk, & E. Corcos (Eds.), *Visual processes in reading and reading disabilities* (pp. 31–56). Mahway, NJ: Lawrence Erlbaum Associates, Inc.

Wilson, B. A. (1984). Memory training in practice. In B. Wilson & M. Moffat (Eds.), *Clinical management of memory problems*. Rockville, MD: Aspen Systems Corporation.

Wilson, B. A., Emslie, H. C, Quirk, K., & Evans, J. J. (2001). Reducing everyday memory and planning problems by means of a paging system: A randomised control crossover study. *Journal of Neurology, Neurosurgery, and Psychiatry, 70*(4), 477–482.

Wilson, B. A., Evans, J. J., Emslie, H., & Malinek, V. (1997). Evaluation of NeuroPage: A new memory aid. *Journal of Neurology, Neurosurgery, and Psychiatry*, *63*, 113–115.

Wright, P., Rogers, N., Hall, C., Wilson, B., Evans, J., Emslie, H., & Bartram, C. (2001). Comparison of pocket-computer memory aids for people with brain injury. *Brain Injury*, *15*(9), 787–800.

Zanetti, O., Zanieri, G., Vreese, L. P. D., Frisoni, G., & Binetti, G. (2000*).* Utilizing an electronic memory aid with Alzheimer's disease patients. A study of feasibility. *Sixth International Stockholm/Springfield Symposium on Advances in Alzheimer Therapy*, Stockholm, Sweden.

Zipprich, M. A. (1995). Teaching web making as a guided planning tool to improve student narrative writing. *Remedial and Special Education*, *16*(1), 3–15.