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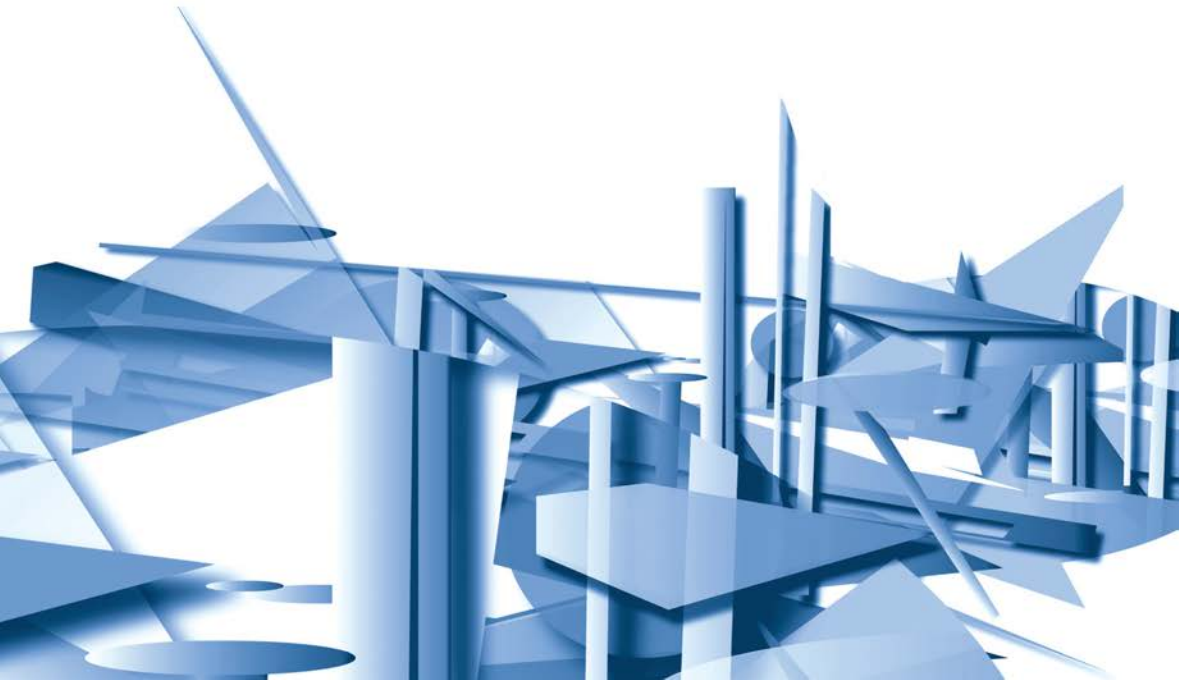
Assistive Technology for Cognition

A handbook for clinicians and developers

Edited by BRIAN O'NEILL and ALEX GILLESPIE



ASSISTIVE TECHNOLOGY FOR COGNITION

Assistive technology for cognition is technology which can be used to enable, enhance, or extend cognitive function. This book systematically examines how cutting-edge digital technologies can assist the cognitive function of people with cognitive impairments, with the potential to revolutionize rehabilitation. Technologies are reviewed which direct attention, remind, recognize, prompt, and generally guide people through activities of daily living.

Written by experts in neuropsychology and technology development, *Assistive Technology for Cognition* provides a comprehensive overview of the efficacy of technologies to assist people with brain impairments. Based on the list provided by the International Classification of Function, each chapter covers a different cognitive function; namely, attention, memory, affect, perception, executive function, language, numeracy, sequencing, and navigation onto which existing and future assistive technologies for cognition are mapped. This structure provides in-depth research in an accessible way, and will allow practitioners to move from an assessment of cognitive deficits to the prescription of an appropriate assistive technology for cognition. The chapters also make suggestions for future developments.

Assistive Technology for Cognition will be of great interest to clinicians and researchers working in brain injury rehabilitation, technology developers, and also to students in clinical psychology, neuropsychology, and allied health disciplines.

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FOREWORD

Ian H. Robertson

The most famous exemplar of what technology can do to reduce the handicap produced by a brain disorder must surely be Stephen Hawking's speech synthesizer. True, there is a remarkable personality and brain driving the artificial speech, but Hawking manages to be a celebrity scientist engaging with the world at an incredibly high level in spite of the most profound disability.

Hawking's tinny voice has become integrated with his media persona to the extent that it is now an icon of modernity – a token of human ingenuity's triumph over its fragile biological underpinning. This is a good example of the 'neuro-socio-technical' mechanisms by which brain, society, technology – and of course psychology – have come together in the application of technology to brain disorders. The editors of a first edition of this volume on assistive technology for cognition – I am sure there will be many future editions through the decades – have made the first step towards what is likely to be the dominant approach to cognitive disorders over the next 50 years.

The human brain rapidly integrates tools and pointers into its body schema[1] and any semi-addicted user of a smartphone will recognize the psychological amputation which occurs when it is lost. This is good news for the future of assistive technology in the realm of cognitive disorders, but the challenges in this domain are also daunting, as several of the chapters in this book point out.

In particular, many technologies make demands on key cognitive functions such as prospective memory and other executive functions, which may themselves be impaired. The great Russian neuropsychologist, Luria, the pioneer of cognitive rehabilitation, was very pessimistic about the possibility of intrinsic compensatory adjustments leading to therapeutic improvement after damage to the frontal lobes, and he believed that only external prompts and aids to 'scaffold'[2] the behaviour deficits would be likely to be successful.

But Jamieson and Evans are more optimistic in their chapter on executive function, suggesting that, particularly in the case of prospective remembering and goal maintenance, technologies may well improve prospects for at least some of these core cognitive deficits. The NeuroPage system is an excellent exemplar of this, one of the few technologies to have been submitted to randomized trials evaluating relative long-term benefits.[3]

Other types of memory are also beneficiaries of technological advances, as Dewar, Kopelman, Kapur, and Wilson show in their chapter on memory. The use of SenseCam is particularly intriguing and the reality of instantly retrievable storage of images and sounds recorded unobtrusively throughout the waking day offers as yet not fully realized possibilities for some compensation for perhaps the most intractable of all cognitive disorders – amnestic loss.

The prospects for novel neuro-pharmacological treatments for most cognitive disorders look limited for the time being, but the prospects for assistive technologies in mitigating the effects of cognitive disorders, now in their infancy, look very promising. This book makes a great start in documenting their rise.

Notes

1 Maravita, A. and Iriki A. (2004). Tools for the Body (Schema). *Trends in Cognitive Science*, 8: 79–86.

2 Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

3 Wilson, B. A., Emslie, H. C., Quirk, K., and 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: 477–82.

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ASSISTIVE TECHNOLOGY FOR COGNITION

Brian O'Neill and Alex Gillespie

This introductory chapter aims to provide an introduction to assistive technology for cognition. It begins with an overview of the long history of augmentation of cognitive functions using technological devices. The chapter will then propose a framework for assistive technology for cognition (ATC) based on the mental functions. The developmental dependence of our cognitive abilities on cognitive technologies throughout the lifespan will be outlined. The loss of cognitive abilities and, thereby, increasing dependence, leads to changes in social relationships and the need for negotiation of roles. Emergent technologies may help reposition individuals with brain impairment within society.

When we refer to ATC we mean technologies which enable, enhance or extend cognitive function when used. We do not mean technology which aims to restore function, that is, cognitive training technology. We do not mean technologies which have awareness of the state of the user but do not feed this back, these are monitoring technologies. We do not mean technologies which perform activities for a person, these are robotic technologies. In ATC, the human user is an autonomous agent using tools to facilitate their own cognition and thereby their independent action and social participation.

A brief history of assistive technology for cognition

The history of human civilization can be written as a history of technology (Mumford, 1934; Clark, 2003; Aunger, 2010; MacGregor, 2010). Technologies are any human-created artifacts that extend human abilities (Kapp, 1877; Lawson, 2010). Bows, catapults, and guns extend our ability to throw objects. Chariots, bicycles, and cars extend the range and velocity of our bipedal mobility. The telegraph, radio, and telephone extend our ability to project the voice over distance. Thus, human culture can be seen to largely comprise technologies which extend human abilities, and, on the other hand, technologies can be seen to mark the major turning points in human history.

McLuhan (1964) refined the conceptualization of technology by observing that technologies were increasingly extending cognitive function. For example, writing, printing, and digitization extend the ability to remember what was heard. Cameras and Google Glass extend our ability to remember and communicate what was seen. Almanacs, indices, and search engine technologies extend the ability to recall information from memory. The range of different technologies, which we often refer to as simply media, have progressively extended our memories and allowed us to communicate them so effectively that they are shared. The key point is that these "cognitive technologies" are not used to act on the world, to do things directly, but they are acting on, and enhancing, human cognitive capacity (Gillespie and Zittoun, 2010).

Arguably, the most longstanding and powerful technology of cognition is language (Vygotsky and Luria, 1994; Mead, 1934). Language makes humans "natural-born cyborgs" (Clark, 2003: 1). Language enables us to leverage the cognition of others to solve problems (Dascal, 2004). But language also changes the way humans think; like any good tool, it makes it more efficient. Young children solve problems better when they are allowed to talk themselves through the task problem (Fernyhough and Fradley, 2005). By using self-talk, including self-questioning and self-arguing, we can enact multi-step behaviors to accomplish complex ends, and remain motivated to continue in the face of adversity to achieve distant outcomes (Larraín and Haye, 2012). Language also enables the encapsulation of cultural knowledge in the form of heuristics, which, again, greatly extend human capacity for learning and action (Gigerenzer and Todd, 1999). Language and heuristics, and other symbolic resources such as narrative structures, are so woven into human psychological processes that it is impossible to completely tease these components apart. Moreover, these ubiquitous cultural technologies are rarely even recognized as technologies, precisely because they are so prevalent (Clark, 2003). They are opaque because we have assimilated these tools as part of ourselves (Cole and Derry, 2005).

Language and heuristics have been amplified in their effect on human cognition by technologies such as writing and numbers. It is likely that writing developed specifically to augment shared human memory, by externalizing and distributing it (Powell, 2012). Its first uses were to store memories for numbers of items, such that two people could later agree on the quantities involved. But later writing also allowed for enhancement of communication and the circulation of ideas, enabling one person, usually a leader, to speak to many. Edicts, pronouncements, and proclamations facilitated larger and more coordinated human collectives (Burke, 2000). Such collective action also required the training of persons in the use of the technology, namely, reading. Tellingly, writing was often less encouraged. This enhanced enhancement was subsequently further extended in power by the printing press, and more recently by the digital revolution (Gillespie, 2010). Historians now increasingly recognize the powerful effects of such technologies in terms of their effect on the cognition of users. The circulation of a perfectly reproduced Bible arguably enabled the Protestant Reformation in which people were encouraged to have their own relation to God via the Bible (Watt, 1994). The printing press allowed nations of people to circulate identical texts and images about themselves and thus to imagine themselves as a collective for the first time; thus, arguably, contributing to the birth of nationalism (Anderson, 1993).

The effect of technologies on cognitive processes has also been documented, with, for example, academic texts and associated thought, becoming increasingly precise and "word processed" in a way which was impossible before word processing (Heim, 1999). Equally, the range of knowledge that people can now access is historically unprecedented, leading to behavioral changes. Where once a medical doctor was consulted as a repository of medical knowledge, patients now increasingly access and read scientific papers relating to their condition (McMullan, 2006). This can empower their position as decision makers in their own healthcare.

The development of electronic computing is a defining advance in human tool use. Initially modeled on human cognitive processes, it is perhaps the tool which resembles us most, has most to offer to our understanding of human cognition (Johnson-Laird, 1988), and which theorists have predicted will increasingly resemble human cognitive processes (Turing, 1950) – and possibly even supersede human cognitive processes (Kurzweil, 2000). Artificial intelligence has become prevalent in most aspects of the contemporary world. Indeed, we use terms such as ubiquitous computing to describe the independent intelligent systems, zero effort technologies that control and coordinate aspects of our environment (Mihailidis *et al.*, 2011). But despite the ubiquity of artificial intelligence, researchers and clinicians have been slow to utilize it explicitly in replacing lost aspects of the intellect; with the first reviews of this topic originating only in the late 1990s (Cole, 1999).

The scope of this book

We hope to have demonstrated that technologies that assist our cognition are normal, ubiquitous, and increasingly integral to human practical and cognitive function. In our recent history, sanitation and health maintaining technologies have proliferated. They have significantly extended our lifespan, which has steadily increased by three months per year for over 160 years (Oeppen and Vaupel, 2002). But this extended lifespan brings with it the increased likelihood of living with infirmity and cognitive decline (Ferri *et al.*, 2005). Medical technologies and techniques mean that we are living longer, but with disabilities following what was once deadly illness. Our chances of surviving damage to the brain have increased steadily over time (Marshall, 2000). Where once inflammation and infection were lethal, now those with brain injury survive with impairments of brain function. The care needs arising from cognitive impairment, secondary to brain injury, and the dementias are prevalent at levels hitherto unseen, and only set to increase in the coming decades. These needs may in part be met by assistive technologies for cognition.

Human societies, enabled by technological advances, have become increasingly complex and, thus, activities of daily living demand increasingly high levels of socialization and cognitive capacity. To have had a prospective memory difficulty before the invention of clocks and time-keeping would, arguably, have been less disabling than the same deficit today. To have had difficulty dividing attention has less of an effect on activity if one has a single task to perform. Our cultural practices are often complex sequences of action requiring high level cognitive skills to achieve. The seemingly simple and near universal social practice of sharing a cup of tea has become a surprisingly cognitively demanding task. Today, to offer a guest a cup of tea demonstrates having an income, being able to use money, interact with shop-keepers, have and use a range of technologies to safely boil the water, and plan and sequence the actions to skillfully make the tea. To be unable to offer a guest a cup of tea marks disability, removes the ability to be hospitable, affects social standing and often marks one out as needing care. Assessment of a person's ability to make a cup of tea, and from that inferring the status of cognitive processes, is a key skill of the occupational therapist (Hannam, 1997). Tea making is a marker for self-care abilities more generally. Accordingly, it is in such daily tasks where advances in technologies for cognition can have the most significant impact. Perhaps new technologies can make the difference between dependency and independence.

Technology for assisting cognition is a huge topic, and, accordingly, we have had to narrow the focus of the book. Specifically, we only consider physical high-tech devices which have been explicitly developed to augment cognitive disability. Thus, we are excluding the many non-physical (i.e. heuristic or semiotic) augmentations of cognition. For example, language (Dascal, 2004), heuristics (Gigerenzer and Todd, 1999), and symbolic resources (Gillespie and Zittoun, 2010) have been found to extend human cognition. Yet, we are leaving these out of consideration because they are difficult to clearly identify, document, and evaluate.

Second, we are excluding from consideration the many "low-tech" physical technologies which extend human cognition. Such devices are commonly used for storing information (notebooks, diaries, and ledgers), calculating large numbers (abacus, pen, and paper), prospective prompting (diaries, alarm clocks, and notices), and sequencing behavior (recipes and manuals). It would take a separate volume to review these devices, their historical emergence and efficacy. Our focus is specifically on the recent development and upsurge of high-tech devices.

Finally, of the high-tech devices that are used to enhance normal or high-functioning cognition, such as computer software, smartphone apps and the alarms, reminders, and prompters used routinely by the population, we will include only those with an evidence base in the alleviation of cognitive deficits. This is the area in which there has been most rapid growth and where new technologies can have the most significant benefits (LoPresti *et al.*, 2004; Gillespie *et al.*, 2012).

Conceptualizing ATC in terms of cognitive function

Despite a surge of interest and research in assistive technologies for cognition, a psychological conceptualization has been lacking. Existing reviews have been organized in terms of the type of assistive technology used (LoPresti *et al.*, 2004), their efficacy (de Joode *et al.*, 2010) and their rehabilitation aims (Cole, 1999), or user groups, such as older adults (Pollack, 2005) or people with dementia (Bharucha *et al.*, 2009).

While extremely important contributions, the underpinning conceptualizations make it difficult to recognize two important factors: first, that similar cognitive deficits arise in different user groups, and, second, that a single technology might be used to support a variety of cognitive functions. We hasten to add that the excellent paper by LoPresti *et al.* (2004) not only coined the phrase "assistive technology for cognition" but also began to define ATC from a neuropsychological point of view. We view our efforts as an expansion of their work (Gillespie *et al.*, 2012).

We propose to use specific mental abilities as a framework for understanding ATC. Specific mental abilities are modular; subject to focal assessments and rehabilitation interventions. Throughout this book it will be shown how these specific cognitive abilities can be selectively augmented by ATC.

Mental functions are specific and seem to have a modular organization. From the 1850s onwards, neurologists and psychologists have produced a literature of careful behavioral descriptions of survivors of specific brain lesions. These accounts began to demonstrate that people can lose specific functions such as the inhibitory control of behavior (Harlow, 1868), language production (Broca, 1861), language comprehension (Wernicke, 1874/1969), face perception (Bodamer, 1947, cited in Ellis and Florence, 1990), episodic memory (Scoville and Milner, 1957), color perception (Pearlman *et al.*, 1979), and semantic memory (Warrington and Shallice, 1984), to name but a few. Thus, neuropsychology began to slowly develop a picture of the functional specificity of brain areas. Later, dissociation studies demonstrated experimentally that people with and without specific damage to a brain circuit differed in yet further mental abilities. The revolutionary functional brain imaging technologies of the 1980s and 1990s largely supported the hypothesis that the mind is modular. We saw demonstrations of specific neural activations underpinning motion perception (Zihl *et al.*, 1983), attention (Posner and Petersen, 1990), calculation (Stanescu-Cosson *et al.*, 2000), and executive functions such as remembering to enact an intention (Burgess *et al.*, 2011). Fodor (1983) extended the case for cognitive modularity by arguing that modularity of function makes evolutionary sense, because it is easier to debug or improve a complex function if it can be differentiated and changed without change to other simultaneously evolving but encapsulated systems. Equally, we suggest, technologies in support of the cognitive functions would be best debugged or improved if they were specific in their function.

The specific mental functions already have a literature on their specific rehabilitation (Halligan *et al.*, 2003; Scottish Intercollegiate Guidelines Network, 2013) and are readily measured with current psychometrics (Lezak *et al.*, 2004; Strauss *et al.*, 2006). Accordingly, conceptualizing ATC in terms of cognitive function will facilitate prescription of ATC. Indeed, it is our aim that the current book will enable clinicians to progress directly from assessment of cognitive deficit to identifying potentially effective ATC.

There have been many attempts to categorize the modules that compose the mind. A consensus statement was required and the present book uses the International Classification of Function (ICF) as our classification of cognition and function (Üstün *et al.*, 2003; World Health Organization, 2002). Using the ICF as a framework to review, assess, and explore the potential of ATC has many benefits.