Age-Related Cognitive Impairment and Home Technology Design

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Abstract: Ability of older adults to use an appliance depends on their mental model of operation. This may depend on transfer of understanding from similar, more familiar technology. Leveraging established mental models creates affordances for operating new technology but may constrain the discovery of advanced functionality. Familiar mental models may also interfere with developing appropriate mental models or interaction behavior. Older adults experience cognitive decline in attention, perceptual encoding, memory (cuing and recall), and self-efficacy. Designing appliances to extend cognitive abilities provides opportunity to prolong functional independence. Concepts from cognitive psychology, human factors, and gerontology are reviewed to explain age-related behavior towards technology to support innovative product development of technologies for older adults with cognitive impairment.

Keywords: cognitive impairment, domestic appliances, elderly, human-centred design, human factors, human-machine interface, man-machine interaction, mental model, working memory, gerontechnology

1. INTRODUCTION

An ageing population and lower birth rates are contributing to a contracting labour market in many industrialised countries. Within ten years, there will be less than half the number of workers for each aged person in the developed world (Anderson and Hussey, 2000). Decrease in working age populations, coupled to increasing numbers of senior beneficiaries, diminishes revenue for programs such as Medicare and social security (Anderson and Hussey, 2000).

Physical and mental decline with ageing concerns psychomotor, perceptual, and cognitive abilities. As the aged population expands, incidences of mild cognitive impairment (MCI) and Alzheimer’s disease (AD) will dramatically increase. The proportion of seniors with MCI is expected to double within forty years (Alwin et al., 2008).

While technology innovation has extended lifespan, there has been little effort in developing technologies that support cognitive decline (Alwin et al., 2008). Cognitive decline can weaken learning and skill acquisition associated with fluid intelligence, spatial ability, perceptual speed, and working memory. Disparity between extending lifespan and declining cognitive abilities highlights the need for research into developing technology to sustain independence during cognitive decline (Vaupel and Yashin, 1985).

Personal independence depends on the ability of seniors to perform instrumental activities of daily living (IADL). Self-reliance depends on their capacity to use domestic appliances such as washing machines, dishwashers, stoves and heaters. Seniors may lack confidence in dealing with new devices: perplexity replacing familiarity. Their inability to adapt leads to increased dependency on family members, friends, and service providers. Where support is scant, seniors may be impelled to move into residential care.

2. APPLIANCES FOR SELF SUFFICIENCY

Developing new appliance technologies that compensate for declining abilities may be a means of sustaining self-sufficiency, thereby delaying admittance to residential care. Integrating behavioural science and engineering in a context of product design allows designers to create technologies for supporting and extending declining abilities.

Competency in using a technology varies from novice to frequent user. Seniors must learn how to use new products that enter their life. In Georgia, USA, research into the use of Automated Teller Machines by seniors showed that users taught the procedural steps outperformed users undergoing conceptual training. These findings held for both learning and retention over 24 hours. Contrastingly, the type of training experienced by younger users did not affect their performance (Mead and Fisk, 1998; Rogers et al., 1994). These studies suggest that instructional design for seniors should be crafted to their learning style.

Proficiency depends on capacities and capabilities of working and long-term memory and attentional resources. Although, the subject of the Georgia studies was studying seniors learning to use a new device—an act of cognition—the researchers did not attempt to measure cognitive impairment.

3. COGNITIVE IMPAIRMENT

As executive control in working memory declines with age, so does functional status measured by IADL (Royall et al., 2004). Performance of IADL concerns planning, organisation
and flexibility, which are functions of executive control. Carlson et al. (1999) found that attention is critical for completion of many complex, everyday activities. Schieber (2003) decomposes attention into four modes. Within these modes, selective and divided attention are of particular interest for the design of appliances to support age-related cognitive impairment.

Impaired attention affects how many objects a person can attend in a display. For example, where the person seeks the “fast forward” button on a DVD player, he/she focuses on a suitable target. In doing so, the number of other objects he/she can attend in their visual field decreases. This decrease, coupled with an age-related increase in latency of ocular movement (Scaiffa et al., 1987) puts elderly people at a significant disadvantage when searching for a particular control in a busy display. This suggests that to reduce the demands on attention, designers should limit the number of control devices in appliances. However, Ball et al. (1988) found that through practice of target selection, seniors could partially recover their ability to attend multiple objects. Therefore, it may be possible to introduce control devices progressively, without detracting from attentional resources.

The visual features of control devices consist of various primitives, such as shape, colour and orientation. From the perspective of Treisman and Gelade’s (1980) feature integration theory, recognising a control device through visual search depends on the user’s perceptual system extracting the graphical primitives followed by integrating features. While extraction takes advantage of perceptual automaticity, the integration process relies on selective attention. However, selective attention declines with age. Plude and Doussard-Roosevelt (1989) found large differences in response time for feature integration between older and younger experimental subjects, where there were a conjunction of features that subjects must detect in identifying the target. The results suggest ageing leads to decreased ability to integrate features for target recognition. Inefficient integration in working memory detracts from encoding. When designing technology for seniors, Schieber (2003) therefore advises limiting the number of features that users must integrate to discern targets from non-targets. The lesson for appliance design is to make control and display items clearly different to both one another and the background by lessening shared features. This will support encoding, thereby making the target selection process more efficient over a shorter period.

Successful uses of appliances depend on users monitoring performance and activating controls when necessary. For example, using a stovetop to cook multiple items and the oven to cook a roast requires independent monitoring of the cooking progress of each item and increasing or decreasing heat accordingly. This monitoring means task switching between items often. However, older adults have difficulty switching their current focus of attention to another in response to a cue (in the above scenario, the cue is the look and smell of the food item). They have to disengage their attention from the current activity and move it to another display item (Posner et al., 1987).

Different cognitive abilities deteriorate at different rates (Hertzog et al., 1996). Lima et al. (1991) found lexical based tasks are bound by a common slowing factor less than that of the slowing factor for spatially based tasks in seniors. This may present an important implication for the design of home appliance technologies for seniors with MCI. For example, it may be beneficial to present stimulus and target information in different modalities (e.g., verbal and visual) and to carefully select control and response/feedback modalities less affected by age related cognitive decline.

Seniors in normal domestic environments must also be able to program or control appliances under the intrusion of demands from other appliances (including phones) and communicating with other persons. Performance depends upon the competition of limited attentional resources and the modality of the input and processing codes (spatial or verbal). Where there are concurrent tasks, performance may be influenced by confusion, cooperation between task processes and competition for task resources (Wickens, 1991). From their testing of dual tasks of car steering and simultaneous visual scanning, Brouwer and colleagues (1990) found that age-related reduction of steering accuracy in older adults was halved when a vocal response to stimuli was required rather than a manual response. Taking advantage in design of dual-modal processing and response presents opportunity to increase operator efficiency. In addition, this method can also inhibit outside stimuli from interfering on the performed task.

Older adults have much greater difficulty performing tasks that require a large degree of self-initiated information processing for tasks that are not accompanied by environmental support (Craik, 1986). Since recognition tasks offer more environmental support than free-recall tasks, and cued-recall offers more support than free-recall, Craik’s notion is supported. It may therefore be possible to improve interface interaction performance in older adults by integrating recognition and cued-recall based retrieval methods into appliance controls.

Control of appliance depends on memory abilities of users, such as reprocessing stored information when making judgements. These abilities deteriorate with cognitive impairment (Bopp and Verhaeghen, 2005). They found that the ability to store information without manipulation in short-term memory worsened with age. Cognitive decline is associated with an inability to inhibit outside stimuli and thereby interfering with resources in working memory that are available for the controlling task.

Creating and manipulating mental models is a function of working memory (Johnson-Laird et al., 1992). In simulating a mental model, a person must operate the mental model while adhering to its constraints. Once formulated, mental models tend to remain static and resistant to change (Richardson and Ball, 2009), until changes to the functionality of the represented system in the real-world requires information to be reprocessed in working memory. Richardson and Ball suggest that difficulty overcoming invalid mental models is due to limitations in the capacity of working memory. Inability to consider, assess and reprocess
alternative action sequences in the formation of mental models is exacerbated by MCI.

Cognitive load associated with learning is often very high for older adults with MCI due to difficulties attending displays, discerning device features, and processing information in working memory. As a result, it hinders their progressive development of well-formed mental models. ISO 20282 is a new set of standards currently under review “Ease of Operation of Everyday Products” which may lead to better product design guidelines for older users with MCI.

4. DESIGNING APPLIANCES FOR COGNITIVE IMPAIRMENT

Effectiveness of new technology correlates with users forming apt mental models that guide their use. Successful formation and use of mental models depends on persons holding and working with information stored in memory. Clearly, persons with MCI are at a disadvantage. However, if they recognise the problems they are trying to solve fit into a familiar cognitive structure, they may be able to reduce the cognitive workload (Sweller, 1988). Sweller argues for training processes that chunk problems into categories that reduce the load on working memory.

Designers of appliances that meet the needs of older adults with MCI should perhaps exploit their understanding of familiar technologies. Users could then transfer learned patterns of control between old and new technologies through top-down processing of information stored in long-term memory (Schieber, 2003). As well as exploiting known mental models, demands on working memory can be reduced through training. Van Gerven et. al. (2002) provide experimental evidence that elderly persons benefit more from training through the study of worked examples than means-ends learning. The worked examples were based on Sweller’s cognitive load theory. The aim is reduce the number of mental operations during learning by encouraging learners to spend time on task-relevant operations.

Control structures that seniors anticipate to be present in the new product from their mental models of its progenitor may create cognitive barriers that restrain exploration of new functionality. A simple example concerns typewriting. Seniors proficient in the use of typewriters may apply their mental model of a typewriter to word processing: for example, hitting the enter key multiple times to get a new page rather than using the command to insert a page break. Recognition of new functions requires time and effort. Such investment can be monumental for individuals with impaired attention and memory. However, if they can control basic functions of the product, users can easily ignore the features for additional controls. They may even be resistant to suggestions to explore other features; adeptness with an inappropriate mental model can lead to cognitive tunnel vision (Moray, 1999). The price of this method of product use is an undeveloped mental model. The obvious cost is partial use of the product. However, there are less tangible costs: perhaps, awareness of incapability and fear of doing something “wrong” may lead to a loss of self worth.

Additional forms of interference can manifest when using a new product, similar to a familiar product, where some functions are common. For example, a VCR and a DVD player have similar functions: controls for “play” and “fast forward” in the DVD conform to a portion of a user’s existing mental model for a VCR. Locating and triggering these controls depends on the similarity of the surface features between the old and the new and confounding presence of many other control and display items. Cognitive workload from searching and recognising them depends on selective attention, which is affected by age-related cognitive decline (Verhaeghen and Cerella, 2008). The classic study by Rabbit (1965) demonstrated higher response time by seniors in discerning target stimuli from non-target. Further, exploring unrecognised control items in the new product requires learning novel functions by reprocessing information in working memory. Cognitive load in attention and working memory abilities are increased in what Verhaeghen and Cerella (2008) call multiplicative compounding.

One way to offset the need to hold and/or modify information in working memory is to offload information to be remembered, by representing it in the environment (Zhang, 1997). Often seniors can cope better in familiar surroundings by externalising information. Many older adults, who wish to remember to perform a task in the future, adopt some form of external memory aid (Maylor, 1990), such as personal notes or intentional placement of objects. This can assuage age-related decrements in prospective memory (Einstein et al., 1997). Older adults who do employ such techniques often outperform younger adults in tests of prospective memory (Schieber, 2003). By externalising information in the environment, sufferers of MCI have available to them cues to prime explicit memory.

An externalised appliance interface can cue an operator in a variety of forms. For example, an operator must be cognisant of the goal of the operation, the current state of operation, what tasks were performed to lead up to the current state, and what tasks are necessary to continue navigating towards the goal. Any combination of these forms of cueing may assist an MCI affected older adult in control of a device. The challenge in designing externalised appliance interface control lies in defining the method of cueing (e.g. audio / video / both) and what singular or combined forms are most effective given the state of cognition of the user. In this regard, the process of externalising information requires care. Setting a suitable degree of externalisation is difficult, as there is no reliable method for measuring cognitive impairment in older adults.

For each person suffering MCI, its form is singular. Therefore, quantifying the range of cognitive deficiencies and its advancement is problematic. Studies of cognitive ageing usually only capture a snapshot of performance at a single time by comparing inter-individual differences for different groups. This does not capture variation in declining abilities of persons within and between age groups. Longitudinal studies of traits within age cohorts may address this issue. Persons born at the same time form a cohort that share a social milieu. Cohort analysis shows varied patterns of ageing contingent on several properties including personality.
development, lifestyle preferences, and cognitive performance (Dannefer and Patterson, 2008). These properties are affected by societal factors such as state of technological advancement, politics, education, economy. These factors vary with the period and therefore affect successive cohorts in different ways.

Familiarity with home appliances from a particular period—may influence a person’s mental models of appliance operation. Exploiting these mental models of control may create affordances for appliance designs beyond simple physical and sensory considerate ergonomics for older adults.

Longitudinal studies of individuals as their physical, sensory, and cognitive abilities decline may help identify the relationships between these changing faculties. However, such studies are fraught with complexities, such as the learning effects of repeated cognitive tests increasing performance opposing age-related declines (Alwin and Hofer, 2008). Turvey (1992) discusses affordances in terms of potential or latent possibilities. Controls on appliances may provide the means for potential possibilities, but they only become affordances if the user realizes their potential. A latent predisposition for an applied method of device control exists when operating a device similar to one a user is familiar with, possibly creating a bias difficult to offset if the new device controls are not appropriately presented.

Integrating classical test methods and latent-trait theory (item response and Rasch models, De Boeck and Wilson, 2004) into longitudinal study may offer a more congruent means of assessing intra-individual factors (across samples) that predispose an older adult for rate and corresponding form of cognitive decline, allowing for better clinical predictions. Designers with access to cohort-specific statistical patterns in changing cognitive abilities will have a much stronger grasp on addressing cognitive ergonomics for this demographic. Determining familiarity with certain forms of technology will provide insight into designing applicable internalised and/or externalised control methods that support latent predispositions whilst enabling encoding of extended functionality.

5. SELF-EFFICACY AND TECHNOLOGY

Advancement of technology moves at a rapid pace and we are frequently required to develop competency in methods of control with which we are unfamiliar. Often, initial attempts to control new devices are unsuccessful before we learn successful strategies (Turnage, 1990). Deficiencies in attention and working memory further exacerbate the learning process. In designing products for older adults with MCI, functionality balances complexity. Difficulties in learning may affect self-efficacy in initiating and completing tasks. Personal choices regarding behaviours to engage in, persistence during task difficulty and likelihood of achieving mastery of behaviour is influenced by self-efficacy (Compeau and Higgins, 1995). For seniors with MCI, learning how to control a new product is stressful. Cognitive distress arising from the feeling of a lack of control over stressors may contribute to the lowering in self-efficacy and thereby impair cognitive functioning (Bandura, 1989). A vicious cycle of stress arising from inability to control the product, lowering self-efficacy, and adding learning with consequential accentuation of stress. In a study of individuals learning to use computers, Compeau and Higgins (1995) found that encouragement of success served to enhance self-efficacy and outcome expectations. They suggest that encouragement indirectly influences behaviour by directly affecting self-efficacy and expected effects of action. For MCI affected older adults using new forms of technology, integrating some form of encouragement of successful action into an interface may positively affect learning by facilitating better encoding, easing the formation of new mental models, and ultimately streamlining control whilst enhancing user satisfaction.

6. ADAPTIVE APPLIANCE CONTROL

Perception, attention, and memory are related to primary and secondary mechanisms of cognitive control theory. Primary mechanisms include active behaviour in manipulating external forces. Secondary mechanisms include internal cognition, emotional constructs, and mental reframing mechanics for offsetting loss of control (Gitlin, 2003). Ashby’s law of requisite variety (1958) concerns the benefits of balancing the variety of the controlled system with the variety of the controller. Addressing an MCI affected system by using adaptive secondary mechanisms of control, creates opportunity to aid forms of cognitive impairment through a joint cognitive systems (Hollnagel, 2003) approach to design. The goal of this approach is to quantify deficiencies on either side of the system and create solutions that extend functional limitations in an effort to optimise efficiency.

Designers of appliances can provide externalised cues in the form of Gibson’s affordances through Ecological Interface Design techniques of Vicente (1999). Affordances in the interface compensate for cognitive deficiencies by transferring information from memory to the world. Existence of affordances depends on users locating the cues within their mental model. By exploiting an individual’s existing mental model, an affordance acts as externalised prospective memory. In effect, the cognitive system combines internalised and externalised memory: that in the head with that in the world.

Designers of home appliances must consider multiple users with varying abilities. The automatic generation of cues that guide persons with MCI may be helpful. However, when using appliances in which the interface and interaction process conform to human-factors principles, many users will not need prompting. The need for guidance may decrease as users become familiar with an appliance’s operations. Nevertheless, lapses in attention and memory of older adults with MCI may affect their mental models of appliance operation. A system of prompting that provides user-specific guidance when necessary, lessens or withdraws as users gain proficiency, and occasionally prompts users during lapses in performance, may assist users with varying levels of ability.

7. DISCUSSION / FUNCTIONING IN THE WORLD

Maintaining independence in the home is a priority for older adults. Lack of ability to perform independent activities of
daily living will create dependence on family, friends, and service providers for assistance, possibly leading to premature admittance to care facilities. The likelihood of strain on social systems is great given the large cohort of baby boomers set to retire over the next few decades.

Developers of home appliances should be aware of the physical, sensory, and cognitive challenges facing a large contingent of the approaching elderly population. Without extending design briefs to encompass these deficiencies, developers will face barriers to the use of their products. Training older adults to use new technology may extend their independence at home. Cohort analysis and integrated latent trait research may provide insight into levels of impairment for representative populations. Familiar mental models from past technologies may then be ‘recycled’ through training that uses familiar cognitive structures. Integrating attentional controls and extending capacity for working memory, in designing the interface and the interaction process of home appliances may further streamline learning and extension of mental models, thereby providing better capacity for planning and achieving goals. In addition, instructional assistance in the home environment without peer pressure or time constraints will support self-efficacy in older adults by reducing anxiety associated with personal awareness of cognitive decline whilst using technology. Encouragement of successful outcomes will also strengthen efficacy, further supporting willingness to learn functionality. Instructional delivery of appliance control must be flexible and adaptive for the variety of users, and due to the unpredictable nature of cognitive decline. Methods of instructional delivery can include varied combinations of audio, visual, or state recognition prompting techniques that increase or decrease based on a users level of mastery and/or cognitive capacity.

A major challenge to research into age-related cognitive decline is the formation of an integrated methodology for measuring intra-individual differences across time. These measurements can help researchers determine the modes for the delivery of stimuli and responses that are efficacy supportive and appropriate for specific levels of prompting for controlling attention and enhancing working memory. Integrating internalised and externalised methods of control into specific levels of prompting and defining transitions between levels will also challenge researchers creating adaptive guidance control for designing home appliances.

REFERENCES