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A FRAMEWORK FOR ANALYTICAL INCLUSIVE DESIGN EVALUATION

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ABSTRACT

The inclusive design approach attempts to accommodate people with reduced functional capability as much as possible in the design of consumer products. This paper presents a generic analytical framework for the evaluation of product usability and accessibility with the aim of minimising the potential number of people excluded. This is achieved through the consideration of sensory, cognitive and motor demands placed on user populations by the design of product features. The framework is envisioned to support prediction of proportions of the user population who may be excluded or experience difficulty with a given design. The feasibility of the framework is demonstrated via a case study using a simple toaster. Though current data is lacking for making these predictions, further research is planned that will address data collection to support the analytical evaluation framework.

Keywords: Inclusive Design, Analytic Evaluation, User Capability

1 INTRODUCTION

Inclusive design is a design philosophy that aims to consider the needs and capabilities of users in the design process. This includes addressing the needs of older and disabled populations. The goal of inclusive design is to design products that are accessible and usable to the maximum number of users without being stigmatising or resorting to special aids and adaptation [1]. The concept of inclusive design has a similar philosophical basis to Universal Design, which is the term used in the United States and Japan. The term 'universal' may connote a 'one size fits all' approach with the aim of designing one product that satisfies all types of users. In contrast, the difference in terminology highlights the focus of inclusive design as attempting to include users with reduced functional capability in mainstream product design without sacrificing product aesthetics and desirability. Recognising that a totally inclusive product is an ideal rather than an actual achievable result, the focus of inclusive design is on implementing a user centred *design process*. The result of such a process should lead to improved products that *minimise the exclusion* of less capable populations [2].

As part of the inclusive design process, designers require information on the spectrum of user capabilities in order to evaluate their designs [3]. The majority of inclusive design information exists in the form of guidelines and handbooks [4-6]. However, research has shown that designers require supporting information in visual formats that go beyond textual guidelines and checklists [7]. Previous research has also shown that quantitative data on the numbers of people with functional capability loss can be useful for designers as well as business managers and decision makers [8]. Therefore, there is a need for user capability data that could enable the evaluation of design concepts throughout the design process; from requirements specification and conceptual design through to prototyping and final product development.

Methods for usability and accessibility evaluation can be usefully classified into analytical methods and empirical methods [9]. Empirical evaluation methods measure design performance by having a sample of users perform representative tasks with a product. Their performance in terms of time, errors and subjective impressions can be measured. Analytical or inspection based methods rely on the analysis of the product and intended scenarios of use without direct user involvement. Human factors experts can evaluate products for potential problems, or user models and capability data can be used to make predictions about real world performance of the product. Ideally, both empirical and analytical methods can be used depending on the resources available. Though the importance of user involvement in the design process cannot be overemphasised, there is value in utilising analytical methods in the evaluation process due to constraints of time, cost and logistical difficulties in recruiting and testing with real users [10]. In addition, analytical methods are especially advantageous in the inclusive design process where a group and population view on user capability is required [11, 12]. This paper therefore addresses the issue of analytically evaluating consumer products via a generic framework based on matching user capabilities to product demands. In section 2, we highlight relevant previous work and in section 3 the research approach for tackling this problem is described. Section 4 describes the conceptual basis for the generic framework details of the stages in the framework is described in section 5. A case study is presented in section 6 with a high level application of the framework to the evaluation of a toaster. This is compared and contrasted to an empirical evaluation of the toaster. Finally, in sections 7 and 8, we discuss the nature of the results produced by analytical and empirical methods, and conclude with further work.

2 BACKGROUND

This work builds on previous work on using capability scales to assess the demands made on users by product features [1]. The engineering model of the Model Human Processor [13] was used as the basis for describing human functional capability in three dimensions: sensory, cognitive and motor capability [1]. These dimensions are not independent and do interact when considering the global functioning of an individual. However, they provide a useful basis for an engineering model of capability for product evaluation. This work led to the development of an Exclusion Analysis tool for predicting the excluded proportions of the Great Britain disabled population by a given product design [14]. The tool is based on global functional capability scales developed for the 1996/97 Great Britain Disability Follow-up Survey (DFS) [15]. Though the scales lack the granularity and completeness to evaluate all aspects of consumer products, they provide a unique set of multivariate capability data that is representative of the Great Britain population.

HADRIAN is another related evaluation tool developed at Loughborough University comprising an anthropometric database of 100 disabled people [16]. HADRIAN demonstrates the advantages of using a multivariate database of measures in ‘virtual user trials’ to estimate the number of people excluded. Such tools are innovative and demonstrate the utility of multivariate capability data in inclusive design evaluation. However, challenges remain as these tools remain limited in scope as they fail to adequately address important domains such as cognitive capabilities. As a result, there is scope for research into the development of predictive methods to assist in analytically evaluating consumer products for design exclusion.

We aim to address this need by developing a framework for evaluating products with the following requirements. The framework should be of adequate scope and comprehensiveness to evaluate a large range of consumer products against a complete range of user capabilities. It should be able to make valid predictions of user exclusion and difficulty under normal assumptions of use. The predictions should be sensitive to changes in product attributes allowing a designer to make changes to the design and see the effects on the predictions. Finally, it should also be usable by designers and allow for extensions and updating.

3 METHODOLOGY

The major dimensions of human sensory, cognitive and motor capabilities were identified from classifications and experimental studies in the literature [17-20], and consultation with domain experts. This list was compiled with the aim of identifying the capability dimensions that most affect real-world performance. This resulted in a set of underlying human capabilities that could be used to assess product features. Predictive models of human performance were also reviewed with the goal of identifying methods of predicting human behaviour [21-23]. However, there appears to be a relatively small number of extant models to adequately describe the relationship between basic human capabilities and performance in real world tasks [24].

A set of ability scales was developed by Fleishman which can be useful in understanding the capability requirements of various tasks [18, 25]. However, Fleishman’s model was found to have marginal predictive performance as it is based on the linear combination of fundamental human capabilities [24]. An alternative is the Elemental Resources Model (ERM) developed by Kondraske [24]. The ERM is a model of human performance based on the concepts of General Systems Performance Theory (GSPT) [24]. A detailed discussion of the ERM is beyond the scope of this paper, and the reader is directed to [24, 26, 27] for background literature. However, the concepts of the ERM fit naturally with a capability-demand approach to product evaluation and are briefly presented in the following section.

4 CONCEPTUAL BASIS

Human Factors and Ergonomic theory is based on the match between users and the designed product by utilising various measures of compatibility [28, 29]. The ideas of user capability and product demand provide a useful framework for evaluation i.e. the comparison of the sensory, cognitive and motor demands made by a product with respect to the ability levels of the expected user population [3, 28]. These concepts are shown in Figure 1.

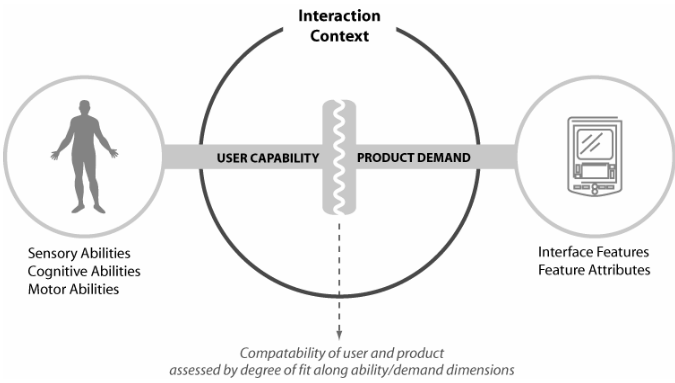

Figure 1. User Capability- Product Demand Framework

4.1 Product Demands

A product demand is a multidimensional construct set by the attributes of the interface features. For example, a given push button design will have attributes such as shape, size, colour, contrast, material finish, and force required for activation. The button makes demands on a person's capability only when considered in the context of the action to be performed. Therefore, in the context of seeing the push button, the button design places a visual demand on the user by virtue of its size, colour, contrast and material finish. It places a cognitive demand on the user in terms of knowing how it works and how to use it based on its form and where it is placed on the product chassis. In the context of pushing the push button, it places a motor demand (finger push or thumb push) on the user by virtue of its force activation characteristics. Other contextual demands are possible depending on the use environment.

Based on this analysis, a product demand is a function of both the interface feature attributes and the sensory, cognitive and motor action to be performed on it. An object-oriented method for classifying interface features and associated propertied can be adopted [30] based on fairly standard interface features. Six general categories for interface features can be identified as follows: (1) Product chassis including handles, (2) Displays and indicators, (3) Controls and Control Groups, (4) Material and media input and output (5) Connectors for energy and data and (6) Software interfaces. Each feature type is associated with a set of static and dynamic attributes. Due to the potentially large set of attributes that may be possible for a feature, the Pareto rule is adopted as a guideline and the assumption is made that most of the feature demand stems from a small set of key design attributes. This is done by focusing on the sensory, cognitive or motor *action* that is to be performed on the feature. For example, the force demand of a push button constitutes the largest portion of the motor demand that can prevent a user from successfully activating the button. This assumption is necessary in order to cope with a large set of design attributes that may be relevant, but not significantly change estimations of excluded populations if addressed.

4.2 User Capabilities

Carroll [31] defines capability as follows: *"As used to describe an attribute of individuals, ability refers to the possible variations over individuals in the **liminal levels of task difficulty** (or in derived measurements based on such liminal levels) at which, on any given occasion in which conditions appear favourable, individuals perform successfully on **a defined class of tasks**."* (emphasis added). Important in this definition is the notion of (1) liminal levels or threshold levels of performance and (2) capability being defined with reference to a class of tasks. There are two main approaches to describing and modeling human performance: *reductionist* models and *first principle* models [32]. Reductionist models use a top-down decomposition of task sequences into fundamental actions which are then assessed for human performance demands. Conversely, first principle models use a bottom-up approach that models the detailed functioning of human sensory, cognitive and motor capabilities. These two approaches are not mutually exclusive and there can be an overlap of both [32]. Our approach to modeling human capability is weighted more to the reductionist approach which implies a reliance on understanding and decomposing the tasks and actions to be performed when interacting with consumer products. By weighting the method toward analyzing actions for capability demands, it will be more accessible to designers wishing to evaluate their own designs without human factors expertise. Thus expert knowledge of human functioning would not be necessary for using the method increasing the likelihood that it will be used.

As mentioned in section 3, the ERM model provides for the calculation of compatibility by utilising resource-demand constructs. The main idea behind the ERM is that people possess a set of basic functions at a low hierarchical level [24]. These include functions such as visual acuity, contrast sensitivity, working memory capacity, force generating and movement capabilities. These functional capabilities can be characterised by their performance threshold i.e. the *maximum* performance that can be achieved. This includes measures of maximum visual acuity, maximum contrast sensitivity for different spatial frequencies and maximum working memory capacity. These measures form a maximum *performance envelope* for a person similar to a performance envelope for engineered systems [24]. A person's performance on a real world task is determined by considering the set of performance resources engaged *relative to* the task demands. Performance is therefore *limited* by any one of the performance resources exceeded by the task demands. This idea of the limiting factor in performing a high-level task leads to a *resource economic* view on human performance [24].

By utilizing the idea of performance envelopes for users with reduced functional capacity, exclusion on a given task can be determined simply by comparing the task demands to the demanded capabilities. If any of the required capabilities are exceeded, a person would not be able to perform the task. The concept of performance envelopes can be extended for the prediction of potential difficulty by defining a comfort envelope which attempts to capture comfortable levels of operation. By definition, the comfort envelope dimensions will always lie within the performance envelope. It is assumed that any product demands that are made that fall between the comfort envelope and the performance envelope will result in the user experiencing difficulty. For the purposes of this paper, we briefly outline relevant user capabilities that are employed in tasks with consumer products.

4.2.1 Sensory Capabilities

For detecting information in the world, the distance senses of vision and hearing are utilised. The following vision and hearing capabilities are important for product interaction, and have been shown to be highly variable in older and disabled populations. Vision capabilities include visual acuity for perceiving fine details, contrast sensitivity for perceiving form, colour perception for detecting the range of color used, usable visual field for seeing extents and depth perception for judging distances in three dimensions. Hearing capabilities include the ability to detect sounds at different frequencies. Speech detection and discrimination capabilities are important for products with speech output and sound localisation capabilities are important for judging the location of sources of sound in the environment.

4.2.2 Cognitive Capabilities

Based on current psychological theories of the information processing approach to human cognition, we address the cognitive demands placed on elements of the human cognitive system. Firstly, human working memory is limited in storage and time duration in which contents are held. It can therefore be overloaded by exceeding the storage capacity or exceeding the time limitations. Secondly, long term memory stores declarative, procedural, semantic, visual-spatial and episodic knowledge. This knowledge is demanded by recognition and recall tasks. Thirdly, language and communication capabilities are demanded where comprehension and expression of oral, written and printed language is necessary to accomplish a task. Working memory and long term memory work in concert for planning and problem solving where mental models are developed of how a product works and how it is to be used. These mental models are developed through trial and error over time as an individual learns from successive episodes of product interaction.

4.2.3 Motor Capabilities

Most consumer products require the use of the upper limbs for manipulating product controls. Upper limb motor capabilities for each hand consists of fine dexterity and finger function, linear and rotational force exertion with and without grasping, two handed coordination abilities and reach ranges. For fixed products that require gross body movement and lower limb functions, bending ranges and locomotion capabilities are important for accessing controls and viewing displays.

5 A FRAMEWORK FOR ANALYTICAL EVALUATION

Based on the requirements outlined in section 2 and the principles explained in section 4, a generic evaluation framework was developed as shown in Figure 2. The diagram shows three main stages of the evaluation process. The first stage involves the description and representation of three components: (1) the interface features and attributes, (2) user goals, tasks, and sequences of actions and (3) a representation of the mental models required for using the product. These three components comprise the demands that the product places on the user's sensory, cognitive and motor capabilities in a given use environment.

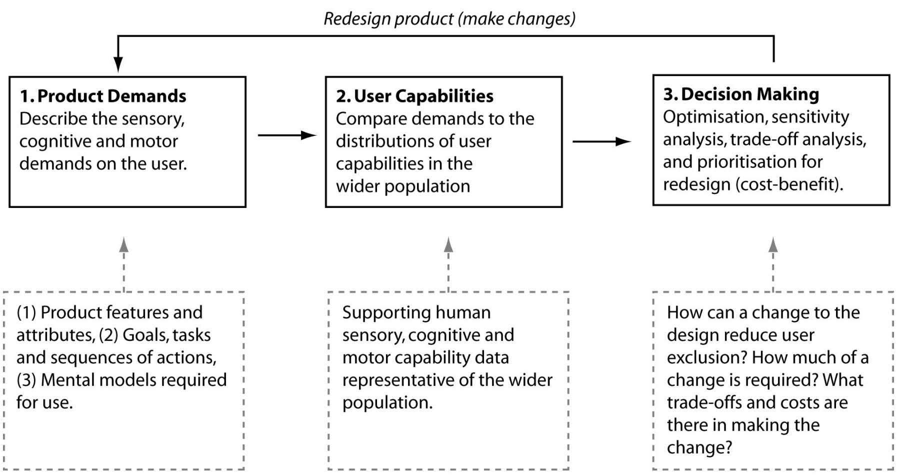

Figure 2. Evaluation Framework

The second stage involves the estimation of proportions of people in a target population that may be excluded or have difficulty with the product design. This is achieved by comparing the demands to capability measures stored in a comprehensive capability database that is yet to be developed. For example, the visual demands of a product feature such as text or a control button can be understood by its demanded levels of visual acuity, contrast sensitivity, colour perception, and visual field. By comparing these demanded levels to distributions of capability levels in the wider population, an estimate of design exclusion can be obtained.

The third stage involves decision making and analyzing user exclusion estimates via sensitivity and trade-off analysis. Sensitivity analysis in this case comprises asking 'what-if?' questions about design attributes and looking at the effects of making changes on excluded populations. For example, a

designer might find that a significant proportion of a population of interest is being excluded by the 8 point text size on a button. By increasing the text size to 10 point, the change in excluded population can be recalculated given adequate data. Thus the designer can see not only what must be done to include more people in terms of increasing text size, but also *by how much* it should be increased to achieve some level of minimal exclusion. Trade-off considerations are also important, such as the impact of increasing text size on the aesthetics of the product or other constraints such as button size that limit the size of the text. In essence, the framework emphasizes the making of informed decisions about design features and prioritises design problems based on objective user capability data. Due to the reliance on a capability database and the quantitative nature of the method, computational support will be required for a full implementation of the evaluation framework.
In the previous sections, we outlined the rationale and the theoretical basis for analytical inclusive evaluation. We now illustrate some of the main concepts of the approach by utilising a simple toaster. The idea is to give a feel for the approach by comparing the type of results obtained from empirical testing to the type of results that can be obtained by analytical evaluation. As the framework is currently in development and relies on user capability data that has not yet been collected, we limit the presentation to a high-level overview of the process and the nature of the results to be expected.

6 CASE STUDY

A simple toaster is used as an example to illustrate the elements of the evaluation framework. The toaster is shown in Figure 3 with the relevant interface features labeled. In order to compare the analytical method with an empirical method of product assessment, an observational study was conducted. Seven users of various ability levels made toast with the toaster while voicing their problems in a think aloud protocol. Participants were recorded with a video camera while performing the task and the video data was analysed to extract the types of problems encountered. Figure 3 shows a categorization of the problems found and some screenshots of the video data.

	Users						
	1	2	3	4	5	6	7
A. Capability Problem	24yr Female Arthritis	30yr Male -	50yr Female Tetraplegic	64yr Female Osteoporosis	27yr Male Cortical Visual Impairment	51yr Male Stickler Syndrome	55yr Female Deteriorating vision and hearing
Vision				•	•	•	•
Hearing						•	•
Cognitive				•			
Motor	•		•	•			
B. Problems by Features							
1 Chassis							v
2 Slots							
3 Slider							v
4 Rotary Control			m		v		v
Rotary control label		v			v	v	v
5 Stop Button						v	
Stop button label						v	v
C. Problems by Actions							
1. Opening bread pack			m				
2. Turning on power	c	c		c			
3. Placing bread in slots							
4. Setting heat control		v	m		v		
5. Depressing slider							
6. Pressing stop button						v, c	
7. Removing toast							

KEY: (v) vision problem, (c) cognitive problem, (m) motor problem

Figure 3. Results of toaster observational study

Users generally encountered problems based on the type of capability loss experienced. For example users 5, 6 and 7 with vision and hearing capability losses encountered problems with seeing various

interface features such as the slider, rotary control and stop button due to lack of contrast and small size. User 3 with relatively low motor capability had problems with the rotary control though other users found no problems with manipulating the control. Users 1, 2 and 4 attempted to depress the slider while the toaster was off at the mains. This highlighted a problem with the lack of feedback from the toaster as to it state i.e. whether it was powered or off at the mains.
In this study, users were asked if they had any problems with their everyday vision, hearing, memory and motor function. However, these capabilities were not objectively measured so the level of capability could not be compared to the types of problems found. Therefore, even though User 4 reported problems with vision, memory and motor problems in daily life, she experienced no major problems with the simple toaster.

6.2 Analytical Evaluation

We now present an analytical evaluation of the toaster according to the procedure in Fig 2. Due to the lack of a complete source of capability data, the exclusion levels shown in the following analysis are approximations based on diverse data sources and expert judgement and are presented for illustration purposes only. The aim is to demonstrate the process and visual formats for analysing capability demands.

6.2.1 Feature and Task Analysis

The features of the toaster can be analysed one at a time by utilising a classification of common features with associated attributes. A tabular format for this analysis is shown in Figure 4. The actions that are demanded by the features are analysed and the excluded population can be calculated based on the demands of the feature attributes under normal assumptions of use. The frequency of use of each feature can also be estimated. For example, once the toaster is placed in the kitchen, it may not be lifted and moved around frequently. Also, once the heating control is set, users usually leave it on that particular setting with infrequent adjustment. The analysis format also includes visual representations of the proportions excluded so that it becomes immediately visible that the low contrast on the slider might be a problem. This could be further modified for showing proportions that may experience difficulty in performing the action. The analysis shows that the slider is a high frequency use feature and it can exclude a large proportion of people based on its lack of contrast. Also both the rotary control and the button text labels exclude people by virtue of their small size and reduced contrast. The improvements column shows suggested changes to the feature attributes to reduce exclusion. With actual data supporting the analysis, it will be possible to determine how much the feature attributes should be changed to achieve some minimal exclusion level.

	INTERFACE DESCRIPTION		INTERFACE ANALYSIS			
	Feature	**Attributes**	**Action Demand**	**Freq**	**Exclusion Level**	**Improvements**
1	Chassis	Weight = 1 kg	Lift, move, carry, push	Low	Low	▼ Decrease Weight
2	MaterialIO.Slots	Contrast = 100%	See	High	Low	
4	Control.Slider	Contrast = 0%	See	High	High	▲ Increase Contrast
		Depression Force = 17.2N	Push downward (fingers)		Low	
5	Control.RotaryControl	Torque = 7Ncm	Rotate	Low	Low	▼ Decrease Force
	Control.RotaryControl.TextLabel	Size = 10pt Contrast = 80%	See		Medium	▲ Increase text size
6	Control.Button	Contrast = 80%	See	Low	Low	▼ Decrease Force ▲ Increase Contrast
		Depression Force = 2.45N	Push		Low	
	Control.Button.TextLabel	Size = 10pt Contrast = 80%	See		Medium	▲ Increase Size ▲ Increase Contrast

Figure 4. Feature Analysis

Features can also be analysed in a task analysis by looking at the sequence of actions required to achieve a goal with the product. By utilising a list of common actions with consumer products, the task analysis can be conducted at a suitable level of granularity for extracting the demands that match to the capability measures stored in a capability database. A tabular representation similar to Figure 4 can be used, except with the demanded action sequence being in the first column as shown in Figure 5.

Only the interface features that are used in the goal (such as making toast) will appear in the task analysis.

	TASK DESCRIPTION			TASK ANALYSIS	
	Action	Feature	Feature Attributes	Demand Type	Task Exclusion
1	**Put bread in slots**				
	See	MaterialIO.Slots	Contrast = 100%	Visual	Low
2	**Set heat control**				
	See	Control.RotaryControl.Text	Size = 10pt Contrast = 80%	Visual	Medium
	Rotate	Control.RotaryControl	Torque = 7Ncm	Motor	Low
3	**Depress slider**				
	See	Control.Slider	Contrast = 0%	Visual	High
	Push down (fingers)	Control.Slider	Depression Force = 17.2N	Motor	Low
4	**IF (toast burning): Press stop button**				
	See	Control.Button	Contrast = 80%	Visual	Low
	See	Control.Button.TextLabel	Size = 10pt Contrast = 80%	Visual	Medium
	Push	Control.Button	Depression Force = 2.45N	Motor	Low

Figure 5. Task Description and Analysis

6.2.2 Cognitive Demand Evaluation

Mental models of products are composed of two intertwined types of knowledge. The first type is declarative knowledge about how the toaster works and the second type is procedural knowledge about sequences of actions that can get the user to their goal. For this example, we illustrate the required procedural model for using the toaster via a state-action representation shown in Figure 5. The figure shows the demanded general usage action sequence intended by the designer. The state based representation of the use process allows for the evaluation of adequate feedback on each state of the device. In addition, the degree of mismatch between the demanded procedural mental model of the product and the user's mental model of how to use the product results in cognitive demand. By examining product states from the user's point of view, we can see that inadequate feedback is provided in the powered state and in the bread cooked state. For example, a user might erroneously forget to power on the toaster before using it (shown in dashed lines in Figure 5), resulting in the toaster slider not activating. This error was noticed in the user observational study (Figure 3). A signal, such as an indicator light to indicate that the power is on, would be a possible improvement to the toaster design. An auditory feedback on reaching the bread cooked state would be another improvement to indicate to the user that the toast is finished. This can also benefit visually impaired users.

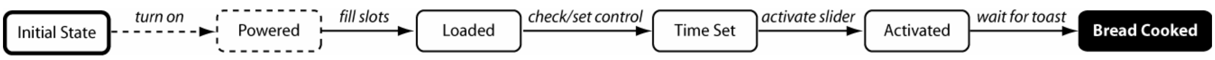

Figure 5. Procedural sequence of use for the toaster

The toaster can also be analysed for demands on working memory and long term memory. When using the toaster, a user is required to keep track of the state of the bread, their current position in the use sequence and probably the next action required or planned. This does not place a high load on working memory in terms of the cognitive processes that are executed. There are also no time demands for task actions that exceed a 15 second working memory window. The overall length of the procedural mental model is also relatively short compared to more complex products, thus indicating a low demand overall on working memory.

Toasters are common products consisting of a relatively straightforward interface. Their reactive behaviour is generally well understood by users. The overall design of the example toaster follows the traditional toaster form factor with slots at the top and a slider at the side (Figure 3). The interfaces features of slots, slider, rotary control and button are standard features that are familiar to most people. No graphical symbols are used requiring recognition and the user is only required to read and understand the 'STOP' button label and the text of a safety sticker on the toaster. Reading the safety sticker is not essential to using the toaster, so within the defined task bounds the toaster does not demand a high degree of language capability. Thus the demands of the toaster on the knowledge and long term memory of users is assumed to be relatively low given normal assumptions of usage. Converting cognitive demands into estimated excluded population values is the subject of ongoing research. Various tests of the above mentioned capabilities are being reviewed for their predictive value in determining exclusion and difficulty with product interfaces.

6.2 Comparison of empirical and analytical evaluation methods

In comparing the output of both the empirical method and the proposed analytical evaluation method, it is evident that both methods are capable of finding problems with product features. Problems with the slider and text features on the toaster were flagged in both cases. However, only one user (User 7) had a problem seeing the slider. This can be explained by the effect of previous experience and expectation. Based on mental models of toaster features and feature placement, users expect a slider control to be in certain positions on the toaster chassis. Therefore, due to this expectation, users were able to locate the slider even though the contrast was poor. It is also possible that the visual capabilities of most participants in the study were not low enough to be challenged by detecting the slider. User 3 had problems with the rotary control given her specific capability profile, even though the torque required to rotate the control is relatively low. This demonstrates the limitations of sampling users with reduced capability in that problems found heavily depend on the specific users in the study. This is in contrast to sampling people for general usability trials from a relatively homogenous capability population. The analytical method also requires a more detailed analysis of the product design. Hence by the very nature of the method, a designer or evaluator is forced to think through the demands caused by individual features or action steps and problems can be found that may not show up in an observational study. When a problem surfaces in empirical trials, the designer is still faced with the question as to what proportion of the population at large might encounter difficulty because of the problem. Thus analytical and empirical methods are complimentary giving different insights into problems with the usability and accessibility of the design.

7 DISCUSSION

In this paper, the conceptual basis for inclusive analytical evaluation was outlined. Based on this, a generic framework for analytical evaluation was presented. The framework represents an effort to integrate and systematise approaches to accessibility and usability. The emphasis is on the prediction of proportions of people excluded and proportions of people with potential difficulty as the key metric for decision making and priority setting. The use of the evaluation framework depends on a database of capability data of the older and disabled populations. The capability data is required to be in some way representative of the larger population for which a design is intended. Creating such a comprehensive, multivariate capability database with large user samples is an ongoing research programme at the Cambridge Engineering Design Centre.
A case study was presented that demonstrated the differences in the type of design information that could be obtained with an empirical method and an analytic method. It is evident that the two approaches produce different but complimentary results. The empirical method is dependent on the users chosen for the study and can give deep insight into the issues faced by specific users. It can also generate empathy and inspire novel design solutions. However, the empirical method cannot determine how many people the product may exclude or how many people have similar capability profiles to the sampled users. The analytical method on the other hand can provide population based information once suitable capability measures are captured in a database. It can also find problems that may not show up in small scale empirical evaluations. This is due to the systematic analysis of product features and tasks for their demands on user capability. Priorities for redesign can be set based on estimated numbers of people excluded by the feature coupled with an estimate of how frequently the feature would be used. The method itself lends to thinking about how a product satisfies *ranges* of sensory, cognitive and motor capability rather than focusing on satisfying the capability levels of specific users who may evaluate a product. The value of the analytical method can also be seen in its

use in addition to its output as it forces a designer or evaluator to critically examine all the features of the product and the scenarios of use.
The issue of coping strategies remains to be investigated and understood. People with capability losses can develop very individualistic means of coping with action demands. These behaviors are important for inclusive design because they can give insight into how people will tend to use products if standard assumptions are violated. For example, how do users with function in only one hand approach two handed tasks? Currently, the analytical method assumes fairly standard interaction behaviors, but it could be expanded with input on the various types of coping strategies that are commonly employed.
With respect to the requirements outlined in Section 2, the scope and comprehensiveness of the framework was addressed by reviewing user capabilities that most influence real world performance. Current work is addressing the predictive validity of the method and further work will investigate the use of such a framework by designers.

8 CONCLUSIONS AND FURTHER WORK

A predictive analytical framework was presented for evaluating consumer products for usability and accessibility. The method aims to estimate proportions of people excluded and proportions with difficulty based on matching product demands to user capabilities. Though the data to support the framework does not yet exist, the feasibility of the method in analyzing consumer products was demonstrated. Further testing and validation is required to ascertain the generalisability of the framework for evaluating a wide range of consumer products. A database of capability data also needs to be developed. Finally, designer feedback on the use of the method will determine the value of the framework in the inclusive design process.

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