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# Emerging Technologies for the Rehabilitation of Executive Dysfunction and Action Disorganisation

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**Abstract**

The inability to use objects to carry out everyday activities presents some of the most debilitating and complex problems in neurorehabilitation. Disorders of the higher level control of tool use and multi-step actions can arise from a wide range of neurological conditions and can be traced to underlying impairments of praxis, executive control and action organisation. Current treatment approaches are inconsistent, labour intensive and inefficient. Yet cognitive technologies, particularly the development of scheduling and reminding tools, is enabling a major shift in how these conditions are being managed and are likely to be treated in future. After briefly describing disorders of executive function, apraxia and action disorganisation syndrome this review considers how innovations in micro-prompting devices, intelligent systems and smart homes are beginning to transform rehabilitation as a product of increasingly accessible mainstream technological advancement. It is argued that in comparison with conventional rehabilitation these cognitive technologies are more flexible, efficient and cost-effective. Key challenges to technological exploitation are noted and to be fully realised user involvement at each stage of development is essential whilst credible studies of efficacy and cost-benefit are likely to be required to ensure widespread adoption and willingness to pay.

**Keywords:** Cognitive technology apraxia; Dysexecutive syndrome; Action disorganisation syndrome

## Introduction

The use of electronic technologies in the rehabilitation of higher neurological disorders has had a patchy history, with much early innovation failing to live up to initial enthusiasm, despite some individual positive outcomes [1-3]. A key problem identified by Robertson [4] was one of generalisation from training scenarios into everyday life, an issue which continues to undermine the effectiveness of computerised rehabilitation programmes [5].

In response a number of *in vivo* methods were developed to be used in daily life as opposed to practice-based therapy sessions. These focussed initially on communication and memory to assist or augment cognitive function. Following the success of reminding systems such as Neuropage [6,7] and Memojog [8] the major growth in cognitive technology has been in the form of organisational and prompting technologies to address functional disability arising from neuropsychological disorders following stroke, traumatic brain injury, dementia and other neurological conditions [9].

Assistive technologies are now starting to be used both as cognitive orthoses, compensating for underlying impairments, and as training tools where there is evidence of learning [10]. Cutting across traditional scientific disciplines, cognitive technology embraces engineering, design, computing, medicine, psychology, sociology and philosophy. The field of cognitive technology is in its infancy but as mainstream technologies become ever more pervasive, portable and customisable no longer is there is distinct division between ‘assistive’ technology used by people with disability and the population at large. In a very real sense we are moving from talking about assistive technology to accessible technology.

This brief review summarises the current state of the art in the technological rehabilitation of two distinct but related syndromes: the dysexecutive syndrome and the deficits of action control that underlie apraxia and action disorganisation syndrome (AADS). Following a brief introduction to these syndromes key emerging technologies are reviewed. They offer potential for more individualised, efficient and cost-effective rehabilitation but there is a clear imperative for user-experience to drive future development and for credible objective evaluations of clinical and cost-outcomes.

### Clinical syndromes of the organisation of action

Executive skills are the most advanced form of cognitive ability, responsible for how we behave in a complex social world. Executive abilities include skills such as planning, problem solving, reasoning, judgment and decision making. They are not usually involved in routine tasks but are critical for everyday adaptive behaviour. Consequently even subtle problems with executive functioning can cause major problems in daily life but may not be apparent in the highly structured context of a formal neuropsychological assessment.

Executive deficits are but one form of behavioural consequence of frontal lobe dysfunction [11], linked to the dorsolateral region. Impaired functioning can also result from other areas of prefrontal damage, notably disorders of drive and motivation (superior medial), emotional and behavioural regulation (ventro-medial) and self-awareness/metacognition (frontal pole). These types of neurobehavioural symptoms often cause a greater degree of handicap in daily life than would be expected from cognitive test results




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alone and a key technological challenge is to develop systems and devices that can address this constellation of difficulties. Treatment to date is based on hands-on input from therapists and support workers for both executive dysfunction [12] and neurobehavioural disorder [13].

Apraxia by contrast is a disorder of gesture and/or tool use not attributable to lower level sensory or motor impairment or higher level language and perceptual deficits. It is typically associated with left hemisphere lesions [14], but multi-step sequences are also impaired by right hemisphere and subcortical lesions [15-17]. Frontal lesions may also cause apraxia, considered by Luria [18] to reflect a loss of goal-directed behaviour and Schwartz and Buxbaum [19] as loss of top-down control leading to competing intentions.

Action Disorganisation Syndrome (ADS) refers to the inability to carry out multi-step actions and is thought to arise from a form of double-deficit: damage to stored knowledge of routine actions and impaired executive control of attention that would otherwise compensate for action slips [20]. This leads to deficits of naturalistic action that have been observed after head injury [21], stroke [22] and dementia [23,24]. Current treatment is largely restricted to formal sessions of therapy with limited results to date [25].

## New and emerging technologies

**Micro prompt devices:** In recent years a number of prompting programmes have been developed with potential to assist a wide range of organisational and memory problems [26]. An early example was Levinson's hand-held Planning and Execution Assistant and Trainer (PEAT) which addressed organisational aspects of behaviour using software developed by NASA [27]. Planned activities are specified as scripts that are incorporated into a daily schedule, the system monitoring task completion and providing visual and auditory prompts as required. The introduction of a dual user interface, with a caregiver designing task scripts, may enhance engagement, as reported for the Memory Aid and Prompting System (MAPS) [28]. Many of these aids were developed for PDAs [29] and have since translated to smart phones [30].

Whereas scheduling devices can be helpful for patients with memory and organisation difficulties, sequencing devices may have more utility for patients who exhibit problems with praxis and action initiation and sequencing. O'Neill and Gillespie [31] developed the General User Interface for Disorders of Execution (GUIDE) system, which provides voice prompts to assist people to carry out self-care tasks independently. It is based on a scaffolding principle whereby performance is facilitated by questioning and prompting that would normally be undertaken by carers, and has been shown to aid learning in washing and dressing [32].

**Action prompting systems:** There is no clear divide between hand-held cueing devices and more extensive prompting systems, as single devices are increasingly able to connect to larger systems, but under this heading are included programmes that require more than a single piece of equipment to fulfil its function. Typically these technologies use sophisticated algorithms to track behaviour and modify output accordingly. For example Autoreminder [33] monitors task execution and provides prompts and incentives as necessary if problems are detected.

La Placa, et al. [34] developed MOBUS, a flexible task planning programme designed to be used by a caregiver in conjunction with a patient. The planner component generates an individualised activity schedule based on information about daily activities, which is exported to a portable assistive device. Algorithms based on a Hierarchical Task Network generate subtasks which require planning (and potential cueing), and which was shown to approximate to how caregiver reasoning would break down complex tasks into smaller steps.

The COACH system [35] was designed to reduce caregiver burden by prompting patients to complete everyday activities such as handwashing. It derives information about the world via camera and provides audio and video cues. In between is a complex process of determining the intentions (belief state) of the user on a probabilistic basis in order to deliver cues effectively.

Methods from human factors have been shown to be valid in characterising apraxic errors and action slips [36] but still the challenge of modelling action effectively is complex. It requires a system that can accurately track what the user is doing in three dimensions, collate multiple sources of information into a single metric, match the data to a pre-specified stage of task execution and identify discrepancies between the task model and the user's behaviour. The systems needs to be able to identify errors of commission and omission, steps completed out of sequence and fatal (irreversible) errors. Ideally it should be able to anticipate failure in order to prevent fatal errors (such as spreading peanut butter onto bread before inserting it in the toaster, or adding too many sugars when making coffee). Having identified an error the system needs to interact with the user to prevent its occurrence or re-start the task from a suitable juncture. All this needs to be done in real time and in a manner that does not disengage the user from the task.

One promising mathematical technique is the use of partially observable Markov decision processes (POMDPs) that allows a system to learn to recognise intent behind action [37,38]. The state of the user in carrying out a sub-stage of a multi-step activity is represented in a hypothetical task model by a probability distribution that is updated multiple times per second by action recognition processes in order to determine whether the user's actions are consistent with the task goals and subgoals.

A similar approach was used in developing CogWatch [39,40] which to date is the only method with cues specifically designed to address the difficulties presented in single object use (apraxia) and sequencing (action disorganisation). The system uses sensors embedded in objects and Kinect-based information on movement to provide errorless feedback via a central processor and can be used as a training tool or compensatory aid. None of these systems has yet been developed to a point where they can be used in large scale trials but they do indicate the direction in which assistive technology is developing.

In essence they embody the new AI - Ambient Intelligence [41] as everyday objects (such as cars, televisions, refrigerators, heating systems) are increasingly embodied with sensors and computing power that allows them to interact with one another and an end-user. Characteristic features of ambient intelligence are that it is ubiquitous, sensitive, adaptive and responsive, all of which offer great potential for a truly immersive rehabilitative environment. This potential is best represented in the Internet of Things which is ripe for exploitation by developers of assistive cognitive technologies [42].

**Smart homes:** The natural extension of inter-connected systems is the Smart Home, a term variably used to describe a range of set-ups from incorporation of 'intelligent' objects in a normal home to a fully integrated, inter-connected domestic environment. For people with disorders of executive and action control the current largely passive technologies like monitor-response systems have potential to develop into tele-prompting systems that may offer off-site assistance much as current manual devices do now. Whilst these would involve personnel resources, limitations to which have been one of the drivers to develop-self-prompting technologies, a central prompting pool may provide a more manageable resource in future [42]. Such systems can also provide valuable information on task performance during the course of the day and highlight hitherto unknown risky behaviours [43]. These systems are likely to prove particularly relevant to individuals with dementia living at home as well as more severely impaired survivors of stroke, head injury and other neurological insults living in sheltered accommodation.

Alternatively, proactive user engagement is a realistic aim for higher functioning adults with more specific impairments of action control (for example stroke survivors or neurosurgical patients with circumscribed lesions). Technological advances mean that cheaper, more flexible integrated home-based systems are likely to increase the opportunities for people who struggle with everyday actions to access a range of tools within the home.

### Advantages of cognitive technologies in rehabilitation of action disorders

Technological interventions for action disorders have three distinct advantages over the current therapist-based approach: flexibility, efficiency and cost-effectiveness. First, with regard to flexibility, this is the major advance of assistive technologies in recent years, as everyday objects can be embedded with sensors, accelerometers, gyroscopes and radiofrequency (RFID) tags that permit wireless communication with a user, healthcare professionals and other devices in the home almost without geographical limit. Objects can also be customised to user requirements, possibilities which are set to be greatly increased with the advent of 3-D printing technology. Software developments, much of it open source, allow increasingly sophisticated data analysis and prompting methods that can be programmed for each patient's unique neuropsychological profile. Finally battery life is becoming less of a limiting factor in ensuring sustainable working devices.

Assistive technology also promises to provide a more efficient rehabilitation method, especially for patients with potential for learning. Whereas therapy is largely hospital-based, people need to learn how to function in their own homes and communities. Portable assistive technologies accomplish this 24 hours a day in a way that no therapist ever could achieve. Even when support is provided at home it is limited in availability. Caregivers may not prompt every time a cue is needed nor do so consistently each time whereas electronic prompts can be delivered invariably and in timely manner (promoting errorless learning which is more efficient than trial and error learning). Data collected can be stored and communicated safely and securely far more readily than paper and pencil checklists. It is also easier to update a programme to instantiate changes in prompting regimes than re-train a caregiver to change their behaviour. In addition it reduces burden on family caregivers and avoids issues of low morale, absenteeism and staff turnover common amongst external care providers.

The above advantages also mean that electronic prompting devices are likely to prove very cost-effective over the longer term compared to conventional therapy which is both labour-intensive and in short supply. As yet prompting technologies have not been subject to cost outcomes analyses although research suggests that they could usefully undertake some of the cueing and guiding currently undertaken by support workers in the home [44,45].

## Conclusion

A wide range of neurological conditions is associated with high-level impairments in organisation of actions necessary for everyday independent living, the most commonly reported being stroke, dementia and traumatic brain injury, which together constitute the major demand for neurological care across the lifespan. It is worth reiterating that debilitating disorders of praxis, executive function and action disorganisation often occur in the absence of sensory or motor impairment and are often misunderstood and overlooked. Yet the growing interest amongst scientists and engineers of various persuasions in developing prompting technologies offers a new paradigm for managing and treating such disorders [46]. Equally, take-up of new technologies depends on many factors including useability, reliability, perceived utility and social norms that calls for a broad-based considerations at the development stage [47-49]. Norman argued that operational knowledge needs to be instantiated first and foremost in the device not the user, making use of natural mappings between structure and operation, yet typically inferences about function drawn from structure are not particularly helpful when people are using technology [50]. One solution is to avoid unsolicited technical development without due regard to the neuropsychological constraints of the patient user; another is to ensure users are closely involved in the design and testing of new cognitive technologies. Phillips and Zoa [51] cited lack of consideration of user opinion in selection as one reason for abandoning devices. Conversely adoption of assistive technology is influenced by design features such as aesthetics, useability and lifestyle compatibility [52].

It is always difficult to predict the future of healthcare and this is especially risky in the field of technology where the pace of development seems to outstrip ability to keep up to date and game-changing breakthroughs can quickly render existing technology out-dated. Nevertheless the prospects for rehabilitation are very promising and nowhere is this more evident than for the management of disorders of action and executive control. Professionals and potential users are positive about the future of cognitive technologies whilst recognising that there needs to be more availability and acceptance of these benefits from insurers and other payers [53]. Greater acceptance will in turn drive further technological development. It is to be hoped that, as prompting devices and systems become more widespread and adaptable for individual patterns of impairment, this is matched by evidence of cost-effectiveness in order for funders to engage and help shape the future of cognitive technology.

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