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DEVELOPING COGNITIVE CAPABILITY SCALES FOR INCLUSIVE PRODUCT DESIGN

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Abstract

In order to assess capability for product design, we aimed to develop new scales to assess the cognitive capability ranges for individuals by using items from the existing UK ONS scale to construct new scales, re-analysed in terms of cognitive requirements. The new scales were constructed by classifying each test item with reference to a simple cognitive user model representing an overview of cognition constructed from well-established findings in mainstream cognitive science [1]. Using the original data from 7,500 interviews of the original survey, new scorings were re-calculated from the resulting scales. These new scales: (1) Executive Function, (2) Memory, and (3) Expression and Comprehension, were compared with data from the existing scales in terms of the amounts of impairment indicated for a number of capability ranges. As a result, suggestions for the improvement of the ONS scales as measures of cognitive capability in product design were identified.

Keywords: product design, customer demands, empirical study

1 Background and Objectives

The rights of older and disabled people are growing in prominence. Increasing awareness of this challenge is reflected in legislation, such as the 1996 Disability Discrimination Act. By 2020, almost half the adult population in the UK will be over 50, with the over 80's being the most rapidly growing sector.

Recent research into inclusive design [2] has investigated the relationship between capabilities of the population at large and guidelines for the design of features of products. This research suggests that a good representation of the capability range of individuals can be made on a three axis scale derived from the basic psychological dimensions of sensory, motor and cognitive capability.

Existing scales for the assessment of cognitive capability ranges, such as those compiled by the UK Office of National Statistics [3], focus on intellectual function as a combination of a number of items and sub-scales devised by health practitioners and validated using panels of judges. While effective in other areas, these scales may not reflect cognitive capability of individuals as they were derived from practical needs in healthcare without any unifying system or theory. We addressed the need to derive scales giving accurate capability estimates for product design by re-analysing the existing survey data in the light of modern cognitive psychological theory.

2 The Cambridge Inclusive Design Model

The development of a systematic basis for cognitive assessment for the purposes of matching individuals to products should make reference to an overall approach to accessibility and disability in the population at large. The simplistic model, to be outlined, is intended to tackle in more detail a number of specific issues more generally addressed by the Cambridge Inclusive Design Cube [2]. Based on early psychological theories of key-stroke interaction with basic character-based computer terminals, the Design Cube is a representation used for analysis of human interaction with computers, such as may take place while using computer–based assistive technology products. The three axes of a 3D cube are used as imaginary scales of degree of capability with the fully able user being represented as the nearest bottom corner (Fig. 1). Clearly, in this representation, the cognitive scale is a summation of the effects on the individual's capability of a range of fundamental cognitive competencies. The simplistic model, to be outlined below, allows the nature and relative importance of those competencies to be examined at a general level. Furthermore, the model allows interactions between sensory, motor and core cognitive functions to be specified in order to address specific tasks and skills.

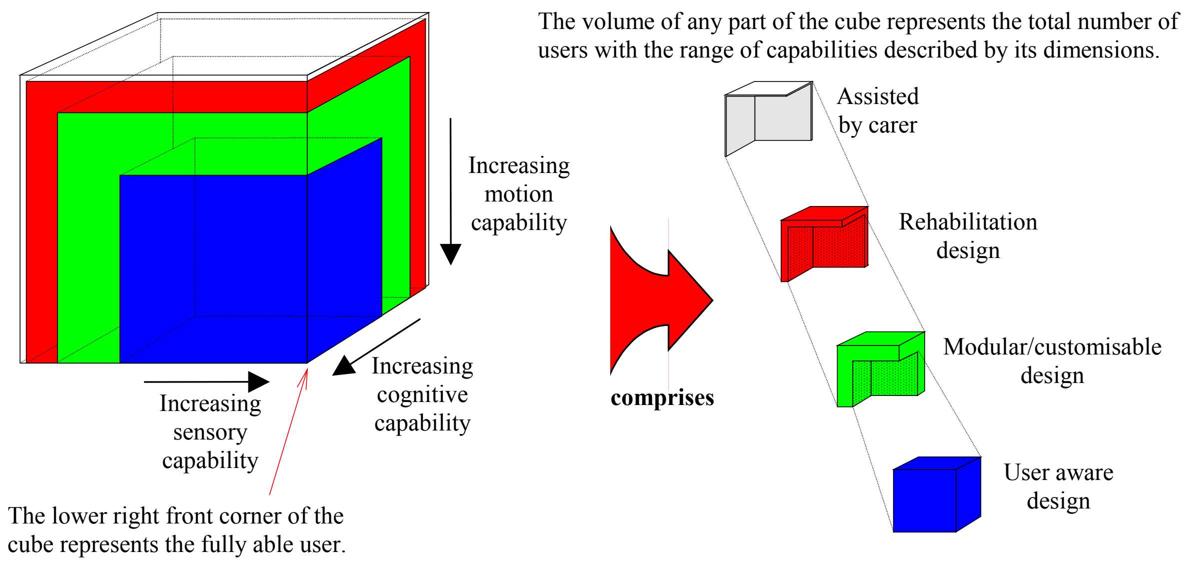

Figure 1. The Cambridge Inclusive Design Cube

It also follows that the cognitive simplistic model can also be used to unpack the detailed considerations that correspond to user perception, cognition, and motor function. For example, methods of verifying the users' perception of a computer–based AT display in an accessible interface can be derived from standard tests of visual cognition, such as visual search tasks that measure the relationship of the features of a target object in a visual display field to the time taken to detect that object [4], or figure-ground detection tasks that relate the time to detect a target to the visual grouping properties of clusters of 2D features. The simplistic model can therefore be used to specify the detailed content of the design of assessment methods for product designs. In particular, it is aimed at the cognitive elements of such an assessment, such as memory, attention and executive function.

2.1 The sources of data

In order to assess the ranges of capability in the UK population pertinent to features of product designs, a source of data is required. Data is readily available for the range of sensory and motor scale dimensions but the cognitive dimension is often poorly addressed, in this case, by only one scale, that of intellectual function. We address the underlying considerations for construction of a scale of cognitive capability both for the purpose of individual and product assessment and as a basis for the creation of guidelines for inclusive product design.

There are many sources of capability data such as: Adultdata [5] and Older Adult [6], which focus on anthropometric-based capabilities; the RNID for data on deafness [7]; and the RNIB for data on visual impairments. We address one of the most complete representative data sets, the disability follow-up to Great Britain Family Resources Survey (FRS) [8] designed to establish the prevalence of disability in the UK. In the following section we examine the methodology used to derive the scales used, focussing in particular, on the "intellectual function" scale.

2.2 The Scales of the Disability Follow-up Survey

The Great Britain Disability Follow-up Survey (DFS) was based on a measure of severity of disability established through the consensus of judges assessing the capability limitations of a variety of disabilities and their combinations. To give an overall severity score a one-dimensional interval scale was constructed from these judgements and used as an estimator.

The Methodology of the DFS

Survey items based on the ICIDH (International Classification of Impairments Disabilities and Handicaps) definitions of disability [9] were used in the field collection of data from 7500 interviews using a stratified probability clustering sample, prior to any scale development. The original items were designed to cover all the disability areas at all levels. The DFS methodology utilised panels of judges for 10 areas of disability identified from the original items and reduced to manageable levels for judging. This was done on the basis of criteria such as: inclusion in the survey; avoidance of inter-correlation; simplicity and elimination of over inclusive items. The 100 judges were selected from professionals with appropriate expertise such as doctors, physiotherapists, occupational therapists, clinical psychologists, independent researchers and disabled representatives of voluntary organisations. Judges were required to place cards notating limiting activities on a scale from 1(least limiting) to 11 (most limiting) without regard to handicap, prognosis or age but with regard to activities of daily living. Items with low reliability were removed at this stage and statistical measures of between-judge agreement were used to assess consensus. Judges out of line with the majority were excluded. The resulting scales were highly correlated with each other (greater that 0.81) apart from that of intellectual function (0.19). This was due to poor agreement between more than half of the judges. As a result of this a new scale was constructed by asking judges to rate the severity of impairment arising from 11, 8 and 4 items expressing an intellectual limitation. It was assumed that there was a linear relationship between severity and number of problems without regard for the nature of the "intellectual" impairment.

It seems likely that this assessment scale, dependent as it is on diverse original test items that confounded a range of cognitive functions, does not reflect cognitive capabilities in a systematic way. For this reason, we aimed to carry out a reassessment and reclassification of the original selected test items in terms of their categorisation in terms of well-accepted elements of mainstream cognitive theory.

The DFS survey finally recognised thirteen capability scales of which seven are most relevant to product evaluation: locomotion, dexterity, reach and stretch, vision, hearing, communication, and intellectual functioning. Each of these scales, ranging from 0 (fully able) through 0.5 (minimal impairment) to 12.5 (most severe impairment), were aligned by 57 judges to ensure that equal scores broadly related to equivalent levels of disability [10].

The DFS explored all thirteen of the capabilities, giving the interviewee a score for each. These scores were therefore moderated to provide a common scale across all capabilities, i.e. a score of 5.5 on locomotion was judged to represent the same loss of capability as a score of 5.5 on vision. As a result, the severity scores are not evenly spaced, indeed neither are the definitions consistent in their language of description. In this case locomotion includes consideration of walking, bending and straightening, falling and balance, and climbing (steps and stairs). This is typical of all the scales and applies in the same way to the intellectual scales and reflects the validity considerations inherent in using the data for anything other than population estimates.

In addition, the DFS assessed the prevalence of multiple capability losses by obtaining judges ratings of severity resulting from a selection of representative profiles of 2, 3 and 4 multiple disabilities occurring together and relating the resulting scales using a liner-regression model of influence on overall severity. The resulting alignment of the severity scales allows for the combination of scores to give an overall severity category. This is derived as a weighted sum where:

$$\textbf{disability score} = \textbf{worst} + \textbf{0.4} \times \textbf{(2nd worst)} + \textbf{0.3} \times \textbf{(3rd worst)}$$

This weighted sum was then re-scaled into a final overall severity category using the mapping shown in table 1.

Table 1. Correspondence between disability scores and severity category

		Least severe									*Most severe*
Disability score	0	0.5-2.95	3-4.95	5-6.95	7-8.95	9-10.95	11-12.95	13-14.95	15-16.95	17-18.95	19-21.4
Severity category	0	1	2	3	4	5	6	7	8	9	10

The survey data allows the Great Britain (GB) population to be segregated by age and gender and capability. This use of a number of capability scales and bands differentiates the approach taken in this paper from standard inclusive design practice, which focuses only on one capability.

2.3 The Simple Cognitive Model

Cognitive psychology can provide a rich variety of architectures for working models. For example, simplistic architectures like Broadbent's Maltese Cross [11] capture an overview of cognition but do not attempt to be complete, whereas more complex models like the Interacting Cognitive Subsystems approach [12] consists of an information processing, parallel approach that attempts to be complete and to address the complexity of realistic cognition. In addition, there are neural networks [13], which aim to mimic the human brain and provide a computer instantiation; production systems such as ACT [14] which reflect both cognitive psychology and computer simulations of cognitive processes. There are also approaches such as Marr's computational model and broader framework [15] which derive from research into Artificial Intelligence, exploiting nerurophysiology, engineering, and computer science. Whilst any of these could be used to model the assessment of cognitive skills, we adopt a parsimonious approach based on Broadbent's (1984) simplistic model (Fig. 2).

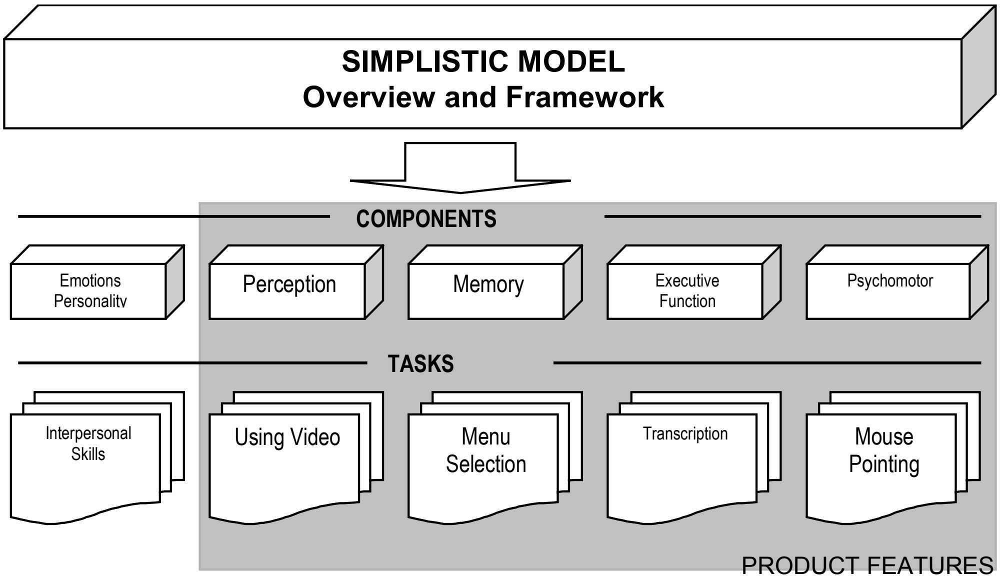

Figure 2. Unpacking the simplistic model for practical application

The aim of this approach is to develop a simplistic framework, which provides a first approximation for a model of cognition. It should be possible to show that the model of cognition can be unpacked to act as a framework for highly detailed sub-models such as a model of memory processes [16].

The overall structure adopted in shown in Fig. 3. It consists of a set of four memory stores that are linked by a central processing system. One of the roles of this central system is to transfer or copy memory traces from one store to another. The processing system also acts as a selection filter. This initial formulation (Broadbent, 1984) leaves out any indication of input and outputs, implying some form of selection or filtering before the sensory memory store. More recent adaptations of this model [17] incorporate a selective filter before sensory memory. However, the present model also allows for more advanced forms of selection when information is transferred between memory stores and allows for memories to be present in one or more stores, either partially or fully.

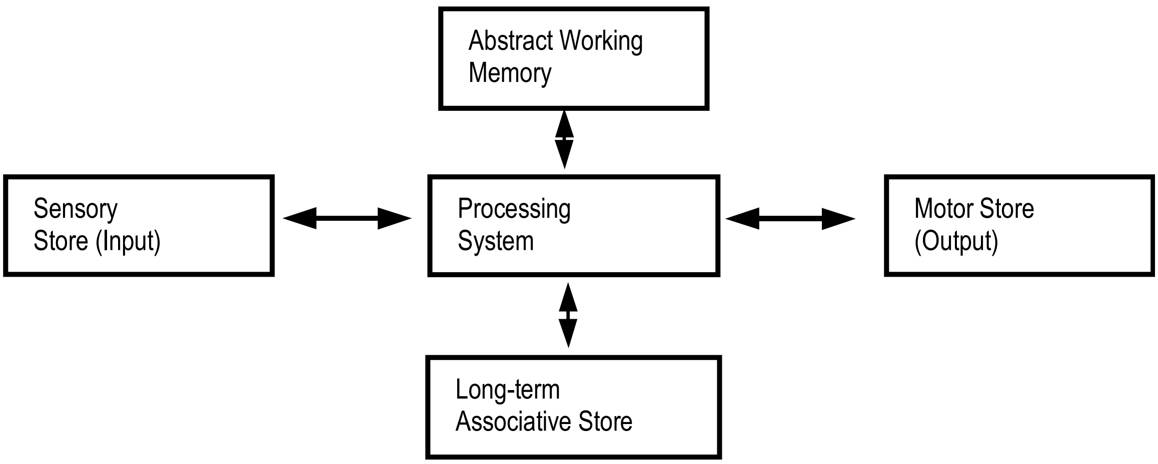

Figure 3. The overall structure of the simplistic model

Sensory Store: This is a limited capacity memory store that accepts transfers from the other stores as a translation or change of code. This store mainly receives a relatively raw input from the senses. It is divided up in terms of the physical dimensions that describe sensory inputs. A key feature is that a fresh input in the same region of store makes it difficult to retrieve items that are already there. The sensory store is not passive but a constructive encoding of the original sensory stimulus. The defining quality of this store is the presence of interference between memory events that share common physical qualities. In particular, where a memory is abolished or reduced by subsequent items, it would only occur where the subsequent items shared physical qualities. The reference experiment for this store would be the "stimulus suffix" effect where recall of memory test items is impaired by the presentation of a following item [18].

Output Store: This store holds sequences of motor output programmes, including sub-vocal speech sequences and is normally the last stage before responding. However, these programmes need not issue into overt actions but can feed back into another store. This it would include the coding of a sequence of inputs into an internal series of articulatory commands such as internal speech. Interference will be produced where a person undertakes actions using the same motor system. Thus, "articulatory suppression" occurs where the speaking of unrelated material impairs performance on an unrelated recall task [19].

Abstract Working Memory: Interference between memories may not depend on similarity of later input, but rather on the sheer numbers of items. It is a temporary, limited capacity memory. Memories could be crowded out by a very large volume of information if a large amount of central processing is performed. Thus memory for letter trigrams such as XDB may be more difficult than memory for familiar acronyms such as USA because of memory chunking of familiar material [20].

Long term Associative Store: This is not concerned with events themselves but with the running totals of the co-occurrence of stimuli e.g. the number of times Event A and Event B have occurred together in the experience of the person. It is not a temporary store and may be used to explain practice effects and automaticity. The model assumes that with practice the individual builds up stronger associations between the relevant items in the task being learned. There is no sudden change from deliberate to automatic processing. As the task becomes more practised, the individual leans the associations better. This would occur when someone learns to associate two items (A – B) and subsequently has to learn a new association (say A and C). The subsequent association impairs recall of the former association. This is known as retroactive inhibition. It should be noted that this is not the only long term memory facility in the model as the processing system needs to store long term changes in procedures. These would not themselves be held in the long term associative store.

Processing System: The processing system or central executive has the principal role of transferring information from one memory store to another. For example, on presentation of a symbol e.g. "2", then this leads to an identification of the name as "two". Thus the system must retain rules for transition on a long term basis, in order to transform "2" into "two". Thus this system need to have its own long term memory, since these rules are not stored in the long term associative store. The Processing System must also have some form of shorter term memory to keep track of current and recent actions.

Extensions to the model: Selective filtering of information is important in the computerised working environment. The model allows for input selection. For example, you might select all envelopes with the words "Confidential" before all others. The model and content selection, as when you select all items that are related to financial planning, since that is the area you are working on. This occurs when transferring information within the model. Implications for Cognitive Scales

It is clear that the simple cognitive model divides a number of cognitive distinctions that reflect findings in experimental psychology but are not preserved within the DFS question items or the intellectual function scale. Rather, the items of the original scales confound and confuse cognitive capabilities in the same way that they combine physical capabilities such as reach and stretch, dexterity and locomotion. The principal gain from using the model in this context is that it supplies a coherent theory based on established findings that can be used to contextualise the construction of specific scales.

The model, as outlined, allows for memories to be present in one or more stores, either partially or fully. In principal, the model subsumes the following areas of capability:

Executive Function

- - input, output and central attentional processes; visual cognition; visual search
- - attention and executive function; reasoning and abstraction; meta-cognition

Memory

- - input, output and working memory; task learning; visuo-spatial memory
- - memory structures: catagorisation and output processes; meta-memory

It also implicates linguistic cognition involved in speaking and writing. However, two scales of expression or comprehension constructed on the basis of the used the model used the same items as the existing communications scale when amalgamated.

2.4 Method

The individual survey questions from the ONS scale were categorised according to the area of cognition they addressed using the simplistic framework for guidance [22]. This categorisation was then used to construct a number of new scales corresponding to cognitive categories using the original SPSS data from the survey. Following the design research methodology developed in [1] validation of the new scales was performed at two levels: (1) self consistency with the original scales (2) conformity with existing derived comparison data. The new cognitive scales were embedded within the Cambridge EDC capability-scaling tool [2] and the calculated scores compared with those generated by the original intellectual functioning scale for a range of age groups.

3 Results

The Cambridge Inclusive Design capability tool uses derived data from the scaled scores of the original DFS data to calculate comparative charts of prevalence of varying capabilities, as represented in the individual scales, a for differing age groups, sex and capability bands. Fig. 4 shows the relationship between the new and existing scales highlights the differences between three new scales and the original intellectual function scale in terms of the numbers of the population scoring at differing degrees of impairment, as indicated by the scale. Three new scales were tested (1) Combined cognitive scale combining the memory and executive function scales, (2) the new memory scale and (3), the new executive function scale. For all three scales the impairment score was arrived at by adding the number of capability problems that were reported as discussed above. It is clear from the graph that while the scales are broadly correlated (as are all the scales in the DFS), the combined cognition and the intellectual function scale are very similar as would be expected since they both account for most of the capabilities involved in mental life. However. Interestingly, the memory scale shows a trend towards less problems than either at mild impairment levels and the executive function a trend towards more problems at the higher impairment levels. This implies that the sample reported either a few memory impairments with some attention and organisation problems or reported serious executive function problems combined with accompanying memory difficulties. The distribution of these impairments with age band and their relation to other impairments are currently being examined but it would be expected that the latter would be more frequent in old age and the former associated with neurophysiological injury.

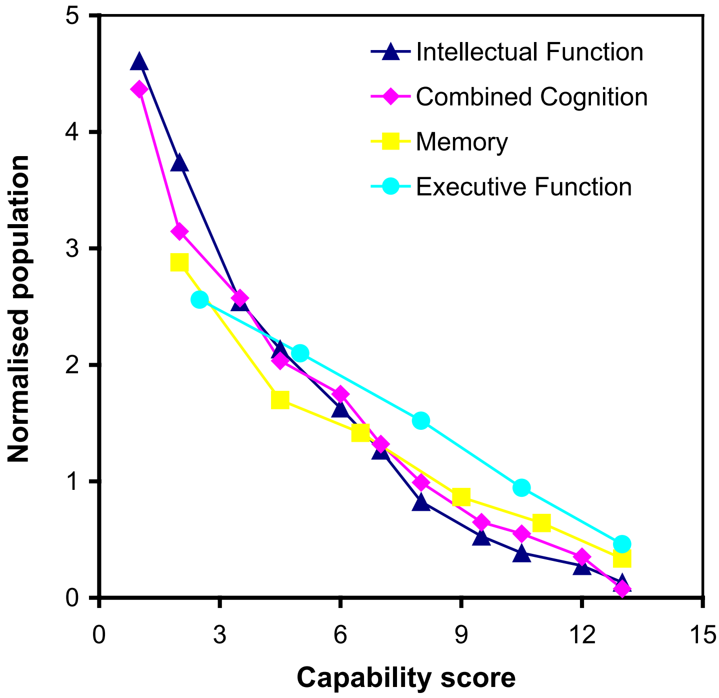

Figure 4. Visualisation charts of prevalence of impairment

4 Conclusions

In the light of the comparison with the cognitive theory derived scales, the original ONS intellectual function scale confounded many aspects of cognition in individual question items. This is not surprising as the question items were devised by health practitioners in order to reflect common disabilities in the ICIDH classification. In addition, the scale operates by simply counting the number of intellectual impairments reported and scales this as a measure of overall impairment, ignoring the interrelations between impairments. The comparisons suggest that this scale would be poor predictor of cognitive usability product designs. The new cognitive scales, however, appear better able to differentiate between product features but only in as much as they were able to do so using the existing question items.

On the same basis, however, the DFS communication scale was found to be adequate in so far as it used only the available existing question items many of which also required a mixture of communication and cognitive capabilities. However, two scales of expression and comprehension constructed on the basis of the model, forming the new communications scale when amalgamated, were found to use the same question items and were therefore deemed equivalent to the existing scale. This suggests that the expression and comprehension requirements of products and their use may be assessed using this capability scale.

A general conclusion, therefore, is that the new derived scales are more accurate cognitively but cannot go beyond the original items. Formation of more accurate capability assessments will require the development of new question items. This process will require careful development of questions by cognitive psychologists aiming to avoid confounding different cognitive functions and will be informed by the considerable body of experimental cognitive psychology findings that already address these distinctions. Ideally, further scales to be used in future surveys would be normalised with reference to known impairment sample groups and re-scaled for equivalence to the other scales used.

Two new scales could be superimposed on the ONS survey items: *executive function* and *memory*. One important conclusion resulting from the use of the model is that there are a number of desirable and important aspects of cognition identified by the model that were not addressed at all by the ONS scales. These include visual cognition and reasoning; categorical memory, meta-cognition and further executive functions such as information filtering and multiple-tasking. The effectiveness of these new cognitive aspects for forming capability scales for product assessment are currently being evaluated.

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