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Assistive Technologies for People with Cognitive Disabilities: Challenges and Possibilities

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Abstract

According to the Journal, 'Inclusion', in 2012, 9% of the US population, or 28.5M Americans, had a cognitive disability. Worldwide the number is believed to exceed 630 million. This is a very heterogeneous group, with a wide variety of abilities and impairments making it challenging to develop assistive technologies to meet their needsA growing sub-set of this cohort is the aging population, who continue to work but experience mild cognitive changes. Though these these individuals have deep funds of knowledge, and valuable skills they may struggle in the workplace, in part due to lack of access to tools that can address their individual challenges. . The development of new technologies, such as cognitive assistants, has opened the door to more useful solutions. This paper will review the history and challenges of assistive technology for cognition (ATC) and highlight the work in which we are currently engaged.

Introduction

Machines and devices have long helped humans overcome physical limitations; we use cars, eyeglasses, airplanes, and hearing aids. Technology to augment cognitive function has also existed for a long time; writing, tape recorders, and search engines all serve to extend functions of memory and recall. However, although pervasive computing and the internet of things are well established, the application of these tools as assistive technologies for cognitive disabilities is still in its infancy.

Progress has been made; the past decade has seen an increasing number of applications which address specific types of cognitive disabilities. Additionally, the growing use of biometric devices, smart service systems and cognitive assistants such as SIRI or Amazon's new M, has also provided potential solutions. However, even as smart systems are being created, the field has still not settled upon a standard model for cognition.

Broadly speaking, cognition is the process by which sensory inputs are transformed, reduced, elaborated, stored, recovered, and used. Among the many feature of cognition are attention, memory, executive functions (eg. planning, problem-solving, self-monitoring, self-awareness) (Diller & Weinberg, 1993), comprehension and formation of speech (Sohlberg & Mateer, 1998), calculation ability (Roux, Boetto, Sacko, Chollet & Tremoulet, 2003), visual perception (Warren, 1993) and praxis skills (Donkervoort, Dekker, Stehmann-Saris, & Deelman, 2001)[2]. Cognitive processes can be conscious or unconscious (Eysenck & Keene, 1990), existing on a spectrum with varying degrees of strengths and challenges.. Even the ability to perceive and act upon social cues is deeply integrated into the concept of cognition.

Cognitive dysfunction, then, is defined as functioning below the expected levels in any of these specific areas[3]. Early insights into cognition in psychology, and other fields, were based on this conceptualization of distinct module of functionality within the brain. This in turn, has led to the development of specific ATC offerings corresponding to these individual areas of functionality. Although the tools that were developed from this view do provide significant value, as George Miller stated in 1956, 'Our journals, in their zeal for objectivity, have become catalogues of spare parts, for a machine they never build'[4]. Current research substantiates that Miller's machine requires a more holistic view. Tools such as fMRI have demonstrated that execution of tasks require cognitive functions that are integrated across multiple areas of the brain. This in turn has given rise to a new awareness; augmenting cognitive deficits is not simply a matter of creating a technology to modify an impaired skill set, but rather it must address the interaction between these various cognitive functions. Interestingly, the concept of an integrated model of cognition has led technology and psychology to join forces to propose a unified theory of cognition through such developments as the novel architectures of SOAR and ACT-R.

While a holistic view is important, the modular approach should not be disregarded. The categorization of discrete modules of cognition can be helpful in that it makes both technology development and rehabilitation programs easier to implement and understand. To this end, we use the International Classification of Function (ICF) as a framework for identifying the range of cognitive functions, defining both health and disability for the individual and for a population. The ICF is also useful in that it looks a cognitive function across all individuals rather than for a particular group. For example, similar cognitive challenges may occur across different user groups (eg. Autism and brain injury), or a given technology may support multiple cognitive functions.[5].

At the same time addressing cognition only from the lens of specific functionality presents a potential weakness in utilization, particularly in the workplace where tasks not only require multiple, interacting cognitive functions but are influenced by environmental factors. These environmental factors encompass such things are the psychosocial aspects of behavior, task specificity, human interaction and available technologies, whether they be as basic as pen and paper or as complex as WATSON. This concept, developed by O'Neil (O'Neil, 2014)[6,] is referred to as the neuro-socio-technical model of Assistive Technology for Cognition (ATC) and is a concept I will utilize throughout this paper. Today, with the advent of cognitive systems and smart technologies, we are in a position to incorporate the neuro-socio-technical model into providing comprehensive and truly personalized cognitive assistants who can enable individuals with cognitive disabilities to achieve employment productivity on par with their more neurotypical peers.

The Problem Description

People with cognitive disabilities are the largest group of individuals with disabilities. They comprise 9% of the population, are an estimated 630 million people globally and have the highest rates of unemployment and poverty of any disability group. They are the largest cohort of persons with disabilities, comprising 43% of all people with disabilities[7]. However, even when they bring strong abilities and deep knowledge to employment their specific challenges make successful employment difficult.

Due to improvements in healthcare, education and knowledge, more people with cognitive disabilities plan to return to work after injury, or to transition to work after completing an education. At the same time a rapidly aging population is experiencing minor, but impactful, cognitive changes that come with age. As both these cohorts engage in the workforce they may struggle to overcome the obstacles their disabilities may present. The cost of lost productivity due to unemployment of individuals with cognitive disabilities exceeds 100 billion dollars annually[8].

Cost is not the only factor. Employment is a key element in well-being for all individuals and especially critical for those with cognitive disability. Experts in the rehabilitation field recognize productive work as both the means and the end of occupational therapy interventions. Occupational therapy theory is founded in the idea that cognitive functioning can only be understood and facilitated fully within the context of occupational performance[9] In this light it becomes even more critical that effective ATC is made available.

Even within the set of available and useful ATC, most individuals with cognitive disabilities do not know what technologies or strategies would be most helpful to support them in performing a particular type of work task. While some individuals have had extensive services to provide training on accommodation, the vast majority have had a limited range of vocational assessments. Even when vocational services have been provided, service offerings are restricted by the knowledge base of the provider. According to ABLEDATA[10] there are an estimated 20,000 assistive technologies, so no single provider can reasonably know about all the options or even the best option for a given individual and task. Similarly when an individual identifies an effective strategy to address a challenge there is no vehicle to capture and disseminate this knowledge to others.

The Challenge for ATC

There are two overarching challenges in providing ATC for individuals with cognitive disabilities. The first is in identifying the correct ATC tools for the individual relative to the type of task (s)he needs to perform. The second is how to address the neuro-socio-technical needs of the user through a holistic and well integrated offering.

Linking a person to the best tools for a given set of tasks can be complex. Persons with cognitive disabilities are a heterogeneous group with a wide variety of skills, interests, abilities and impairments. Individual differences in style, interaction with environment, age, education, and experience can all inform how a given cognitive disability is best addressed. Comfort with technology and self-awareness are also critical factors in this selection. While occupational models of cognition do exist, they ultimately require an individualized approach to be successful. To successful meet these goals a team approach has been the standard of care[11], requiring neuropsychologist, occupational therapists, assistive technology specialists and others. Given the large number of individuals with cognitive disabilities however this is not always feasible. Consideration must also be given to the people with whom the individual interacts; caregivers often naturally assume a role of human cognitive assistant. An example of this is distributed memory; couples often naturally divide up domains of responsibility for what to remember[12]. This concept is referred to as 'scaffolding' and helps 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). Recognizing the role that therapists and caregivers provide is especially critical when addressing sequence performance difficulties. Scaffolds perform many prescriptive functions, demonstrating insight into a user's needs by providing external support for initiation, problem-solving, planning, sequencing, organization, self-monitoring, error correction and behavioral inhibition[13]. Thus part of the process of selecting ATC is identifying these kinds of tasks as they may be transferred to a technology system.

Incorporating the neuro-socio-technical aspects of task execution it makes it clear that ATC adoption is very individualized; even two individuals with a similar impairment performing the same task may require different type of ATC (or interactions with the same ATC). Likewise two individuals with very different disabilities, performing different tasks, may both benefit from the same tool. While human assessments are good at providing a fluid insight into a given individual's needs, they are constrained by the impossibility of having a comprehensive grasp of all the elements in a large database of available technologies. The size of this database continues to expand at a rapid rate; for example, apps for Apple Iphones for example will soon number in the one million, making the task ever more challenging.

The very nature of the cognitive disability may also impact technology usage; many individuals are not able to identify the specific cause of problems with a task, only that the task itself does not get executed properly. If queried, they may misattribute the problem; for example, individuals may assume that a failure to recall information is a memory deficit, when in fact it is rooted in an attentional challenge. The person sees the outcome (failure to remember) but misses the deeper problem of focus. Thus, self-reporting or self-identification is not always a reliable indicator for determining a person's challenges. Some users may have difficulty in sequence execution, thus recalling the steps for usage may present an obstacle that leads to abandonment of a technology. Indeed 90% of technologies are abandoned due to this reason. A key element for successful ATC is what is referred to as zero effort technology.

A user interface then must incorporate a user based design fomat, and provide an interaction that is iterative (learns from mistakes), adaptable (self-modifies as user needs change), unobtrusive and mobile (can be accessed and utilized from a range of devices and under different conditions), and prescriptive/always on (system recognizes users unique patterns and acts to predict user needs).

The human computer interface for ATC is critical. Successful ATC must address the specifics of a cognition function and must allow for integration of static information into fluid intelligence. For example, memory involves a number of sub-components (working-memory, retrieval, emotional content, rehearsal, attention, long-term memory etc). Capturing information in a static format (e.g. a voice recording) is not always enough to compensate for memory challenges; first the user must recall that they captured the information, and second they must put forth the effort to review it. Imagine that you recorded all your conversations in a given day and the only means by which to remember them was to review them by listening to them again. To do this even once would mean the individuals were doubling their work effort. Quickly this would become unmanageable. A more effective solution is to have a system which can provide cuing to support both recall that an exchange occurred, what occurred in the exchange, and its relevancy to the task at hand. Another advantage of such a prescriptive system is that it would assist in addressing problems with initiation, task re-immersion (after interruption), and perseverance.

Similarly, individuals with cognitive disabilities can find information overload as disabling as lack of recall. For example, while search functions allow a user to retrieve related files based on key words the person must still sort through files, some of which they may not remember at all and must reread in their entirety. Losing sight of the task goal can pre-empt the process of task execution.

These scenarios illustrate some of the important considerations as new types of ATC are developed. In summary, key factors in the next generation of ATC are; e; individualized systems that are tailored to a user's strengths, preferences and disabilities, support the socio-neuro-technical model through awareness of context, provide customized prescriptive functions that can act as scaffolds for task execution, be seamlessly accessible, support integration of static data into fluid intelligence, and be both dynamic and continuous in their interaction.

Where We Are Today

Much work has been done toward developing effective technology in the area of ATC. Traditional memory aides, such as calendars have been augmented in recent years by digital assistive technologies, such as personal organizers. Some, such as Evernote or Outlook, are geared towards the general population but still provide valuable functions; others such as Bionic Brain or Endeavor 3 are specifically designed for persons with cognitive disabilities[14].

Individuals with cognitive challenges may have difficulty with organization and execution of complex work efforts. The difficulty is not one of comprehension but rather of visualizing the overall process. Traditional ‘todo’ lists may fail to provide enough guidance. To address this some tools have expanded upon the traditional ‘todo’ list, creating sequencing systems that act as guides. These sequencing devices provide easy recall of the steps that need to be performed and the executive sequencing to order those steps correctly. Voice activated commands, sometimes in the users own voice, or other visual prompts have been shown to be effective in improving task performance (Lancioni, Van den Hof, et al, 1999)[15].. One of the earliest sequencing systems is the Planning and Execution Assistant and Training System (PEAT, Levinson, 1997). PEAT employs artificial intelligence systems to provide users with daily plans and includes an interactive Voice Mediated Assistive Technology for Cognition, which allows it to dealing with unexpected events and provide a degree of micro prompting based on visual cues (Levinson, 1997)[16].

The commercial product Pocket Coach provided by AbleLink, also uses a prompting system.. Pocket Coach enables 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).

PEAT, and other tools, such as, Neuropage and COACH (Cognitive Orthosis for Assisting with Activities in the Home), are used to guide users in completing activities of daily living and address issues of prospective memory by incorporating smart system functions, primarily, however, in the home environment.

To address memory and organization, many individuals rely on query-response techniques, such as search tools, to find data and files needed for task execution. However, a user with a cognitive disability may experience lack of recall in creating a document, resulting in them not even realizing that they have a need to search for it. Equally a broad search can result in gathering large amounts of data, some of which is irrelevant. This can prove to be distracting and result in overwhelm which impairs initiation and deflects from task completion.. One tool which was developed to address this is The Remembrance Agent (RA), a program designed to augment augments human memory by displaying a list of documents which might be relevant to the user's current context. Unlike most information retrieval systems, the RA runs continuously without user intervention. Its unobtrusive interface allows a user to pursue or ignore the RA's suggestions as desired.

Tools from business analytics, such as executive information systems, also represent a form of cognitive assistance, by presenting an overview of progress and change via a high level dashboard. For individuals who have difficulty with time awareness, or who need to see the status of all their activities for planning this can be very helpful.

Interface continues to be a major design issue for all these systems. The very cognitive disability that these tools seek to address may make adoption of the product challenging. In reviews of the field there is some concern that (LePresti, Mihailidis and Kirsch (2004) that ATC is not achieving the full level of success because instead of reducing cognitive load sequencing systems increase cognitive burden by requiring complex and unfamiliar interactions. These authors recommend that future ATC be more sensitive to the needs of their cognitively impaired users. (Scherer, 2001)[15]

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). Scaffolding was originally used to conceptualize the verbal support that parents provide to help children with task performance (Luria, 1961; Vygotsky & Luria, 1994; Zittoun, Gillespie, Cornish & Psaltis, 2007). Therapists and caregivers 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 behavioral 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.

Finally, the scaffolding provided by caregivers 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 caregivers. 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 Voice Mediated Assistive Technology for Cognition 9 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[15].

What is Missing?

Frequently associated with cognitive disabilities are certain challenges that present as behavioral issues, but are in fact linked to cognitive issues. Initiation of task, perceived as lack of motivation, may be related to organization or big picture thinking. This struggle can lead to task anxiety when any new task is performed. Individuals with cognitive disabilities may also process information more slowly, though accurately. Others may have greater difficulty with changing perspective rapidly. Recognizing and responding to social cues, often a critical element of the workplace, can be another challenge. Few ATC products currently address these issues. Some biometric devices can help with anxiety and new facial recognition systems are a step toward improving awareness of body language and social cues. However, much more needs to be done to understand how these challenges interact with other cognitive functions to support task execution and full engagement in the workplace.

Future Direction

As more individuals move into the workforce there is an increasing need for ATC can support the demands of knowledge work. . Individuals with cognitive disabilities have demonstrated they are capable of complex and productive work, but newer technologies are needed to address these challenges. It is our view that cognitive computing and smart service systems can be very effective in creating new pathways to address this need.

Our vision is for a service system that will provide a cognitive friendly gamified assessor that will help identify both abilities and challenges. The smart assessor will be able to integrate this information with context aware data to select a best fit tool or set of tools. Over time our system will develop its own ATC modules that are based on task type, and user profile and history. These modules will help meet the users' specific needs for both their individual challenges and for the tasks they need to perform. The cognitive assistant will continuously collects more information about user preferences and response patterns, learning to become more efficient and effective over time. Based on this the system will also be able to use predictive modeling, making assumptions about what the user will need, learned from patterning of interactions. Predictive modeling has faced challenges in the past due to the lack of context. However, we believe that context can be extracted from user patterns of interaction and be built up over time with increasing accuracy. The use of a service system to provide a fully integrated assessor, ATC modules and recommender system will also insure privacy, which is often a concern.

In summary our goal is to develop novel cognitive assistive technologies embedded in a self-modulating and self-sensing smart service system platform, to address cognitive challenges when performing work related tasks. This service system platform will also serve as a means to collect real time usage data for further understanding of how individuals with cognitive disabilities interact with their environment.

t is our belief that we are on the cusp of changing our understanding of cognition as well as breaking through existing limitations for many individuals with cognitive disabilities. Our work in this area has just begun.

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