

Using disability data to estimate design exclusion

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Abstract Exclusion auditing is a process that can quantitatively evaluate the inclusive merit of different products, or alternative design decisions. The results from such an audit can provide prioritised directions for product improvement and support the business case for reducing the capability levels required to use mainstream products. The 1996/1997 disability follow-up survey, conducted by the Office of National Statistics, is currently the most comprehensive data source for estimating design exclusion in the UK. In this paper, the data source is explained in detail, and a method is presented that uses this data to estimate the exclusion associated with several tasks that occur in series or in parallel, illustrated through worked examples. Having evaluated how many people are excluded, one can investigate why they were excluded, thus generating design insights into how they could be included. Data from the survey is also converted to a series of stylised graphs, which are intended to inspire designers to think about the relationship between the demands required to use a product and the resulting levels of population exclusion.

Keywords Inclusive design · Usability data · Product assessment

1 Introduction

The Cambridge Engineering Design Centre is unique in developing analytical tools that can quantitatively assess

the inclusive merit of different design decisions or products, according to the number of potential users that would be excluded. Such tools have the potential to greatly assist the implementation of inclusive design in businesses [1]. In addition to those excluded from using a product, many more people will experience difficulty or frustration, so reducing the number of people excluded can improve the experience for a wide range of users [2]. Indeed research commissioned by Microsoft [3] reported that 60% of Americans aged 18–64 years were likely or very likely to benefit from the use of accessible technology.

Early work on the psychology of human computer interaction found that the ability to successfully interact with computer terminals could be predicted according to the demands made on sensory, cognitive and motor abilities [4]. Following this work, the “inclusive design cube” used sensory, cognitive and motor axes to help represent design exclusion according to various different population definitions [5]. However, more recent psychological models, such as Barnard’s Interactive Cognitive Subsystems model [6], recognise that sensory and cognitive abilities are typically used in combination to perceive information, while sensory, cognitive and motor abilities are all required to perform actions. Figure 1 shows a framework for the typical cycle of perceiving, thinking and acting that occurs for a product interaction, which represents the factors that can predict whether a person will find the use of a product easy, difficult or impossible [7].

The tools that comprise an exclusion audit intend to present population data about users’ context dependent abilities to perceive, think and act, so that designers choosing the interface attributes of mainstream products and services can make better informed decisions to reduce the number of people who find the usage difficult or impossible.

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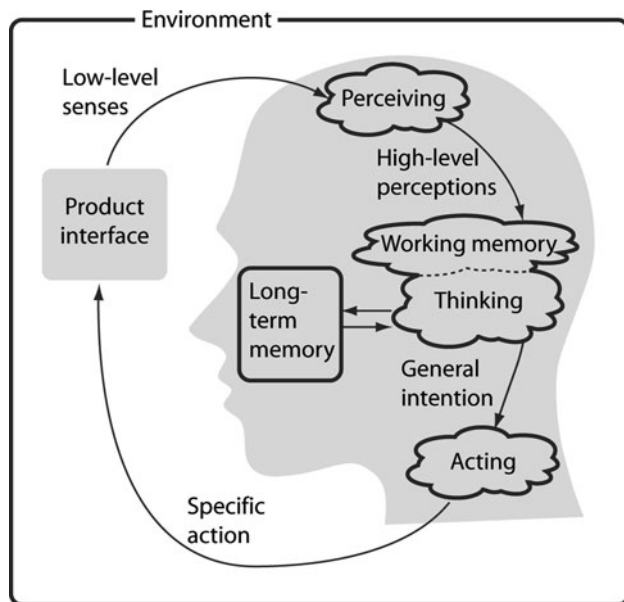


Fig. 1 Framework for the factors that contribute to whether a person will find the use of a product easy, difficult or impossible

Exclusion auditing is intended to complement other tools for evaluating inclusive merit, such as expert opinion [8], user trials [9], and impairment simulators [10]. In combination, these tools provide a holistic approach to discover the causes of design exclusion, and identify appropriate design improvements. An ideal data source for evaluating UK design exclusion would.

- Represent the UK national population, and be customisable towards specific markets of interest.
- Contain data that covers users' abilities to perceive, think and act in real-world contexts.
- Be simple to apply and directly relevant to product interaction.
- Have sufficient scope to incorporate the variation of capability typically found within developed societies, yet sufficient granularity to predict the difference in exclusion between alternative mainstream products.

Unfortunately, no dataset exists that satisfies all of the required criteria [11]. The latest *i~design* [12] research programme aims to address this shortcoming directly, by designing and undertaking a national survey for the purpose of estimating design exclusion. Until the results from this survey become available, the Office of National Statistics 1996/1997 Disability Follow-up Survey (DFS) [13] remains the best available data source for estimating design exclusion. As a result, this paper focuses on the use of data from the DFS survey. Further details of this survey are first presented, followed by a procedure that uses the survey data to estimate exclusion for one or more tasks, with worked examples. In each case, the objectives are to

understand how many people are excluded, why those people are excluded, and provide design insights into how they could be included. The DFS data is then used to construct a set of stylised graphs that communicate how demand relates to exclusion, which are intended to inspire designers to reduce the capability demands of mainstream products, and support the business case for doing so. Further research that is required to inform the future national survey is then discussed.

2 The disability follow-up survey

The DFS was commissioned to measure the prevalence of disability within Great Britain, in order to help plan welfare support [13]. Disability was defined as “any restriction or lack of ability to perform an activity in the manner or within the range considered normal for a human being” according to the International Classification of Impairments Disabilities and Handicaps [14]. Adults were selected for the DFS if they met certain criteria, such as being in receipt of incapacity benefit. Those under the age of 16 were not included. Approximately 7,200 participants were asked up to 300 questions regarding whether they were able to perform certain tasks, such as

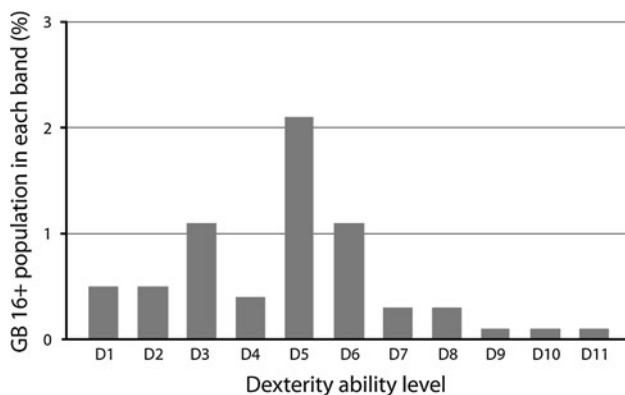
“Can you pick up a safety pin with your left hand?”

“Can you tie a bow in laces or string without difficulty?”

The survey intended to measure the participant's ability to perform everyday tasks, but did not intend to cover the detailed reasons for why the participant might be unable to perform the tasks. The questions were grouped together in 13 ability categories, 7 of which are most relevant for product interaction, namely seeing, hearing, intellectual function, communication, locomotion, reach and stretch, and dexterity (for the sake of clarity, seeing and intellectual function will be referred to in this paper as vision and thinking). Within each ability category, a panel of approximately 100 judges created a scale to measure the severity of quality of life impairment for reduced ability within that category. The judges included a range of professionals with experience of disability, independent researchers working in the field, staff involved with the survey, and disabled people and their carers [15]. To use the DFS for assessing product exclusion, one has to assume that incremental points on these seven quality of life scales are equivalent to incremental levels of ability to interact with products, and the scales will henceforth be referred to as ability levels. Note that this assumption is particularly weak for the thinking scale, as explained in more detail in Sect. 2.3.

Table 1 Dexterity ability categories

D1	Cannot pick up and hold a mug of coffee with either hand
D2	Cannot turn a tap or control knob on a cooker with either hand
D3	Cannot pick up and carry a pint of milk or squeeze the water from a sponge with either hand
D4	Cannot pick up a small object such as a safety pin with either hand
D5	Has difficulty picking up and pouring from a full kettle, or serving food from a pan using a spoon or ladle
D6	Has difficulty unscrewing the lid of a coffee jar, or using a pen
D7	Cannot pick up and carry a 51b bag of potatoes with either hand
D8	Has difficulty wringing out light washing or using a pair of scissors
D9	Can pick up and hold a mug of tea with one hand but not the other
D10	Can turn a tap or control knob with one hand but not with the other. Can squeeze water from a sponge with one hand but not the other
D11	Can pick up a small object such as a safety pin with one hand but not with the other. Can pick up and carry a pint of milk with one hand but not the other. Has difficulty tying a bow in laces
D12	Full dexterity ability

**Fig. 2** Dexterity prevalence data from the disability follow-up survey, where each ability level is defined in Table 1

The statements used to describe the dexterity ability levels are shown in Table 1, together with the proportion of the GB adult population within each level in Fig. 2. The dexterity ability levels range from extremely low ability, such as level D1 “Cannot pick up and hold a mug of coffee with either hand” through to moderate ability, such as level D8 “Has difficulty wringing out light washing”, to high ability, where Level D12 represents full dexterity ability. The complete set of ability levels were first published by Martin et al. [16], but can also be found online [17].

Interacting with a product will typically place demands on up to seven of the capability categories identified within the DFS, which are outlined in the following paragraphs. It should be noted, however, that the survey was not intended

for the purpose of estimating design exclusion for mainstream products, so important aspects of capability that are not sufficiently covered within the survey are also highlighted.

2.1 Product interaction demands covered within the DFS

For each of the seven capability categories in turn, the demands associated with product interaction that are covered within the DFS data are stated, along with other relevant issues pertinent to evaluating capability demand.

2.1.1 Vision

The DFS vision ability levels cover demands where the user is required to perform tasks such as:

- Read text of various sizes,
- Recognise a friend at various distances.

The DFS measured corrected vision, but did not specify the ambient lighting, or cover colour blindness, depth and motion perception, or the usable visual field.

2.1.2 Hearing

The DFS hearing ability levels cover demands where the user is required to perform tasks such as:

- Understand speech against various levels of background noise,
- Detect sounds of various volumes.

The DFS measured corrected hearing, but did not specify whether an induction loop was available to transmit the speech, and only specified the sound types and levels in very general terms.

2.1.3 Thinking

The DFS thinking ability levels cover demands where the user is required to perform tasks such as:

- Understand or express written language,
- Recall things from memory, or remember to do things in the future,
- Hold attention and process information with clarity.

The DFS did not sufficiently cover working memory capacity, recognition, visual-spatial thinking, verbal thinking, or the ability to use long-term memory.

2.1.4 Communication

The DFS communication ability levels cover demands where the user is required to perform tasks such as:

- Use speech to communicate with people who are well known to the user,
- Use speech to communicate with strangers.

The DFS covered understanding and expressing spoken language, but did not cover which language is first spoken, or cover communication difficulties associated with regional dialects, or with nonverbal aspects of communication.

2.1.5 Locomotion

The DFS locomotion ability levels cover demands where the user is required to perform tasks such as:

- Walk various distances on level ground, with any desired aids, but without any assistance,
- Ascend or descend stairs without assistance,
- Balance without holding onto something,
- Bend down to reach something, with something available to hold onto.

The DFS did not specifically cover fatigue effects, and did not ask people how far they could move themselves in a wheelchair.

2.1.6 Reach and stretch

The DFS reach and stretch ability levels cover demands where the user is required to perform tasks such as:

- Reach out in front, up to the head, or behind the back with one or both arms.

The DFS did not specifically measure the overall height to which the arms could reach, or what size objects could be lifted to the various different positions, and did not specifically cover the range of motion of each upper limb joint.

2.1.7 Dexterity

The DFS dexterity ability levels cover demands where the user is required to perform tasks such as:

- Perform fine-finger manipulation,
- Grasp objects,
- Pick up and carry objects.

These were measured according to the ability to perform different example tasks, such as tying a bow in shoelaces, squeezing a sponge, or picking up a bag of potatoes.

2.2 The DFS capability database

The collection of self-reported ability levels for each of the 7,200 survey participants in each of the seven categories forms the DFS capability database, the structure of which is illustrated in Table 2. Each person surveyed has a unique identifier, and statistical measures were used to calculate the number of people in the country represented by that person (labelled multiplier). Recall that Table 1 shows an example set of ability levels for dexterity, a person with ability level D2 has greater dexterity than someone with level D1, and the complete set of categories can be found online [17]. The age and sex of each person was recorded, which can be of particular benefit for calculating exclusion according to specific populations. This may be of particular interest when assessing a given product or service.

Access to the DFS capability database is available from the UK data archive [18], indeed such access is essential to correctly estimate exclusion when multiple different capabilities are involved, as will be explained in Sect. 3.1.2.

2.3 Evaluating the DFS for predicting exclusion

The DFS capability database is nationally representative and covers many aspects of perceiving, thinking and acting. The real world activities used to define the ability levels are often analogous to many of the tasks associated with product interaction. The ability levels are intended to provide several graduations that range between extremely low capability (unable to lead an independent life) and full capability (no difficulty with everyday activities). These factors make the DFS data the best available source to estimate the number of people who would not be able to perform the typical tasks that are required to use a mainstream product.

It is worth noting, however, that the data was collected over 10 years ago, and the original DFS scales were

Table 2 Extract from the ONS dataset

ID	Multiplier	Age	Sex	Vision	Hearing	Thinking	Communication	Locomotion	Reach & stretch	Dexterity
1	1894	24	M	V9	H8	T9	C6	L14	R11	D9
2	1312	61	M	V10	H6	T12	C6	L9	R11	D12
3	1865	49	F	V10	H9	T12	C6	L8	R7	D12
4	1267	35	F	V10	H9	T12	C6	L14	R11	D12

The 4th row represents a person with full ability, according to the definition used in the survey. There are approximately 7,200 rows in the actual dataset

developed by health practitioners and therapists to measure the quality of life impairment associated with being unable to perform activities of daily living. As such, the scales were not originally intended to cover all aspects of user capabilities that are involved with product interaction. They also do not follow a consistent model for measuring independent or compound aspects of human capability, and do not correspond with the model of product interaction shown in Fig. 1.

The DFS measured the ability to bend down and pick something up from the floor as part of locomotion, yet it is usually more useful to consider this as part of reach and stretch. The DFS survey also separated communication through speech from the rest of thinking, because the survey aimed to measure the relative prevalence of the different factors that can reduce quality of life. However, communicating through speech requires the ability to speak, hear, understand language and produce language, so in the context of a product interaction it is extraordinary to have to consider speech communication separately from thinking.

The model used to create the thinking ability levels is significantly less applicable to product interaction than many of the other categories. The DFS thinking questions asked people whether they were able to perform 11 everyday tasks, such as “Can you count well enough to handle money?”. The judges’ first attempt to rank the DFS thinking tasks in order of quality of life impairment was not used, because the agreement between the question rankings of different judges was too low [15]. To resolve this issue, a person’s ability was calculated by counting up the number of thinking tasks they were able to perform. The exclusion associated with the thinking demands of a product interaction can therefore only be predicted by counting up how many of the 11 DFS thinking tasks are comparable to those required for product use. An alternative cognitive scale has been constructed from the original DFS questions [19], but a holistic approach to assessing exclusion requires considering the whole cycle of perceiving, thinking and acting, which is currently best supported by the DFS capability database in its original form. Given that the underlying survey did not sufficiently cover long term memory, the DFS capability database is best suited to predict exclusion when the user is generally familiar with the type of product being assessed, but has not seen that specific one before.

Eligibility for the DFS survey was determined through sift criteria, which led to several sources of systematic sampling bias, expected to affect capability prevalence predictions [13]. The survey questions asked participants to self-report their capability in imagined scenarios. It is acknowledged that the purpose of a survey can affect participant’s self-reports [16], and it is unclear to what

extent the participants knew that their answers would be used to plan welfare support. The survey data was collected 12 years ago, and no attempt has yet been made to adjust for changes in population demographics since then.

Using the DFS survey to estimate design exclusion requires judging to what extent and people who are unable to perform the tasks in the survey would be unable to use the product in question, in real world contexts. Research investigating the reliability and validity of this judgement process is currently being planned by the authors, although knowledge in the fields of ergonomics and disability are expected to help improve such judgements.

Given all these issues, the data is considered appropriate for a trained assessor to estimate broad orders of magnitude for the numbers of people who would be unable to perform tasks with familiar mainstream products, if it can be assumed that the tasks required are comparable to those covered in the survey, as summarised in Sect. 2.1. The exclusion figures can be broken down to help understand why those people are excluded, and the design insights generated to reduce this exclusion are expected to have greater merit than the exclusion figures themselves. For convenience and clarity, the exclusion figures given in this paper have been rounded to two significant figures, yet this is not intended to imply their accuracy level. The lessons learned in applying the DFS data to estimate and visualise design exclusion continue to inform the i~design 3 research programme, which will culminate in a future national survey that is directly intended to estimate exclusion.

3 Estimating exclusion from the DFS

The number of people excluded from using a product or service will depend on the demands that it makes on their capabilities, which depends on the goal the user wants to achieve with the product, and the tasks needed to reach that goal. The tasks that are actually required and the level of ability required to perform those tasks depends on the user’s familiarity with the product, and the context of use, which includes both the current environment and the initial state of all the items involved in achieving the goal.

For example, charging the battery is one goal that a user will likely want to achieve with a mobile phone. The tasks involved will depend on whether the charger is currently already plugged in, and the demands of inserting the charger jack will depend on whether it is daylight. If the user is in his or her own home, the required tasks and demands may be different from when the user is staying in a hotel.

In the first instance, a method is presented to evaluate population exclusion for one goal with one product,

according to one particular context of use. The simplest case with one task that can be achieved in one way is first examined, followed by multiple tasks that can be achieved in multiple different ways. In each case, the objective is to evaluate how many people are excluded and why, in order to generate and prioritise design insights into how they could be included. Other examples of exclusion audits have also been published [5, 20].

3.1 Estimating exclusion for one task

To estimate the exclusion associated with a task, the demands placed on each DFS capability must first be assessed in a manner that is directly compatible with the DFS database, then the demand assessment can be used to evaluate exclusion. These two procedures are now explained in detail, followed by a worked example.

3.1.1 Assessing demands

The assessor must first breakdown the task in question and examine the demands it places on each of the seven DFS abilities. For each ability category in turn, the assessor should examine all the statements in all the ability levels of that category, and judge whether that capability is required to perform the task. A demand of zero is used to indicate that a capability is not required.

If some level of that capability is required, the assessor should then consider the lowest ability level within the capability of interest, and judge whether a person with that ability level would be able to perform the task. In most cases, a person with such low ability would be unable to perform the task, in which case the judgement should be repeated for each higher ability level, until the threshold is identified where the task first becomes possible. The demand on that capability is now defined as the ability level that is one lower than the threshold just identified. This procedure is repeated to identify the demand on each of the seven DFS ability categories.

Although each DFS ability level is described according to what the person “cannot” do, a close examination of the original survey questions reveals what the people in each ability level “can” do; this greatly assists identifying the threshold ability level. Several hours of training with the DFS data is therefore required before an assessor can correctly use the data in its original form. Nevertheless, the original ability categories provide the greatest accuracy and validity for estimating exclusion, as trade-offs inevitably occur if the data is simplified or restructured.

Although the demand that the task places on each capability is assessed in turn, the complete set of demands should represent a holistic account of capabilities that may be used in combination. For example, although the vision

and dexterity demands of pushing a button are assessed separately, the combined set of demands are assumed to provide a holistic representation of the hand–eye coordination.

3.1.2 Evaluating exclusion

A person may be excluded from a task because the demands are too high in several categories, and this person would be counted several times if exclusion were to be estimated from typical population statistics such as graphs or tables of capability variation. However, the DFS capability database can resolve the multiple counting issue, because each person is flagged if they have an ability to score in any category that is less than or equal to the demand level, and each person is only flagged once. Each person has a multiplier that indicates how many UK adults they represent, so summing together the multipliers for these excluded people provides an estimate of the total number of UK adults in 1997 who would be excluded from the task. All population numbers throughout this paper refer to 1997 predictions. Proportions of the national population excluded can then be calculated by comparing the excluded population with the number of adults in the UK at the time of the survey, which was 45.6 million. A freely available online exclusion calculator [17] has access to the DFS capability database, and uses this procedure to evaluate exclusion. The survey participants used during the calculation can also be screened according to particular age and sex criteria to calculate the exclusion for a population of interest.

3.1.3 Worked example

The mobile phone shown in Fig. 3 is assessed to estimate the number of people who would not be able to plug in and charge it. In the first instance, it is assumed that the charger is already plugged in, the charger jack is lying on the floor, and the user is initially standing with the phone in their hand. The user is assumed to be familiar with mobile phones in general, but has not seen this one before, so has to first find the correct socket for the charger using his or her sight, with typical indoor lighting. The relevant demands on each DFS ability category are shown in Table 3. These demands are summarised as [V9;H0;T1;C0;L8;R5;D6], where each letter and number come from the third column of Table 3, and a zero value indicates that the capability is not required to use the product. Searching through the DFS capability database and flagging each person who cannot meet the demand of [V9;H0;T1;C0;L8;R5;D6] estimates the exclusion at 5.0 million UK adults.

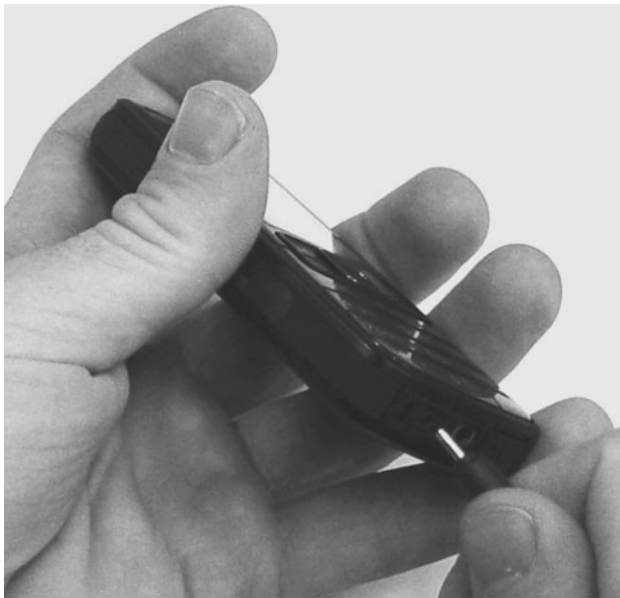


Fig. 3 Attaching the charger cable for the phone that was assessed

3.1.4 The excluded population

In order to understand why people have been excluded, and how they could be included, it is useful to break down and visualise the excluded population. Of the excluded population, some cases are excluded because only one demand exceeded their capabilities, whereas others are excluded because several of the demands exceeded their capabilities, as shown in Fig. 4. Now considering just the people who were excluded because only one demand exceeded their capability, Fig. 4 also shows the breakdown of these people by each different capability type. This graph helps to understand which types of demands are causing the most difficulty for the most people. Supposing it was possible to

redesign the task to eliminate the demand on one particular capability altogether, this graph indicates how much the overall exclusion would reduce as a result.

It is also possible to calculate the number of people who would be excluded from the task based on each capability separately, as shown in Fig. 5. Considering each capability separately may break the link with the real world situation, but Fig. 5 remains useful as another way to understand which demands are causing the most difficulty for the most people.

3.1.5 Insights gained

Figures 4 and 5 suggest that reducing the locomotion demand will make the greatest difference to the number of people unable to charge the phone that was assessed. One way to achieve this reduction might be to supply the phone with a freestanding desk charger, or ensure that such an accessory is readily available with a mainstream price point; indeed this accessory was available in August 2008 for approximately £10. This alternative method of charging also provides an opportunity to reduce:

- The dexterity demand through auto alignment of the phone and charging jack;
- The vision demand, as identifying the correct socket is no longer necessary;
- The reach and stretch demand, because the operation could be performed one-handed.

Alternatively, the initial assumptions could be further examined to refine the analysis. One could assume that the owner only charges their phone in their own house, which they have customised such that the plug sockets, and indeed the charger jack are positioned at a readily accessible location. This new assumption would change the locomotion demand to zero, so further analysis could

Table 3 Demand assessment for charging the phone shown in Fig. 3

Capability	Demand that product interface makes on the capability	Highest DFS ability level for which the person is judged unable to meet this demand
Vision	Required to discriminate the charger socket on the phone from its chassis	V9: Has difficulty reading ordinary newspaper print
Hearing	Not required to perceive anything by hearing	H0: No-one is excluded because of the hearing demand
Thinking	Required to plan and execute the task	T1: Often forget what was supposed to be doing in the middle of something
Communication	Not required to communicate with other people	C0: No-one is excluded because of the communication demand
Locomotion	Required to bend down to pick up the charger jack	L8: Cannot bend down and pick up something from the floor and straighten up again
Reach & stretch	Required to reach both hands out a short distance from the body	R5: Has difficulty holding either arm out in front to shake hands with someone
Dexterity	Required to hold the phone in one hand, then align and insert the jack with the other	D6: Has difficulty unscrewing the lid of a coffee jar or using a pen and pencil

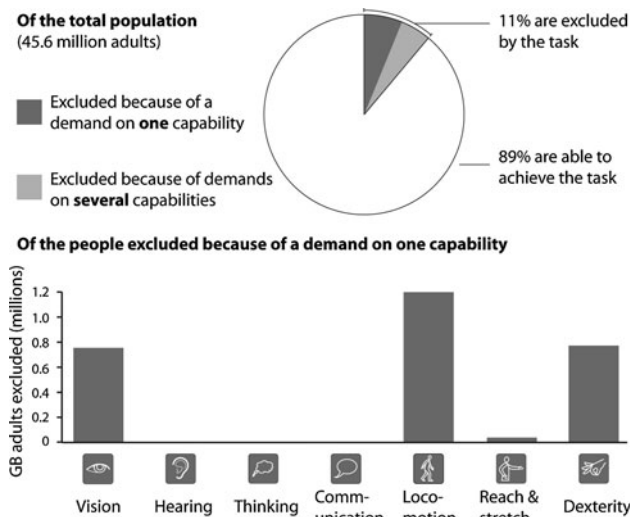


Fig. 4 Breakdown of the excluded population for charging the phone shown in Fig. 3. Note that missing bars on the lower graph indicates either that there is no demand on that capability, or that eliminating the demand on that particular capability would not actually make any difference to the overall exclusion

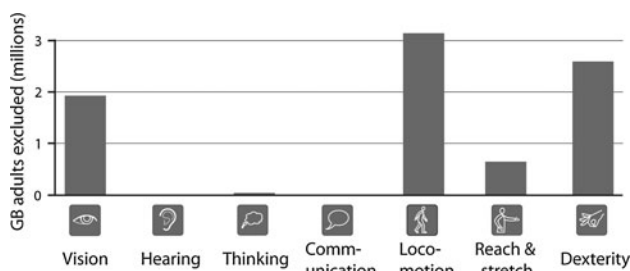


Fig. 5 Number of adults who would be excluded from charging the phone shown in Fig. 3, based on each capability separately

investigate the design exclusion associated with the remaining demands, thereby inspiring further design solutions to reduce this exclusion.

3.2 Estimating exclusion for two tasks

Using a product often requires performing more than one task. Assuming that the demands associated with each task are independent from each other, the number of people excluded from performing several tasks can be calculated by searching through the DFS capability database, flagging each of the people who are unable to perform one or more of the tasks, then summing together the multipliers for these excluded people. The demands of several tasks are likely to be independent from each other if fatigue is not an issue, or if they require different capabilities, or are separated by a long period of time.



Fig. 6 Inserting the SIM card into the phone that was assessed

3.2.1 Worked example

The assessment from the previous example is further extended to compare the demands associated with inserting the SIM card (which needs to be performed once at first set-up). The action of inserting the SIM card is shown in Fig. 6. For this task, it is assumed that the phone and SIM card are on a desk, which the user is sitting at. The user is familiar with the general concept of inserting a SIM card, but will use the instruction book to guide them through the task for this particular phone. The task takes place with typical indoor lighting and no background noise.

The demands are considered in Table 4, giving a demand summary for the setup task of [V9;H8;T5;C0;L0;R5;D11], which excludes 5.5 million UK adults. The previous analysis gave a demand summary for the battery charging task of [V9;H0;T1;C0;L8;R5;D6] which excludes 5.0 million UK adults. Note that for these two tasks the demands on some capabilities are similar, others are different, and different people will be unable to perform one, the other or both tasks. Searching through the capability database and flagging each of the people who are unable to perform one or more of [V9;H8;T5;C0;L0;R5;D11] and [V9;H8;T5;C0;L0;R5;D11] gives an overall exclusion for both tasks of 6.3 million adults. The additional hearing, thinking and dexterity demands of the setup task mean that an additional 1.3 million adults are excluded, compared with the original 5.0 million adults who are unable to charge the phone.

Table 4 Demand assessment for inserting the SIM card into the phone shown in Fig. 6

Capability	Demand that product interface makes on the capability	Highest DFS ability level for which the person is judged unable to meet this demand
Vision	Required to read the text in the manual (~10 pt), discriminate the back cover release catch from the chassis, and identify, the release lever for the SIM card hatch	V9: Has difficulty reading ordinary newspaper print
Hearing	Required to hear the SIM card hatch click to confirm that it is correctly closed (this confirmation is difficult to achieve through vision or touch)	H8: Has great difficulty following a conversation against a background noise
Thinking	Required to read short passages of text, plan and execute a structured series of activities	T5: Often loses track of what is being said in the middle of a conversation, thoughts tend to be muddled or slow, cannot read a short newspaper article, cannot remember a message and pass it on correctly, often forgets what was supposed to be doing in the middle of something
Communication	Not required to communicate with other people	C0: No-one is excluded because of the communication demand
Locomotion	Not required to walk or use steps, or to balance on own of any period, or to perform any bending tasks	L0: No-one is excluded because of the locomotion demand
Reach & stretch	Required to reach both hands out a short distance from the body	R5: Has difficulty holding either arm out in front to shake hands with someone
Dexterity	Required to perform compensated to handed tasks that requires fine alignment of small objects	D11: Has difficulty tying a bow in laces or string

3.2.2 Insights gained

Given these results, further design improvements may focus on the alignment of parts required to insert the SIM, and attempt to reduce the dexterity demands such that they are comparable with inserting the charger jack. An alternative approach is to examine the overall provision of service associated with purchasing, setting up and using the phone. Given the one-off nature of the setup task for the majority of users, the best approach to reducing exclusion might be to ensure that the phone is setup for the customer at the point of sale. Indeed, this strategy has gained increasing momentum in UK high street retail of mobile phones.

3.3 Estimating exclusion for two alternative ways to complete a task

Tasks with products can often be achieved in multiple different ways. In this case, the number of people who are excluded can be evaluated by searching through the DFS capability database, flagging the people who are unable to perform all the different ways of doing the task, then summing together the multipliers for these excluded people.

3.3.1 Worked example

This example considers the exclusion associated with the task of noticing the signal from a UK pedestrian crossing, shown in Fig. 7. In the first instance, it is assumed that the



Fig. 7 Example of a UK pedestrian crossing

task can be performed in two ways, namely seeing the green man or hearing the beeping noise. Considering each of these ways separately, the highest DFS ability level for which the person would be unable to see the green man is judged as V7—cannot recognise a friend across the room, which excludes 450,000 UK adults. Similarly, the highest DFS level for which the person would be unable to hear the

beeping noise is judged as H4—cannot hear an alarm clock, which excludes 690,000 UK adults. However, many of the people who are excluded from one of these options could perform the other, so the demand of V7 or H4 excludes only 80,000 UK adults.

3.3.2 Insights gained

When considering design improvements to further reduce exclusion for a task that can be achieved in alternative ways, the best approach is to try and ensure that the demands for each alternative way are as low as possible, and as different as possible from each other. Offering yet another completely different way to achieve the task can also further reduce exclusion. Performing several different exclusion audits is the best way to evaluate the true effectiveness of these different options.

In many cases where the user has more than one way of achieving a task, the greatest danger is that the user will simply end up confused by all the different options. Clarity and simplicity are particular priorities for older users, so extreme caution is required to ensure that adding alternative usage modes does not exclude the very people the alternative modes were intended to help. One such example is the provision of audio output for electronic programme guides within digital set-top boxes, where this additional usage mode could potentially benefit many older or blind users, yet these users may be excluded from the entire system because of its additional complexity compared to analogue televisions.

3.4 Estimating exclusion for task networks

Using a product will typically involve several tasks, one or more of which could be achieved in multiple different ways. Assuming that they are all independent from each other, a task network can provide a useful way to represent all the different ways of performing all the tasks that are required to achieve the goal. A matrix interpretation of set theory can readily calculate the number of people who would be unable to achieve all the possible different combinations of all the ways of performing all the tasks, and also sum together the correct combinations to calculate the overall exclusion associated with the particular task network of interest.

Visualising and comparing the exclusion associated with a network of tasks remains an area of further research. Having performed an exclusion analysis for a single target population, achieving a single goal with a single product in a single context, the analysis could be repeated with multiple different combinations of these choices. Future research is also required to investigate how to present the combined results of several such analyses to provide further design insights.

4 Visualising the relationship between demand and exclusion

Whenever users are required to perform tasks with a product, this will inevitably lead to demands on their capabilities, which will cause exclusion. For the design of products and services, entirely eliminating the demands on any particular capability is likely to remain within the realm of specially produced assistive technology devices. In many cases, however, alternative design choices can make small reductions to the capability demands of mainstream products, while keeping the features, functionality, aesthetics and price-point viable for mass market businesses.

The method presented in Sect. 3 for calculating exclusion through judgement against the original DFS ability levels is only suited to an assessor who has had several hours of training with the DFS dataset. However, the authors have used the DFS dataset to construct a set of stylised graphs that communicate how demand relates to exclusion, which are far more powerful tools to inspire designers to reduce the capability demands of mainstream products, and support the business case for doing so. Figure 8 shows the stylised graph for dexterity, first published in the Inclusive Design Toolkit [17] along with the graphs for the other six DFS abilities that are relevant for product interaction. The demand levels within Fig. 8 are defined in Table 5.

For each of the seven ability categories, producing these stylised graphs first requires changing the language used to define the data points from people who cannot do “task X”, as shown in Table 1, to a product that requires the user to perform actions similar to “task X”, as shown in Table 5. The population data is then expressed in a continuous and cumulative form. These steps are now explained in more detail, followed by a summary of the intended purpose and accuracy of the resulting graphs.

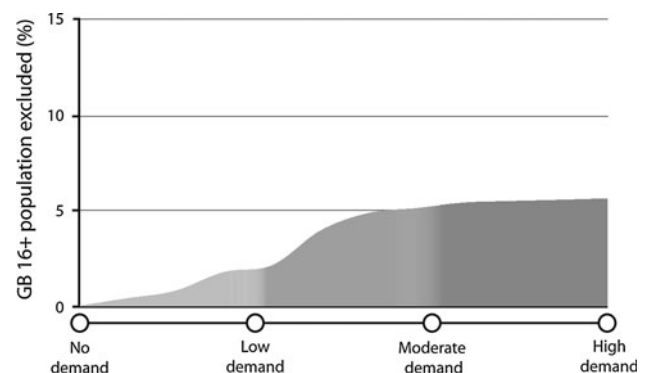


Fig. 8 Visualisation of demand and exclusion of dexterity, where each demand level is defined in Table 5

Table 5 Dexterity demand levels

No demand	The user is not required to pick up and carry objects, or perform fine-finger manipulation, or grasp objects
Low demand	The user is required to have sufficient ability to do things like: Perform simple fine-finger manipulation with either the left or right hand; e.g. pick up a safety pin Pick up and carry a light object with either the left or right hand; e.g. carry a pint of milk Grasp an object with either the left or right hand; e.g. squeeze a sponge
Moderate demand	The user is required to have sufficient ability to do things like: Perform complicated fine-finger manipulation with either the left or right hand; e.g. use a pen without difficulty Pick up and carry a heavy object with either the left or right hand; e.g. carry a 2.5 kg (5 lb) bag of potatoes Use both hands to grasp something lightly; e.g. unscrew the lid of an instant coffee jar
High demand	The user is required to have sufficient ability to do things like: Perform two-handed fine-finger manipulation; e.g. tie a bow in laces without difficulty Pick up and carry a heavy object in each hand; e.g. carry a 2.5 kg (5 lb) bag of potatoes in each hand Grasp an object in each hand; e.g. squeeze a sponge with each hand

4.1 Interpreting the DFS ability levels

When first trying to understand the relationship between demand and exclusion for a particular capability, it is vital to quickly identify what sorts of actions are contained within that category. To provide this information, a “No demand” statement was written for each of the seven categories, based on the user not being required to perform any of the actions covered within any of the underlying ability levels. For example, the “No demand” statement for dexterity is “The user is not required to pick up and carry objects, or to perform fine-finger manipulation, or to grasp objects”. In this case, no-one would be excluded from using the product due to its dexterity demand.

Typically, the next task is to identify the scope of demand levels covered within the data, so a “High demand” statement was written for each ability category, based on the user being required to perform the hardest tasks contained within that category. One could then present demand statements corresponding to each and every original DFS ability level. However, when training others to perform exclusion audits, the authors’ found that the sheer number of different levels and their lack of structure caused unnecessary and unhelpful confusion. Therefore, the data is only presented at two intermediary anchor points, which was considered to provide the best balance between reflecting the granularity of the underlying data, without ‘data overloading’ the assessor. As shown in Table 5, these two intermediary anchor points were named “Low demand” and “Moderate demand”.

Continuing the example for dexterity, the “Low demand” statements were constructed to exclude those in ability levels D1–D4, while “Moderate demand”

statements would exclude those in D1–D8. All demands are expressed in a unified language in the form of “The user is required to have sufficient ability to perform actions like”. Additionally, the statements chosen to describe each of low, moderate and high demand were distinctly structured. For dexterity, the first statement for each anchor point is about fine-finger manipulation. The second statement is about picking up and carrying, and the third statement is about grasping or squeezing. In general, the original DFS ability categories duly supported such a distinct structure for the anchor point statements. However, the underlying data for dexterity and locomotion was particularly unstructured, so artistic licence was required to present the data in a simple and manageable form, resulting in an inevitable trade-off in accuracy.

4.2 Plotting the data in a cumulative form

The original DFS data is in ordinal form, because it refers to the number of people that exist in certain categories, and each category exists in a ranked order (D1, D2, D3 etc.). The most accurate presentation of this data is shown in Fig. 2, yet Fig. 8 shows a more pleasing form, obtained by curve fitting a cubic spline through a cumulative version of data points. Although the ordinal level underlying data does not support such a curve fit, the resulting visualisation remains suitable for its intended purpose, which is to inspire designers to think about the trade-off between demand and exclusion. The rapid nature of some of the gradient changes in the resulting curves represents situations where one of the underlying DFS ability categories contains far more people than its predecessor (or far less than its successor). These rapid changes were intentionally

kept in the published graphs, to communicate that the relationship between demand and exclusion can be distinctly nonlinear.

4.3 Summary

These graphs are intended to present at first glance the relationship between demand and exclusion for each of the different capability categories, in a very general sense. However, the simplified visualisations were constructed through application of artistic licence, and the graphs have very limited accuracy for demand positions other than the four anchor points. Although a true consideration of exclusion arising from multiple capabilities requires using the original DFS capability database, using the set of seven demand and exclusion graphs on their own can provide an order of magnitude approximation for exclusion, and inspire design solutions to reduce it.

5 Conclusions and further work

In combination with other tools, an exclusion audit can help to identify the causes of design exclusion, and to prioritise design improvements to reduce this exclusion, thereby improving the product experience for a broad range of users. Quantifying design exclusion requires a new national survey to be conducted specifically for this purpose, which covers ergonomic, psychological and social causes of exclusion in real-world contexts. Designing and piloting such a survey is one objective of the *i*~design research project, due for completion around 2010. Until the data from this survey becomes available, the 1996/1997 Disability Follow-up Survey remains the most suitable dataset, even though this survey was conducted for a different purpose.

An exclusion audit process has been presented that uses an assessor's judgement to compare a particular task against the generic DFS capability data, and the authors are currently planning research to investigate the reliability and validity of such judgements, and investigate how training an assessor with different tools and techniques could support this process. Although the best available accuracy in estimating exclusion from the DFS data is limited, the relative magnitudes of the different causes of exclusion and the design solutions they inspire are expected to retain some validity. Using the DFS data to investigate potential algorithms for exclusion calculation and visualise the results also directly informs the requirements for the future survey.

Many research questions remain to ensure the future survey is fit for purpose, such as: what models are best able to predict whether a person will have difficulty or be excluded

from using products in real-world contexts; what manner of measurement, consistent within the constraints of a national survey, can provide such predictions with the greatest reliability and validity; and what demographical data, in addition to age and sex, would be of most interest to designers selecting particular populations of interest to assess exclusion? These research questions are being addressed by the current *i*~design research consortium [12].

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