Scaffolding Rehabilitation Behaviour using a Voice Mediated Assistive Technology for Cognition

Dr Brian O'Neill[1]
Department of Psychology
University of Stirling
Stirling, FK9 4LA
UK

and

Central Scotland Brain Injury Rehabilitation Centre
Murdostoun Castle
Newmains, ML2 9BY
UK

Tel: + 44 (0)1698 384055
brian.oneill@fshc.co.uk

Kate Moran
Douglas Grant Rehabilitation Centre
Ayrshire Central Hospital
Kilwinning Road
Irvine, KA12 8SS
UK

Dr Alex Gillespie
Department of Psychology
University of Stirling
Scotland, FK9 4LA
UK

Accepted for publication in *Neuropsychological Rehabilitation* published by Taylor and Francis

Acknowledgement: The authors would like to acknowledge the financial support of a Chief Scientist Office Research Grant (CZG/2/319). The support of Helen Scott and the therapy staff at the West of Scotland Mobility and Rehabilitation Centre was invaluable.

---

[1] Author and address for correspondence

Abstract

A variety of cognitive deficits can lead to difficulties performing complex behavioural sequences, and thus disability in the performance of routine and rehabilitation behaviours. Interventions to date involve increasing support or providing behavioural training. Assistive technologies for cognition have the potential to augment cognitive capacity thus enabling the performance of behavioural sequences. Guide is an assistive technology for cognition that scaffolds task performance by providing verbal prompts and responding to verbal feedback. Guide was used to provide verbal support and guidance for eight amputees (mean age 64), with cognitive impairment of vascular origin, putting on their prosthetic limbs. Participants were referred to the research due to problems learning the correct behavioural sequence. The research used repeated trials with random assignment to intervention and baseline conditions. The voice mediated assistive technology for cognition resulted in a significant reduction of safety critical errors and omitted steps. Discussion focuses upon the relation between voice mediated cognitive support for memory and executive function, and suggestions are made for future research.

Keywords: Assistive technology for cognition, executive function, Guide, complex behaviour, limb-donning, activities of daily living

Scaffolding Rehabilitation Behaviour using a Voice Mediated Assistive Technology for Cognition

Difficulties carrying out goal-directed behavioural sequences can lead to a high degree of disability for which there exist few treatments (Evans, 2003). Sequence performance difficulties are common in patient groups such as traumatic brain injury (Evans, 2003), schizophrenia (Semkovska, Bedard, Godbout, Limoge, and Stip, 2003; Krabbendam, de Vugt, Derix, and Jolles, 1999), learning disability (Cavalier & Ferretti, 1993), cerebrovascular accident (Curran, 2004) and dementia (Feyereisen, Gendron, and Seron, 1999). Sequencing deficits can lead to problems performing activities of daily living (ADL) such as dressing, grooming, household tasks, social participation and food and drink preparation. Accordingly, severe sequencing deficits often necessitate a high degree of personal care and support, which entails a significant economic cost (LaPlante, Harrington, and Kang, 2002).

The cognitive underpinnings of goal-directed sequencing behaviour include memory storage, retrieval of the steps in the sequence, timely initiation of the actions, self-monitoring of goal and sub-goal achievement and error correction. Thus the sequencing of behaviour entails both memory and executive functions. Support for this association is evident in several studies of ADL performance and rehabilitation outcome. For example, executive function measures predict shopping performance (Semovska, Bedard, Godbout, Limoge, and Stip, 2004), memory and executive function deficits predict failure to perform personal hygiene routines amongst older adults living alone (Tierney, Snow, Charles, Moineddin, and Kiss, 2007), memory and executive function have been linked to post-amputation outcome (O’Neill, 2008) and executive function predicts indices of rehabilitation outcome following traumatic brain injury (Crepeau & Scherzer, 1993). Accordingly, rehabilitation of executive dysfunction has received much research attention, though medications and training have had limited success (Evans, 2003).

When cognitive function cannot be regained it is possible that compensation is possible (Bäckman & Dixon, 1992; Baltes, 1987). One common mechanism of compensation has been called scaffolding (Stone, 1998). Scaffolding refers to the provision of verbal guidance during task performance. The verbal guidance is meant to be just beyond the ability of the performer thus providing the cognitive support to enable the performer to achieve beyond their unaided ability. Scaffolding was originally used to conceptualise the verbal support that parents provide to help children with task performance (Luria,1961; Vygotsky & Luria, 1994; Zittoun, Gillespie, Cornish & Psaltis, 2007).

Recently scaffolding has been used to understand the verbal support provided by carers and therapists to people with cognitive impairments during task performance (O'Neill & Gillespie, 2008; Pea, 2004; Ylvisaker, 2003). Therapists and carers working with people with sequence performance difficulties can be conceptualized as providing external support for initiation, problem-solving, generativity, planning, sequencing, organization, self-monitoring, error correction and behavioural inhibition. To benefit from this instruction patients require different, often intact cognitive processes such as verbal comprehension, object identification, memory of single stage directions, and verbally mediated motor control.

Several studies support the efficacy of performance scaffolding. Curran (2004) examined the role of verbal scaffolding in teaching new naturalistic action sequences to patients following a cerebrovascular accident. Results indicated that participants in the scaffolding condition learned the novel sequences in fewer trials, made fewer errors, but required more time to perform the tasks. Additionally, the use of verbal instruction alone by carers has been shown to successfully scaffold individuals with executive dysfunction in carrying out ADL (Gitlin et al., 2002).

Although scaffolding can be effective, intensive carer support has some problems. Intensive carer support can be upsetting and embarrassing to the adult recipient who might feel a loss of autonomy due to feelings of invasion of privacy, dependency, and being positioned as child-like (Proot, Crebolder, Abu-Saad, Macor, and Ter Meulen, 2000). Additionally, the informal care providers experience emotional strain (Proot et al., 2000). From an economic point of view, intensive carer support is expensive (LaPlante, Harrington, and Kang, 2002), with costs increasing with extent of cognitive impairment (Langa et al., 2004). Providing verbal scaffolding using technology rather than carers has the potential to avoid these problems.

Assistive technology for cognition (ATC) has the potential to revolutionise the management of cognitive disabilities (Gregor & Newell, 2004). According to a review by LoPresti, Mihailidis and Kirsch (2004) assistive technologies for cognition can generally be categorised into those which augment or compensate for information processing deficits (i.e. perceptual and communication aids) and those which augment or compensate memory and executive function impairments (i.e., memory aids and prompting systems). Augmenting performance of rehabilitation sequences relies upon the latter, and thus we will focus our review on assistive technologies for memory and executive function. We distinguish between scheduling devices which remind the user to perform a behaviour and sequencing devices which guide users in the performance of behaviours.

The majority of existent memory and executive function aids are scheduling devices. These devices augment prospective memory and facilitate the performance of a behaviour at a time in the future which might otherwise be forgotten (e.g., visit the doctor, take medication, or cook a meal). Traditional prospective memory aids are commonly used and include paper notes, diaries, calendars, alarms and reminders (Evans, Wilson, Needham, and Brentnall, 2003). These traditional assistive technologies have been augmented in recent years by digital assistive technology. Personal digital organisers and voice recorders can now undertake the function of several of the traditional assistive technologies, such as temporal prompting and thus recall of the to-be-performed behaviour (Yasuda et al., 2002; Kapur, Gilisky, and Wilson, 2004). Computer systems allow central storage of schedules to be delivered as text prompts at the point when a behaviour requires to be carried out. The effectiveness of pager-type prompting, as provided by MemoJog (Inglis et al., 2003) and Neuropage (Wilson, Emslie, Quirk, and Evans, 2001), has been demonstrated to increase achievement of target behaviours. Similarly the MEMEX project, utilising text messaging to mobile phones, has demonstrated effectiveness in improving attendance at appointments and medication compliance (Pijnenborg, Withaar, Evans, van den Bosch, and Brouwer, 2007). Schedulers are macro-prompting devices that remind users to perform a given behaviour, but they do not provide on-task support for the performance of that behaviour.

Sequencing devices provide on-task step-by-step scaffolding. Sequencing devices augment memory of the steps that need to be performed and the executive sequencing to order those steps correctly. Research has shown that during task performance visual prompts and visual instructions provided by a computer can act as useful cues for improving task performance (Lancioni, Van den Hof, Furniss, O'Reilly, and Cunha, 1999). One of the earliest sequencing systems was the Planning and Execution Assistant and Training System (PEAT, Levinson, 1997). PEAT employed artificial intelligence systems to provide users with daily plans. It had a mechanism for dealing with unexpected events and a degree of micro prompting based on visual cues (Levinson, 1997). Essential Steps software is a PC based system designed to support users in a variety of daily tasks through on-screen cues, which could also be presented by a computer generated voice (Bergman, 2002). Fifty four people with cognitive impairments demonstrated rapid skill acquisition in individual trials with the Essential Steps software. More recently, this tradition of research has resulted in MAPS (Carmien, 2005) and the commercial product Pocket Coach provided by AbleLink (Gentry, Wallace, Kvorfordt, and Lynch, 2008). Both MAPS and Pocket Coach enable users to create a sequence of primarily visual prompts on a desktop computer. The prompts are then loaded onto a PDA and, once activated, the system prompts the user step-by-step through the given task. Users respond by pressing buttons on the PDA. Recent research demonstrates considerable success in compensating for task performance deficits (Gentry et al., 2008).

In their review of the field LoPresti, Mihailidis and Kirsch (2004) suggest that ATC has not been achieving its full potential. The main problem has been the complexity of ATC. Rather than reducing cognitive load, the sequence support systems often increase the cognitive burden by necessitating that users interact with complex and unfamiliar devices. Accordingly, these authors call for future ATC to be more sensitive in orienting to their cognitively impaired users (see also, Scherer, 2001).

We suspect that one problem may be the widespread use of visual interfaces. Not only are visual interfaces an unfamiliar medium of interaction for many people with cognitive impairments, but they also consume visual attention. Attentional function predicts use of cognitive aids in sample of people with acquired brain injury (Evans et al., 2003). Yet the main ATC systems, such as Neuropage (Wilson, Evans, Emslie, and Malinek, 1997), MemoJog (Inglis et al., 2003), and Pocket Coach (Gentry et al., 2008) require users to interact with the ATC via a screen. Users usually receive information via the screen, and give feedback to the device via the screen. Visual interfaces are effective if the user's visual system is free and the user is familiar with such interaction. However, in cases where a user is engaged in a task (such as dressing, transfer or donning a limb) interacting with a computer screen entails a shift of visual attention and an interruption of the ongoing task, thus increasing the cognitive load of the task.

We argue, on the basis of the literature on scaffolding, that an effective way forward is for ATC to model more closely the verbal support provided by carers. First, the cognitive scaffolding provided by carers is verbal, not visual, and thus does not lead the patients' visual attention away from the task at hand. Second, the verbal guidance provided by carers is in a familiar mode of interaction, namely, communicative interaction, and thus there is no learning curve. Finally, the scaffolding provided by carers is task-focused and tailored to the individual, that is to say each verbal prompt is contextually relevant to the patient's present goal and context. Previous research has demonstrated the efficacy of verbal prompting to facilitate memory of therapy goals after traumatic brain injury (Hart, Hawkey, and Whyte, 2002) and control of a patient's verbose speech (Kirsch et al., 2004). However, these voice based systems have been unidirectional, that is, not taking feedback from users. The literature on scaffolding leads us to suggest the need for ATC that is not only based upon voice prompts, but which emulates verbal interaction and are able to provide context sensitive cognitive support.

Guide is a prototype ATC that emulates the cognitive scaffolding provided by carers. The device prompts users, asks users questions and accepts verbal responses. Guide uses the verbal responses to direct the deployment of subsequent prompts and questions in a context sensitive manner. The range of answers that Guide accepts is deliberately limited to two necessary responses (“yes” and “no”) and three optional responses (“done,” “back,” and “what?”) so as to reduce cognitive load. When loaded with a protocol mapping the action pathway and common problems, Guide is an expert system able to deal with problems that might arise. The system sequences the task for users in terms of sub-steps, and for each sub-step, a series of questions are asked. Affirmative responses lead to the next question or sub-step. Negative responses lead to problem solving sub-routines. Thus, relatively able users can move quickly through the protocol, while less able users receive more guidance.

Guide is a response to Mihailidis, Barbenel and Fernie’s (2004, p. 166) recommendation for constructing a verbal prompting system. It is in the tradition of COACH (Mihailidis, Barbenel, and Fernie, 2004) in that it is focused upon a particular task and uses verbal prompts. It is task specific and achieves context sensitivity (Cole 1999) by asking the users questions about step completion. It builds upon evidence for the efficacy of voice based prompting (Hart et al., 2002; Kirsch et al., 2004). The contribution is in the close simulation of carer scaffolding of task performance: it is not only verbal, it emulates conversational interaction, is sensitive to context and able to resolve basic problems that arise.

The following investigation was carried out during the development and refinement of a Guide protocol to support donning a prosthetic limb for a transtibial amputation for people with cognitive impairment. The aim of the research was to test the efficacy of an ATC which emulates therapist scaffolding of performance in a rehabilitation setting. A series of single participant studies were used to test the hypothesis that Guide use would increase the performance accuracy of the rehabilitation relevant task above baseline.

Method

Participants

Ten patients with difficulty acquiring the correct sequence in rehabilitation as usual were referred to the project. Rehabilitation as usual comprised instruction by physiotherapy staff on how to don the transtibial prosthesis and carry out safety-critical checks. Two of the patients referred to the project dropped out, one due to a medical deterioration and the second due to bereavement. Accordingly, data were gathered on eight patients (mean age 64 years). All participants provided informed consent.

Neuropsychological assessment results for participants are shown in Table 1. Participants were assessed using the Repeatable Battery for the Assessment of Neuropsychological Status (RBANS: Randolph, 1998) and the Addenbrookes Cognitive Examination – Revised (ACE-R: Mathuranath, Nestor, Berrios, Rakowicz, and Hodges, 2000). The mean RBANS total score was 61.9, the mean ACE-R score was 72.9, placing the sample as a whole in the impaired range of cognitive function on both measures. On the RBANS, six of the eight participants were in the extremely low range, one was borderline and one average range but with an impaired index of executive function. On the ACE-R, seven of the eight were below the cut-off for significant cognitive impairment and one was above this cut-off. Participants had been in rehabilitation as usual for 147 days on average (40-484). Cognitive impairments are proposed to account for failure to gain from rehabilitation as usual.

[Insert Table 1 about here]

Ethics

Ethical approval for the intervention was granted by the Multi-Centre Research Ethics Committee for Scotland (March 2007).

Setting

The West of Scotland Mobility and Rehabilitation Centre provides regional post-amputation prosthetic and rehabilitation services to inpatients and outpatients. The mobility rehabilitation team comprises medicine, nursing, occupational therapy, physiotherapy and clinical psychology.

Materials

In experimental trials participants used a prototype ATC referred to as Guide. The Guide system has four components: a PC running Windows XP and optimised for audio processing, voice recognition software, a protocol of verbal prompts and questions, and the Guide software program that coordinates the parts. The software program is designed to take input from the voice recognition program and use this to trigger the pre-recorded questions and prompts on the basis of the protocol. Communication between the system user and the PC was via wireless headphones. The equipment used is illustrated in Figure 1. The equipment and was managed by KM who opened the programme and initiated the protocol for each trial.

[Insert Figure 1 about here]

The most important component is the protocol because it contains expertise, gleaned from therapists and expert users of prosthetic limbs, which guides users through the optimal sequence of limb donning, including important safety critical checks, and the resolution of common problems. The protocol has branches so that able users can proceed swiftly through the prompts and checks, while users who get into difficulty can access additional verbal support for the resolution of specific problems. The protocol was developed using procedures of task analysis (Shepard, 2001). Interviews with four physiotherapists and three prosthetists, talk-aloud simulations with two physiotherapists and one prosthetist, and observation of an expert patient talk aloud while donning his limb formed the basis of the task analysis. The final protocol was also checked by a prosthetist for accuracy.

The prompts were constructed based on neuropsychological and speech comprehension considerations (Caplan, Waters, and Hildebrandt, 1997). First, each prompt was designed to be independent and thus not rely upon the user's memory of a previous prompt. Second, each prompt was created to be as concrete as possible and use vivid descriptors where possible so as to hold users attention. Third, alerting redundancy was included at the start of each prompt in order to make users aware of incoming information (e.g., "OK, great, the next step is…." and "No problem, have you…."). Fourth, syntactic complexity and number of propositions was kept minimal and prompts were kept short to avoid over extending working memory. Fifth, passive sentences were avoided. An excerpt from the protocol is presented in Appendix 1.

Design

Eight single participant baseline-intervention experiments were carried out. Data were gathered by video recording on-task behaviour. The eight participants engaged in an average of 17 trials (minimum 10) in which they put on their prosthetic limb. Each trial was randomly allocated to either a Guide intervention or a baseline condition which entailed unaided limb donning. An exact probability test using randomization procedures was used to statistically assess differences in accuracy of task performance

(Todman & Dugard, 2001). Paired t-tests were also carried out to compare performance in baseline for the group as a whole with performance using Guide.

Measures

The video data of participants putting on their prosthetic limbs was analysed for omissions, deviations, repetitions and safety critical errors (KM). These indices were constructed by scoring participants' performance on two scales.

The first scale measured number of safety critical errors. A list of these was developed in consultation with physiotherapists and prosthetists. The list is presented, in order of sequence performance, as part of the results section (Table 3). Each error could lead to a negative outcome. For example, failing to secure the brakes on the wheelchair may lead to a fall and failure to smooth out wrinkles from the socks may lead to blistering and infection. The video recordings of each trial were scored against this list of errors thus producing a data point of number of safety critical errors for each trial.

The second, sequence performance scale, was scored against an optimal performance sequence (Bakeman & Gottman, 1997; Burgess, 2000; Semskovska et al., 2003) by KM (with a subset re-examined by BON to assess inter-rater reliability, Cohen's Kappa, ranged from 0.73 to 0.77). This optimal sequence was developed in conjunction with physiotherapists and prosthetists. The steps in the optimal sequence were: First, identifying and bringing together the component pieces (socks for the residual limb, foam rubber (pelite) liner, prosthesis, nylon slip sock, and suspension sleeve if proscribed). Second, securing the wheelchair and removing obstacles. Third, putting on the correct number of socks to ensure a good fit. Fourth, correctly preparing and putting on the foam liner. Fifth, donning the prosthetic limb. Finally, securing the limb and checking the security and fit of the limb. Against this optimal sequence errors of omission, deviation from the sequence, and repetition of steps provided data points for statistical analyses.

Results

Table 2 presents the mean number of safety critical errors, omissions, deviations, and repetitions of previous steps. Statistically significant (Todman & Dugard, 2001) reductions of omissions and errors were observed for participants 2, 3, 4, 5, 7, and 8. Thus six of the eight participants showed statistically significant benefit. There was no significant improvement in case 1 and this may have been due to the fact that an early version of the Guide protocol was being used. The protocol was refined on the basis of the trials with the first participant. There was also no significant improvement in case 6 and it is likely that this is due to the participant hitting ceiling. As is evident from Table 2, there were 0.73 errors in the baseline condition for this individual and thus, although the intervention reduced those errors to zero, the result was not statistically significant. Visual inspection of the data across trials suggests a learning effect which may have reduced the effect of Guide use. This tends to support the robustness of the reported results.

Comparison between the conditions for the sample as a whole. Paired sample t-Tests were calculated. Mean errors were significantly reduced in the intervention condition in comparison with Baseline ($t = 4.80$, $p = 0.002$). Mean omissions were significantly reduced in the intervention condition ($t = 3.95$, $p = 0.006$). Deviations were not significantly different between conditions ($t = 1.04$, $p = 0.12$). Repetitions were not significantly different between conditions ($t = 0.22$, $p = 0.83$). Mean time per trial increased significantly in the intervention condition ($t = -3.78$, $p = 0.007$). This result is a by-product of participants pausing to listen to the prompts and not omitting any steps.

[Insert Table 2 about here]

There appears to be a trend towards fewer errors made in baseline across the eight case studies. We suspect that early successes perceived by the physiotherapists led to patients with cognitive impairment and difficulty in sequence acquisition being referred to the research earlier. Providing scaffolding earlier in rehabilitation, thus preventing errors becoming learned, would likely reduce baseline error rates in line with errorless learning theory. One consequence of this may have been a reduction in the impact of Guide for these participants.

Particularly important for assessing the effectiveness of the intervention is the reduction in safety critical errors. Table 3 provides a breakdown of the errors made by condition in order of performance sequence. There are no errors which are more frequent in the intervention condition. Guide scaffolding was particularly successful at helping participants secure the brakes on their wheelchair, checking the fit of the liner, and conducting post-donning checks.

Discussion

The participants demonstrated a baseline performance characterized by safety critical errors and frequent omissions. These deficits are in line with the memory, attention and executive function deficits assessed and previous research suggesting that similar patterns of cognitive impairment could lead to rehabilitation problems (Larner et al., 2003; O'Neill & Evans, 2009; Schoppen et al., 2003). In six of the eight single-n experiments Guide produced significant performance improvements compared to the baseline. This finding suggests that Guide shows promise as a cognitive orthosis, scaffolding users' performance and leading to fewer errors and omissions.

Guide demonstrates potential as a rehabilitation tool. Rehabilitation can be conceptualised as the acquisition of sequences (Langan-Fox, Grant, and Anglim, 2007). Cognitive problems contribute to rehabilitation outcome following amputation. This is attributed to difficulty acquiring and reproducing complex sequences (O'Neill, 2008). For many of these conditions rehabilitation is labour intensive due to the need for repeated instruction or supervision to prevent errors. Computer assisted guidance of repeated instruction could thus allow patients to engage autonomously in rehabilitation relevant task performance.

The current system used required to be initiated by a trained person, thus limiting current applicability to the rehabilitation context. Use in a home environment requires further development such that system initializing might be automated and triggered by approach to the device or user location. Development of the software for a portable device is planned.

The success of the intervention, we speculate, stems from the verbal interface. While use of an interactive verbal interface is relatively novel for ATC, it is familiar for users. Each of the participants easily adapted to the use of Guide. Other ATC studies have reported difficulties in training users due to long learning curves (LoPresti et al., 2004). We suspect this has been due to the lack of familiarity with the interface. A possible second advantage with the verbal interface is that it provides a relatively direct route to augmenting self-talk. Research with children and the development of executive function has shown that problems that are difficult can stimulate self-talk (Vygotsky & Luria, 1994; Winsler & Naglieri, 2003). Guide could be conceptualised as an attempt to augment self-talk directly (Berk & Winsler, 1995; Gillespie & Cornish, in press). In several baseline trials it was noted that participants engaged in self talk using the Guide prompts verbatim.

The success of the intervention is largely dependent upon the underlying protocol. Task analysis (Shepard, 2001) can help provide a functional analysis of tasks, but this needs to be complemented by a neuropsychological analysis of how people sequence tasks, resolve problems, and respond to prompts. Unanswered questions remain regarding the best phrasing of prompts, whether prompts or questions should be used, what the optimal sub-step size is, what the optimal sentence length is, and what the optimal user responses are. Future protocols for scaffolding the sequencing of behaviour should be based as closely as possible on linguistic and neuropsychological research concerning the way in which prompts are comprehended and tasks are sequenced.

The sequencing provided by scaffolding intervention is regarded as having an orthotic function, as without it performance returned to baseline. However, for individuals with better memory function the system might also restore performance of complex sequences. The system can guide error free performance and might thus be used in the errorless learning paradigm, suggesting efficacy in teaching ordered semantic information (Kessels & De Haan, 2003) and behavioural sequences (Maxwell, Masters, Kerr, and Weedon, 2001). Guide, or similar sequencing ATC, could be used to instruct the errorless performance of behavioural sequences. Once the system is successfully guiding errorless task completion, prompts could be gradually replaced by questions, which, in turn, could be faded out from last to first, incrementally increasing the amount of steps to be recalled.

ATC that emulates the performance scaffolding provided by carers is likely to have a wide range of application. We conclude by considering the circumstances in which the use of interactive verbal scaffolding of sequencing behaviour is likely to be optimal. Verbal sequencing requires that the user is able to hear the prompts, understand the prompts, hold the prompts in working memory, and physically carry out the task unaided. Regarding the task, we suspect that verbal scaffolding is suited to tasks with a strong visual component, which keep the user's hands busy, and which produce relatively routine problems. On this basis, future research should focus upon complex ADL such as dressing, drink preparation, food preparation, laundry, personal hygiene, medication regimes, physiotherapy regimes, and household tasks. Focusing on these activities can make a crucial difference at the level of everyday routines and practices (Cornish & Gillespie, 2009), because these activities have been identified by people with dementia as important (Wherton & Monk, 2008). Research needs to examine the potential of verbal scaffolding ATC to provide an orthotic function and learning in these domains. Pursuing these strands of research has the potential to create autonomy and independence for people with sequence performance difficulties both within the home and beyond.

References

Bäckman, L., & Dixon, R. A. (1992). Psychological compensation: a theoretical framework. *Psychological Bulletin*, *112*, 259-283.

Bakeman, R., & Gottman, J.M. (1997). *Observing interaction: An introduction to Sequential Analysis, 2nd Edition*. Cambridge: Cambridge University Press.

Baltes, P. B. (1987). Theoretical propositions of life-span developmental psychology: On the dynamics between growth and decline. *Developmental Psychology, 23*, 611-626.

Bergman, M. M. (2002). The benefits of a cognitive orthotic in brain injury rehabilitation. *Journal of Head Trauma Rehabilitation, 17*, 45-51.

Berk, L. E., & Winsler, A. (1995). *Scaffolding children's learning: Vygotsky and early childhood education*. Washington: National Association for the Young Children.

Burgess, P.W. (2000). Strategy application disorder: the role of the frontal lobes in human multi-tasking. *Psychological Research, 63*, 379-288.

Caplan, D., Waters, G.S., & Hildebrandt, N. (1997). Determinants of Sentence Comprehension in Aphasic Patients in Sentence-Picture Matching Tasks. *Journal of Speech, Language, and Hearing Research, 40*, 542-555.

Carmien, S. (2005). End user programming and context responsiveness in handheld prompting systems for persons with cognitive disabilities and caregivers. In *In Proceedings of CHI'05 Conference on Human Factors in Computing Systems* (pp. 1252-1255). Portland, Oregon.

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.

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

Cornish, F., & Gillespie, A. (2009). A pragmatist approach to the problem of knowledge in health psychology. *Journal of Health Psychology, 14*(6), 800-809.

Crepeau, F. & Scherzer, P. (1993). Predictors and indicators of work status after traumatic brain injury: A meta-analysis. *Neuropsychological Rehabilitation, 3*, 5-35.

Curran, C. (2004) Scaffolded training facilitates learning of naturalistic actions after stroke. *Dissertation Abstracts International: Section B: The Sciences and Engineering, 64(8-B)*, 4074.

Evans, J. J. (2003). Rehabilitation of executive deficits. In B. A. Wilson (Ed.) *Neuropsychological rehabilitation* (pp. 53-70). Abingdon: Swets and Zeitlinger.

Evans, J.J. Wilson, B.A., Needham, P., & Brentnall, S. (2003). Who makes good use of memory aids? Results of a survey of people with acquired brain injury. *Journal of the International Neuropsychology Society, 9,* 925-935.

Feyereisen, P.M., Gendron, M., Seron, X. (1999) Disorders of everyday actions in subjects suffering from senile dementia of Alzheimer's type: An analysis of dressing performance. *Neuropsychological Rehabilitation, 9,* 169-188.

Gentry, T., Wallace, J., Kvarfordt, C., & Lynch, K. B. (2008). Personal digital assistants as cognitive aids for individuals with severe traumatic brain injury: A community-based trial. *Brain Injury, 22*, 19-24.

Gillespie, A. & Cornish, F. (in press). Intersubjectivity: Towards a dialogical analysis. *Journal for the Theory of Social Behaviour xxxxxxxxxxx.*

Gitlin, L. N., Winter, L., Dennis, M. P., Corcoran, M., Schinfeld, S., & Hauck, W. W. (2002). Strategies used by families to simplify tasks for individuals with Alzheimer's disease and related disorders: psychometric analysis of the Task Management Strategy Index (TMSI). *The Gerontologist, 42*, 61-69.

Gregor, P., & Newell, A. (2004). Introduction. *Neuropsychological Rehabilitation, 14*, 1-3.

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. *The Journal of Head Trauma Rehabilitation*, *17*, 556-570.

Inglis, E., Szymkowiak, A., Gregor, P., Newell, A., Hine, N., Shah, P., et al. (2003). Issues surrounding the user-centred development of a new interactive memory aid. *Universal Access in the Information Society, 2*, 226-234.

Iverson, G.L. (1998) Interpretation of Mini-mental State Examination results in community dwelling elderly and inpatient neuropsychiatry patients. *International Journal of Geriatric Psychiatry. 13(10),* 661-6.

Kapur, N., Glisky, E. L., & Wilson, B. A. (2004). Technological memory aids for people with memory deficits. *Neuropsychological Rehabilitation, 14*, 41-60.

Kessels., R.P.C., & de Haan, E.H.F. (2003). Implicit Learning in Memory Rehabilitation: A Meta-Analysis on Errorless Learning and Vanishing Cues Methods. *Journal of Clinical and Experimental Neuropsychology, 25*, 805-814.

Kirsch, N. L., Shenton, M., Spirl, E., Simpson, R., Lopresti, E., & Schreckenghost, D. (2004). An assistive-technology intervention for verbose speech after traumatic brain injury: A single case study. *The Journal of Head Trauma Rehabilitation, 19*, 366-377.

Krabbendam, L., de Vugt, M.E., Derix, M.M., & Jolles, J. (1999). The behavioural assessment of the dysexecutive syndrome as a tool to assess executive functions in schizophrenia. *Clinical Neuropsychology, 13,* 370-375.

Lancioni, G. E., Van den Hof, E., Furniss, F., O'Reilly, M. F., & 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,* 61-66.

Langa, K.M., Chernew, M.E., Kabeto, M.U., Herzog, R., Ofstedal, M.B., Willis, R.J., et al. (2004). National Estimates of the Quantity and Cost of Informal Caregiving for the Elderly with Dementia. *Journal of General Internal Medicine, 16*, 770–778.

Langan-Fox, J., Grant, S., & Anglim, J. (2007). Modelling skill acquisition in acquired brain injury. *Australian Psychologist, 42,* 39-48

LaPlante, M., Harrington, C., & Kang, T. (2002). Estimating paid and unpaid hours of personal assistance services in activities of daily living provided to adults living at home. *Health Services Research*, *37,* 397-415.

Larner, S., Van Ross, & E., Hale, C. (2003). Do psychological measures predict the ability of lower limb amputees to learn to use a prosthesis? *Clinical Rehabilitation, 17,* 493-498.

Levinson, R. (1997). PEAT: The planning and execution assistant and trainer. *Journal of Head Trauma Rehabilitation*, *12*, 769-775.

LoPresti, E., Mihailidis, A., & Kirsch, N. (2004) Assistive Technology for Cognitive Rehabilitation: State of the Art. Neuropsychological Rehabilitation. 14, 5-39.

Luria, A. (1961*). The role of speech in the regulation of normal and abnormal behaviour*. London: Pergamon Press.

Mathuranath, P.S., Nestor, P.J., Berrios, G.E., Rakowicz, W. and Hodges, J. R. (2000). A brief cognitive test battery to differentiate Alzheimer's disease and frontotemporal dementia. *Neurology, 55,* 1613-1620.

Maxwell, J., Masters, R., Kerr, E., & Weedon, E. (2001). The implicit benefits of learning without errors. *The Quarterly Journal of Experimental Psychology, 54A,*1049-1068.

Mihailidis, A., Barbenel, J. C., & Fernie, G. (2004). The efficacy of an intelligent cognitive orthosis to facilitate handwashing by persons with moderate to severe dementia. *Neuropsychological Rehabilitation*, *14*, 135-171.

O'Neill, B. (2008). Cognition and Mobility Rehabilitation following Lower Limb Amputation, in Gallagher, Desmond and MacLachlan (Eds.) *Psychoprosthetics: State of the knowledge.* London: Springer.

O'Neill, B., & Evans, J.J. (2009). Memory and executive function predict mobility rehabilitation outcome following lower-limb amputation. *Disability and Rehabilitation. E-pre print.* DOI: 10.1080/09638280802509579

O'Neill, B., & Gillespie, A. (2008). Simulating naturalistic instruction: The case for a voice mediated interface for assistive technology for cognition. *Journal of Assistive Technologies Volume, 2*, 22-30.

Pea, R. D. (2004). The social and technological dimensions of scaffolding and related theoretical concepts for learning, education, and human activity. *The Journal of the Learning Sciences, 13,* 423-451.

Pijnenborg, G.H., Withaar, F.K., Evans, J.J., Bosch, R.J. van den, & Brouwer, W.H. (2007). SMS text messages as a prosthetic aid in the cognitive rehabilitation of schizophrenia. *Rehabilitation Psychology, 52*, 236-240

Proot, I.M., Crebolder, H.F., Abu-Saad, H.H., Macor, T.H., & Ter Meulen, R.H. (2000). Facilitating and Constraining Factors on Autonomy: The Views of Stroke Patients on Admission Into Nursing Homes. *Clinical Nursing Research, 9,* 460-478.

Randolph, C. (1998) *Repeatable battery for the assessment of neuropsychological status.* San Antonio, TX: The Psychological Corporation.

Scherer, M. J. (2001). *Assistive technology: Matching device and consumer for successful rehabilitation*. Washington: American Psychological Association.

Semkovska, M. Bedard, M.A., Godbout, L., Limoge, F., & Stip, E. (2003). Assessment of executive dysfunction during activities of daily living in schizophrenia, *Schizphrenia Research 69*, 289-300.

Shepherd, A. (2001). *Hierarchical task analysis*. London: Taylor & Francis.

Schoppen, T., Boonstra, A., Groothoff, J.W., De Vries, J., Goeken, L.N., & Eisma, W.H. (2003). Physical, mental and social predictors of functional outcome in unilateral lower-limb amputees. *Archives of Physical Medicine and Rehabilitation, 84,* 803-811

Stone, C. A. (1998). The metaphor of scaffolding: Its utility for the field of learning disabilities. *Journal of Learning Disabilities, 331*, 344-364.

Tierney, M., Snow, W., Charles, J., Moineddin, R., & Kiss., A. (2007). Neuropsychological predictors of self-neglect in cognitively impaired older people who live alone. *The American Journal of Geriatric Psychiatry, 15*, 140-148.

Todman, J.B., & Dugard, P. (2001). *Single case and small-n experimental designs: A practical guide to randomisation tests*. London, Lawrence Erlbaum Associates.

Vygotsky, L. S., & Luria, A. (1994). Tool and symbol in child development. In R. Van de Veer & J. Valsiner (Eds.), *The Vygotsky reader*. Oxford: Blackwell.

Wherton, J. P., & Monk, A. F. (2008). Technological opportunities for supporting people with dementia who are living at home. International Journal of Human-Computer Studies, *66 (8),* 572-586.

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

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

Winsler, A., & Naglieri, J. (2003). Overt and covert verbal problem-solving strategies: Developmental trends in use, awareness and relations with task performance in children aged 5 to 17. *Child Development, 74*, 659-678.

Yasuda, K., Misu, T., Beckman, B., Watanabe, O., Ozawa, Y., & Nakamura, T. (2002). Use of an IC recorder as a voice output memory aid for patients with prospective memory impairment. *Neuropsychological Rehabilitation, 12,* 155-166.

Ylvisaker, M. (2003). Context-sensitive cognitive rehabilitation after brain injury: Theory and practice. *Brain Impairment*, *4,* 1-16.

Zittoun, T., Gillespie, A., Cornish, F., & Psaltis, C. (2007). The metaphor of the triangle in theories of human development. *Human Development*, *50*(4), 208-229.

Appendix 1: Excerpt of interactive verbal scaffolding during intervention

The protocol is hierarchically organised with steps, checks, and problem solving routines in the form of questions and actions. Each step comprises a series of checks. If the user passes each check, then no problem solving routine is initiated, and the user moves swiftly on to the next check. If the user fails a check, the protocol moves to the relevant problem solving routine. The protocol comprises 112 distinct prompts which are organized into 5 sub-steps, 17 checks, and 89 problem solving prompts.

In response to checks users say 'yes', 'no' or give no response. There are three optional verbal responses which although not necessary provide meta-control of the protocol. At anytime a user can say 'back' to go to the previous step, check, or prompt. At anytime the user can say 'done' to go to the next step, check or prompt. At any time users can say 'what?' to hear a prompt or question again.

The following is a short excerpt from a patient's interaction with Guide.

Guide:	[Sub-step 1] Welcome I am going to help you put on your artificial leg. The first step is to get all the bits you need. (Pause) [Check] Have you got your artificial leg?
Patient:	Yes
Guide:	[Check] Have you got your liner?
Patient:	Yes
Guide:	[Check] Have you got your socks?
Patient:	No
Guide:	[Problem solving routine] Are your socks in your leg?
Patient:	No
Guide:	[Problem solving routine] Are your socks in your liner?
Patient:	Yes
Guide:	[Problem solving routine] OK, get your socks (pause) [Check] Have you got your socks?
Patient:	Yes
Guide:	[Sub-step 2] Good, in this next step you will be securing your wheelchair (pause) [Check] Have you got *both* (emphasis) breaks on?
Patient:	(no response)
Guide:	[Problem solving routine] Would you like some help to put the breaks on?
Patient:	No
Guide:	[Check] Have you got both (emphasis) breaks on?
Patient:	Yes
Guide:	[Check] Have you moved any stump boards out of the way?
Patient:	Yes
Guide:	[Check] Have you removed any footplates that might be in the way?
Patient:	Yes
Guide:	[Sub-step 3] Great, in this next step you will be preparing your stump for limb donning (pause) Look at your stump (pause). Is there anything in the way?

Tables and Figures

Table 1: Participant characteristics

Participant number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Age	67	67	68	70	64	46	72	60
Aetiology of amputation	PVD [1.]	PVD	DM [2.]	PVD	PVD	PVD	PVD	DM
Days since amputation	319	43	40	53	113	41	484	86
Immediate memory [3.]	78	61	65	78	90	53	78	40
Visuospatial [3.]	62	56	112	58	84	75	64	50
Language [3.]	98	78	82	88	87	72	88	60
Attention [3.]	60	60	79	68	85	53	79	53
Delayed memory [3.]	44	68	48	64	102	64	71	60
Global cognition [3.]	50	55	71	64	85	54	69	47
Hayling classification	Impaired	Impaired	Poor	Abnormal	Average	Low average	Impaired	Impaired
Brixton classification	Impaired	Impaired	Impaired	Abnormal	Abnormal	Abnormal	Poor	Abnormal
ACE-R [4.]	70	72	83	69	92	81	65	51
MMSE [5.]	23	23	28	20	29	25	19	17

1. Peripheral vascular disease; 2. Peripheral vascular disease with comorbid diabetes mellitus.
3. Index Scores with Mean of 100 (s.d. 15).
4. Cut-off: <88 = dementia 94% sensitivity, 89% specificity; <82 = dementia 84% sensitivity, 100% specificity.
5. Cut-Off: <25 = significant impairment for age group and education (Iversen, 1998).

Figure 1: Laptop and wireless headphone used in the Guide system

Table 2: Average sequence performance indices by participant and condition

Performance indices	**Errors**		**Omissions**		**Deviations**		**Repetitions**		**Time (mins)**	
Condition	**Baseline**	**Guide**	**Baseline**	**Guide**	**Baseline**	**Guide**	**Baseline**	**Guide**	**Baseline**	**Guide**
Participant										
1	5.8	4.50	5.70	4.29	**7.70**	**0.86****	2.10	0.86	10.85	9.63
2	**2.58**	**0.80****	**1.33**	**0.55***	2.08	1.55	0.58	0.95	**2.20**	**5.02****
3	**3.13**	**0.85****	**3.00**	**0.00****	2.00	1.08	0.00	0.62	**1.12**	**4.18****
4	**2.33**	**0.20****	**1.83**	**0.50***	0.17	0.00	0.17	0.00	**0.37**	**2.17****
5	**1.42**	**0.14****	**1.50**	**0.14****	0.17	0.29	0.00	0.00	**1.01**	**2.64****
6	0.73	0.00	0.73	0.00	0.00	0.43	0.00	0.29	**1.87**	**3.26****
7	**1.00**	**0.44***	**1.11**	**0.89****	0.22	0.00	0.00	0.00	**0.44**	**2.63****
8	**0.56**	**0.17***	**0.56**	**0.00***	0.44	0.50	0.56	0.00	**0.38**	**2.57****
Mean	**2.22**	**0.94****	**1.97**	**0.76****	0.64	0.48	0.38	0.34	**2.28**	**4.06****
SD	1.71	1.48	1.69	1.46	0.88	0.57	0.72	0.41	3.53	2.43
T		4.80		3.95		1.04		0.22		-3.78
Sig.		0.002		0.006		0.33		0.83		0.007

* $p<0.05$, ** $p<0.01$

Table 3: Breakdown of safety critical errors by condition

Safety critical error	**Guide**	**Baseline**
Equipment not close at hand	3	12
Brakes not on	4	25
Urine bag not moved	2	5
Suspension sleeve inside out	0	0
Stump boards/foot plates not removed	4	24
Not removing a stump protector	0	0
Not removing a shrinker sock	0	0
Wrinkles not removed	29	113
Wrong prosthesis for side	0	1
Putting stump into liner and prosthesis at same time	2	5
Putting on foam liner but not pulling up sock	3	9
Taking brakes off then lifting leg	0	1
Knocking prosthesis with stump board	2	5
Placing stump boards/foot plates in an unsafe position	0	0
Side arms not down on chair	2	4
Pulling a second sock over foam liner	0	1
Prosthesis on backwards	0	0
Not checking fit of liner	7	34
Rolling nylon sock over prosthesis	1	2
Moving forward in chair with no brakes on	0	1
Sock inside liner	0	0
Not checking fit after donning	4	42
Putting on more than one sock at a time	0	0
Putting on leg with no liner	1	2
Wrong liner for side	0	0
Prosthesis at unsafe angle for donning	2	6
Liner backwards	0	0