‘Design for all’: methods and data to support designers

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‘Design for All’: methods and data to support designers

by

Ruth Elise Sims

Doctoral thesis
Submitted in partial fulfilment of the requirements for the award of
Doctor of Philosophy of Loughborough University

6th June 2003

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Abstract

If designers are to meet the needs of the growing population of older and disabled people then data on size, shape, posture and capabilities will be increasingly important. This thesis details a methodology for the collection of anthropometry, joint constraints, reach range, postural capability and task specific information, to create a unique database of ‘individuals’. These data were then used in the development of a computer-based design tool (HADRIAN), to allow design professionals to estimate the percentage of people who could be accommodated by a design. Having complete data sets for individuals is vital to enable multivariate analysis, as opposed to traditional univariate percentile data.

Following a review of the literature two interview surveys were conducted with 32 design professionals and 50 older and disabled people. The majority of designers were aware of the philosophy of ‘design for all’, but rarely considered the approach due to perceived time and financial costs. With respect to older and disabled people it was found that nearly all experienced problems completing basic activities of daily life, and that improvements to existing designs could improve quality of life. Activities such as being able to cook a meal, and use the bath were reported as being particularly important.

Firstly, a pilot study was conducted with 8 participants to assess the different data collection options. Data were then collected on 100 people, with the majority being older and/or disabled, and encompassing a wide range of capabilities. From these data it was possible to see that the anthropometric data showed a range beyond 1st and 99th percentile for each dimension when compared to existing anthropometry data, and a breadth of variation in task specific behaviours. Validation trials were then conducted to compare the actual task performance of 10 of the 100 ‘individuals’ with that predicted by HADRIAN, with postures and task capabilities being correctly predicted for open-access reach-and-lift tasks. This gives some confidence that it is possible to predict postures and capabilities from the data collected.
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And finally Richard, who stuck with me and reminded me there was more to life than a PhD, made me laugh, and changed my surname from Oliver to Sims part-way through, just to confuse anyone trying to trace papers and work by the same author.

I would like to dedicate this thesis to my grandparents, none of whom got to see what I have become and what I have achieved, but I hope they would be pleased.
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Chapter 1. Introduction

1.1 The EQUAL programme

The research detailed in this thesis forms part of a project undertaken for the Engineering and Physical Sciences Research Council (EPSRC) programme EQUAL, concerned with work to Extend QUALity Life. This initiative is designed to encourage research that will benefit the quality of life of older and disabled people, and to address the issues concerned with the fact that the population is ageing. The term 'older and disabled people' is intended to cover as wide a range of people as possible, with a variety of abilities, size and ages. Since the first call for proposals in 1998, there have been 34 research projects taking place across the United Kingdom under the EQUAL initiative, involving 42 research teams from 27 universities.

The project, part of which is detailed in this thesis, aimed to facilitate designers in adopting a 'design for all' approach, to avoid the exclusion of sections of the population from being unable to use a product, service or environment. More detail of the concept of 'design for all' is given in Section 1.2. The proposal for the project was to develop a computer-aided design tool which would estimate the percentage of the population who could use a given design, based on assessment of their physical abilities and the task behaviours involved. Taking into account the
variability of physical characteristics, size, shape, and strength, within individuals is referred to as multivariate analysis (see Section 1.3). By using multivariate assessment of the design, the percentage of the population able to use the design can be more accurately estimated.

1.2 Design for All

'Design for all', inclusive design, or Universal Design, was first discussed in the 1970s by the architect Ron Mace, who founded the Centre for Universal Design at North Carolina State University. 'Design for all' is a philosophy with the aim of producing products, environments, services and systems that are usable by all people, whatever their age, size, and abilities. The terms are used interchangeably throughout this thesis.

Some designs are already beneficial to all; pull out cupboards that remove the problems of reaching to the back of high shelves, fully adjustable chairs, adjustable desk heights, lowered kerbs, zebra crossings with verbal and auditory signals. Some were products originally designed specifically for older and disabled people, for example the television remote control and the ballpoint pen (Jordan, 2000); others have been designed by ergonomics and human factors specialists who have an awareness of issues of accessibility and adaptability.

There is not a clear point where a person with one set of physical characteristics can be said to be disabled, and someone else can be said to be able-bodied. Ability is a continuum, from the almost fully able at one end, to the severely disabled at the other (Goldsmith, 1997). No one is fully able, everyone has some activities that they have difficulties with, or cannot accomplish as well as other people. It is desirable that designers (in terms of 'design for all') design to include as many people as possible, starting from knowledge of the needs and abilities of the least able sections of the population to be included within the design. Special aids and equipment for disabled people are designed with consideration of less able users, but such products are not always the best solution to the problem, whether financially, aesthetically or physically (Goldsmith, 1997). In considering function, sometimes aesthetics are neglected, or a specialist product may be more expensive than the main stream equivalent, due to the lower numbers being manufactured and sold. This may increase the stigma associated with buying such products, and put people off buying 'ugly' products. Aesthetics and function are both as important to disabled people as they are to the able-bodied (Feeney et al, 1999; Jordan, 2000; Fulton Suri, 2000; Soares & Kirk, 2000). In many cases it would be relatively easy for designers to make small alterations to existing designs that would enable a larger percentage of the population to use the design with less
difficulty. Examples of such design include constructing a slope into a building instead of a step, and designing hand-tools that can be used with the wrist held in a neutral position.

In a study by Vanderheiden and Tobias (2000), the current practices and perceptions of designers with regard to universal design (or 'design for all') were investigated. The main findings were that universal design was seen as being too specialised, it resulted in increased design and manufacturing costs, and increased time from design to a marketable product. They also found that most designers were unaware of the increase in the older population and subsequently the effects that this will have on market forces in the future. It was felt that awareness of such change could encourage universal design.

As a result of workshops with 150 participants from a range of companies, Keates, Lebbon and Clarkson (2000) found that most designers felt that they would implement universal design 'if it was easy to do' and did not increase costs. The idea of training designers was not well received, and also many did not realise the extent of the growing market for accessible products. Many believed that universal design/design for all' was really design for disabled people, rather than for all people. Where successful universal designed products did exist, they usually had support from top management and clients, rather than being brought about by designers.

It may be that a 'design for all' approach within all areas of product design would provide more attractive solutions, not just in terms of aesthetics but also in terms of usability, cost, and decreasing the stigmatisation resulting from the use of 'special' equipment. More disabled people would then be able to use the design, and consideration of their needs may also advise the development of future specialist tools for those who still require further assistance. The designs would also then, by default, be easier for all people to use. Many people already use badly designed equipment by adapting and coping, but this does not mean that such designs are acceptable. How many of us struggle with tin openers, or have to get someone else to open a jar of pickles for us? These are difficulties that many people experience and cope with day to day, caused by poor design (Keates & Clarkson, 1999; Soares & Kirk, 2000). Kahmann (2000) stated that a designer cannot actually ever 'design for all', but designers should be aware of who they are excluding, rather than simply designing with no consideration of who can or cannot use the design. Elderly people are not all the same, with the same problems. 'Design for all', inclusive design and universal design are all ideals to aim for.
The population is ageing: according to the World Health Organisation, the worldwide population of people aged 60 years and over will have increased from 580million in 1998 to 1000million in 2020. Many of these people will have money and influence (Rogers et al, 1997; Keates, Lebbon & Clarkson, 2000; Jordan, 2000; Clarkson et al, 2000), and be used to voicing their concerns and having their needs met, at a time when they will begin to experience age-related problems and disabilities (Sandhu, 1997). It is likely that the level of dissatisfaction with the design of every day products will become greater, which is likely to result in ‘design for all’ becoming a more frequently considered philosophy.

Research into ‘design for all’ is increasing, as are the sources of information and support available to designers. These include the work of the other projects funded by the EPSRC EQUAL initiative (Section 1.1), the Helen Hamlyn Institute (part of the Royal College of Art), and work presented at the Include conferences, as well as others. All this work will serve to increase awareness of the issues and encourage consideration of a wider breadth of the population during design.

1.3 Multivariate Analysis
Multivariate analysis involves considering a number of body dimensions and capabilities simultaneously, in order to predict whether an individual can achieve a specified task with a given product or environment. Anthropometry usually concerns a single variable (univariate analysis), for example, stature, or arm length. Such an approach does not allow appreciation of the variation within people, and takes no account of important aspects such as the effect of standardised data collection methods (typically in fixed postures, on the right-hand side of the body) or issues such as handedness, asymmetric impairments, and so on. In order to assess or predict performance and interaction with a product or environment, a designer needs to consider more than just one variable at a time. To consider an example of multivariate analysis, Susan wishes to get some money out of her bank account, using an automated teller machine (ATM). In order to do this, she needs to be able to see the screen, to reach to and push the buttons, to reach to the card slot and insert her card, and to be able to reach to the slot where the money comes out. If Susan is unable to do any one of these things, she will not be able to use the ATM and get her money out. There may be other factors that need considering by the designer of the ATM: does Susan suffer from an impairment that would make it difficult or impossible for her to push certain types of button, is she able to grasp the money when it comes out, and so on. Considering all these issues, of anthropometry, and ability, together at the same time is what is involved in multivariate analysis.
Just considering Susan’s stature or arm reach would provide some information for the designer of the ATM, but not give the full picture.

Whilst it may be that a design based purely upon population stature and arm reach could result in an ATM that is usable by a percentage of the population, those who are excluded will not be able to use the machine. Multivariate considerations allow all physical dimensions and capabilities involved in completing a task or using a product to be assessed, and so more accurately predict who could or could not use a design. This approach is fundamental to the project (Section 1.4), which aims to develop a computer-based design tool to estimate the percentage of the population who would be accommodated by a concept design. Further discussion of anthropometry and its limitations, and the need for multivariate analysis, is given in Section 2.3.

1.4 The EPSRC Project

In order to provide a context for the work presented in this thesis, details are given of the EPSRC project proposal. The project aimed to support the ‘design for all’ approach to the design of products, environments, services and systems by developing a computer-based design tool, with an integrated database concerning the 3D characteristics and abilities of people together with an effective methodology to exploit the use of such data. The focus of this project was on the physical aspects of a particular design so that the whole population, including those who are older or disabled, could be considered when evaluating multivariate issues including access, reach, fit, vision, strength and posture. A fundamental aspect of the proposal was the desire to keep individual participants’ data sets as individuals. This was in contrast to traditional methods whereby physical data collected are usually presented as percentile tables (Section 2.3). It was felt that by keeping data sets for individual, real, people, it would enable designers to have greater empathy and understanding of the variation in dimensions within and between individuals. By maintaining data sets for individuals the database would also serve as a set of ‘virtual users’ for use in ‘virtual fitting trials’ by designers at the earliest concept stages of the design process. Keeping complete data sets for individuals also encourages and promotes multivariate consideration, as it is impossible to ignore the variation in dimensions within real people. Such richness of data cannot be extracted from percentile tables, where arms are considered separately to legs and to torsos, and so on.
The objectives of the EPSRC project as a whole were:

- To create a prototype design tool to support and encourage adoption of the 'design for all' approach
- To provide a multivariate estimation of percentage accommodated for a particular design, including consideration of older and disabled people
- To support the designer in maximising percentage accommodated by a particular design
- To collect sample data on older and disabled people i.e. anthropometric, functional reach range, and strength, for input into the design tool and for validation purposes
- To identify the needs of older and disabled people with respect to achieving optimum independence in activities of daily living
- To identify the needs of designers whilst attempting to ‘design for all’
- To disseminate the project results via academic journals, conferences, a workshop and WebPages

The project also included contact with industrial collaborators, to inform the research and to ensure that the resultant tool had the needs of industrial practitioners in mind. These were:

- Ideo Europe (international design consultancy)
- Nottingham Rehab Supplies (manufacturer and supplier of specialist assistive equipment for older and disabled people)
- Disabled Living Foundation (providers of information and equipment to enable disabled people to live a more independent life)
- SammieCAD (human-modelling computer software company)

Two Research Associates were employed on the project: one with primary responsibility for the construction of the computer-based design tool; the other (the author of this thesis) to inform the collection of the necessary data for the tool. The work programme for the 3-year project included a survey of design professionals (Chapter 3), a survey of older and disabled people (Chapter 5), collection of data (Chapters 6 and 7), and validation of the computer-based design tool (Chapter 8). Within this planned framework few details were specified.

1.5 Research detailed within this thesis

The broad objective of the research detailed within this thesis was to support the needs of designers in order to encourage them to consider the design requirements of older and disabled
people with regard to everyday products, environments, services and systems. In order to do this the following research questions were established:

1) What is the current understanding and practice of ‘design for all’ by design professionals (product designers, architects, transport designers)? What are the obstacles and opportunities? In order to inform the author of the current issues within the design community with regards to consideration of ‘design for all’ and older and disabled people, a literature review of design practice was conducted (Chapter 2), and this in turn informed the survey of design professionals (Chapter 3).

2) What specific information do design teams require in order to encourage them to consider older and disabled people during designing? What format should such data be presented in, and in what media? Chapter 3 details the survey of design professionals, in order to answer these questions, also to determine the types of data that should be included in the computer-based design tool, and whether such a tool was needed or wanted.

3) What do older and physically disabled users think of current everyday products, environments, services and systems, and what problems do they experience? How could designers most effectively improve their quality of life? A literature review was conducted to attempt to answer these questions (Chapter 4), and served to highlight issues for consideration in the survey of older and disabled people (Chapter 5). This survey was used to discover the nature and extent of problems experienced by older and disabled people, and to provide ideas for tasks and behaviours to consider during the main data collection phase.

4) What data are needed to support the development of the computer-based design tool, and what methods could be used to collect such data from older and disabled people? The collection of data for the computer-based design tool would involve 100 people and take up considerable time, and so a pilot study (Chapter 6) was conducted to investigate the issues involved and test the various methods that had been proposed. The results and conclusions from this pilot study then informed the main data collection study (Chapter 7).

5) Have the physical and behavioural data that were collected, and the computer-based design tool that was developed, resulted in a valid approach for estimating percentage accommodated? The second researcher used the data collected in the main data collection phase to develop the computer-based design tool. This was then validated by comparison of computer-predictions of participants’ behaviours, and data collected of their actual behaviours in the same situations (Chapter 8).
The final chapter (Chapter 9) provides a summary of the work undertaken, issues for consideration in further work, and the knowledge gained from this thesis.
Chapter 2. Design practice literature review

2.1 Introduction
As background to the research it was necessary to understand the design process, along with details of what information currently exists to support this process and 'design for all' specifically, and any areas where data and information are lacking. It was also important to investigate the current understanding and practice of 'design for all' by design professionals. This literature review describes and discusses the current research. Sources used were on-line databases of journal and conference paper abstracts, and library catalogues. Few papers discussed 'design for all' explicitly, but a larger body of work was found concerning design practice and the design process. The most relevant literature is presented by means of discussion of individual papers and reference to papers with similar or contradictory findings.

2.2 Why is information about end-users needed?
The client or manufacturer usually defines the required product characteristics that the designer has to work to, which can include the specified production costs, weight, and rate of production (Cross, 1983), as well as the look and style of the product. The value of the product to the consumer is harder to quantify (Erbug, 2000). People may choose and use products for any
number of reasons: for example frail older people, not surprisingly, often dislike products that cause them discomfort due to vibration or any jerking motion. Also the ease of cleaning small parts of products becomes an important issue if hand mobility is a problem, as incidental and insignificant this may seem to the designer. The preferences of end-users are much the same whether they are able-bodied or not, with aesthetics being as important as usability (Jordan, 2000; Soares & Kirk, 2000, Hasdoğan, 1996). In fact, people may even buy specialist equipment that they like the look of, even if they know it is not functionally the best product (Harding, 1999): designers need to be aware of such issues.

Products can be made more usable if designers have available, relevant, reliable and detailed information about end-users and the tasks that they will be performing. Increasingly, research is finding that ergonomics should be an important, if not essential part of the design process (Erbug, 2000), with Jordan (2000) stating that inclusive design is increasingly a commercial necessity. If designers proceed with a design without due regard to the needs of end-users, then the resulting prototype or finished design will end up having to be altered post-design in order for it to be usable, which can be an expensive option. Poorly researched products that fail to sell result in a waste of time, effort and resources (Margolin, 1997): designers may need to be made aware of the cost-effectiveness of ergonomics (Grossmith, 1992). End-users should therefore be involved in the design process (Benktzon, 1993; Soares & Kirk, 2000) but, according to Sharrock & Anderson (1994), are frequently are not involved. Hasdoğan (1996) adds to the discussion the fact that “products are made to be useful”, but reminds us that the end-user is not just the person who must be able to use the product, but also the person who goes and looks at products and chooses which one to buy. They also are the ones who have existing knowledge and experience of similar products. Therefore, designers need to consider all these different points of view when designing.

Many designers do use information about end-users, but the information available may be of limited relevance to the product being designed. For example, anthropometric data are often static measurements of distances between specific bony prominences and skin surface of the human body. Of more value to designers may be dynamic measurements and joint-centre to joint-centre measurements (Erbug, 1999), which are less well documented. In addition, the population from which the available data are obtained may not reflect the intended consumer population. Variation due to differences in nationality, age, gender, socio-economic class, date of data collection, and given ability of the sample, will all affect the relevance to the design being considered. Designers can only use whatever information is available to them, however appropriate or not it may be, and
Attempting to apply it to the situation they are designing for. Designers who attempt to include the needs of older and disabled people might never have had to consider the problems and empathise with the needs of these individuals. How effective the subsequent design is at meeting these needs is therefore dependent on the amount of research that the designer does, and the relevance and accuracy of the information gained (Rogers et al, 1997).

Whilst the work of Johnson and Johnson (1989) primarily considered the use of task analysis by systems designers, they presented some useful findings regarding the way that designers use and need information during the design process. They interviewed three systems designers, for a period of between one hour forty-five minutes and two hours forty-five minutes each. It was found that whilst these designers recognised the 'traditional' design process as described by text books (requirements definition, specification of a system to meet the requirements, implementation, validation, updating and maintenance), in reality there was very little structure or sequence of events between the client brief and the finished system. Most information about requirements for the systems came from the client, and was mostly functional with little or no information about the end-users or their requirements. Where end-user information was available, it rarely came from end-users themselves but from others who worked with or knew the end-users. The designers were aware of the shortcomings of trying to design generic products for a large user base without any end-user requirements specified, but relied on intuition and past-experience to 'guess' what the end-users requirements might be. The fact that information available about end-users actually came from marketing departments rather than users themselves may implies that it was of limited detail and relevance to the product or the users concerned. The small sample size used in this study means that the findings cannot be taken to be representative, even of systems designers, but do provide an indication of the state of the design process with regard to the inclusion and consideration of end-users. This study supports the view that designers require end-user information and involvement at all stages of the design process, a fact that the designers themselves were able to identify, realising that such involvement would prevent later problems with the design occurring. So it must be asked, why did the clients not realise this too?

In order to more fully consider end-users, designers must broaden their approach from the creative processes they normally rely on, and use objective methods, such as task analysis (Rogers et al, 1997). Rogers et al (1997) developed a prototype design tool which designers could use to put in information about task analyses, and be given specific guidelines as to the necessary ergonomics considerations for a concept product. Interestingly, whilst they were obviously aware of the need...
to include users in the design process, they still designed their design tool without involving any designers until a working prototype was available. Students were used in the iterative design of the software tool, but it is not indicated whether the students were design students or not. Even when the working prototype was tested, only ten design professionals and ergonomists tested the package, which seems a small sample considering the possible diversity of design companies and the needs of each.

The recognition of the need for end-user information, and yet the failure to obtain and use it, is a common theme in research on the subject, not just in the cases of Johnson and Johnson (1989) and Rogers et al (1997). Sonnenwald (1996) discusses at length the different roles that design team members must fulfil in order to communicate effectively throughout the design process. Whilst it is acknowledged that designers need to know about such things as marketing, manufacturing, documentation, maintenance, and end-users, no mention of communication with end-users is made. A similar contradiction is highlighted by Fulton Suri (2000), who says that designers "work at a distance from their ... users", but no suggestions are made as to why this is. Why do designers not get out and meet users? The paper goes on to discuss how useful it is for designers to 'connect with real people', to actually observe real end-users, to talk to them, to try things as they do. Given that people within the design process realise the importance of end-user involvement, it does not appear to be something that happens often.

Margolin (1997) concurs that end-users are not well-understood by designers. As a possible counter-argument to the view that design needs to be informed by the needs of the end-user, successful designs such as the frisbee, and walkman are cited. But in most cases, such success stories are the exception, and designers need to make more effort to know who they are designing for and why. It is stated that the knowledge to do this comes from personal experience, with designers having intuitive insight due to their own problems with existing products (but surely they might not experience all the problems with a design that other people might, or they might experience different problems!). Margolin (1997) also mentioned that end-users involved in the design process can help designers consider the end-user more fully.

It seems there is a breakdown somewhere between designers realising that, in order to design a successful product, they must consider the end-user, and the designer actually being motivated and getting access to such information. It is possible that issues such as time pressure, client
inclination, and availability of information could be put forward as reasons that affect this breakdown.

2.3 Anthropometry for designers

“Anthropometry is the branch of the human sciences that deals with body measurements: particularly with measurements of body size, shape, strength and working capacity” (Pheasant, 1999).

As such, anthropometry concerns the physical aspects of the human body and how it interacts with environments and objects around it. It must be mentioned that when civilian anthropometry data were first collated and published by Dreyfuss (1960) it was something of an innovation. Before this time few designers had considered the physical dimensions of users, and as such Dreyfuss and his peers heralded the start of a new era of research thinking.

It is general knowledge that people vary widely as to size and shape, so in order to make sense of the variation in different body dimensions, it is necessary to look at how each dimension varies within the population. Anthropometry usually deals with this by measurement of a representative sample of the population of interest. The resulting values can be used to identify the mean value for that dimension, the point at which 50% of the population measured are shorter/smaller on that given dimension, and 50% are taller/larger. The mean of a normally-distributed sample is equal to the 50th percentile, however it must be remembered that percentiles are specific to the population and the dimension that they describe (Pheasant, 1999). The 50th percentile stature for a Chinese population will not be the same as the 50th percentile stature for a Dutch population, and likewise a person who is 50th percentile for stature will not necessarily be 50th percentile for any other body dimensions.

Pheasant (1999) discussed ‘Five fundamental fallacies’ that can arise when designers consider end-user requirements and ergonomics:

1. This design is satisfactory for me: it will, therefore, be satisfactory for everybody else.
2. This design is satisfactory for the average person: it will, therefore, be satisfactory for everybody else.
3. The variability of human beings is so great that it cannot possibly be catered for in any design, but since people are wonderfully adaptable it doesn’t matter anyway.
4. Ergonomics is expensive and since products are actually purchased on appearance and styling, ergonomic considerations may conveniently be ignored.

5. Ergonomics is an excellent idea. I always design things with ergonomics in mind, but I do it intuitively and rely on my common sense so I don’t need tables of data or empirical studies.

These fallacies are refuted at length in Pheasant’s book ‘Bodyspace’ (1999). The fifth fallacy in particular has already been illustrated by some of the papers discussed in Section 2.2, with the use of ‘intuition’ and personal experience in designing. More recently, three further fallacies were put forward by Porter and Porter (2001):

6. The design is not satisfactory for me: it will, therefore, be unsatisfactory for everybody else.

7. Percentiles are a very clear and simple way to present and use information concerning body size.

8. Designing from 5th percentile female to 95th percentile male dimensions will accommodate 95% of all people.

Percentiles can create as many problems as they solve. They can lead designers to believe that the data they have is applicable to all people in all situations, when in fact it is specific to the gender, race, age and ability of the people who it was obtained from. Designers may also think that by designing for 5th to 95th percentiles they are including 95% of people (fallacy 8), when in reality, on any given dimension used, they are excluding up to 10% of the population. If different dimensions are used in designing a product, then the number excluded increases rapidly: consider the following example. A product is being designed in which arm and leg length are important. The designer uses 5th to 95th percentile values for both dimensions. Those people with arms shorter and longer than the 5th to 95th arm length will not necessarily be the same people as those with legs shorter and longer than the 5th to 95th leg length, such that on each dimension up to 10% of the target population will be excluded. If the designer were to consider further dimensions, then for each (for example, sitting height, hip breadth, and so on) up to 10% of the population would be excluded, with those being excluded on one dimension possibly being different people to those excluded on another dimension. The result is that the percentage of the population being excluded increases with every new dimension considered. No one person is any given percentile for more than a couple of dimensions at most (Roebuck, Kroemer and Thompson, 1975).

Designing as if an average person (in terms of 50th percentile) does exist, results in half the population for any one dimension not being accommodated: this is the point highlighted by fallacy
2. Sadly, the 5th and 95th percentiles are generally accepted by ergonomists and designers alike as the ‘outer limits’ that should be included within a design (extending to 1st-99th percentiles for safety-critical dimensions). This perpetuates the misinterpretation of the available data, as highlighted by the eighth fundamental fallacy.

Percentiles also remove all possibility of a designer considering a ‘whole’ person. Data for measurements of arms, legs, torsos, heads, are all split into different tables for the entire population measured. It is then difficult to collate data from separate tables or diagrams to make a real, whole person, with the variance in percentiles for the different dimensions that are found in real people. It may be, in the opinion of the author, that keeping data sets complete for individuals, would allow designers to see real people in terms of dimensions and abilities.

Also, anthropometry in tables of data is usually ‘static’. That is, it is collected from people holding themselves in a fixed standard posture. Whilst these data can still be useful in this form, a designer needs to be aware that static arm length is not the same as dynamic anthropometry, such as measuring an arc of how far someone can reach. Such dynamic functional anthropometry may be more useful for a designer (Haigh, 1993; Erbug, 1999). The difference between static and functional measurements may make all the difference to the design of an item where issues such as reach and movement are of importance (Erbug, 1999). Standardised data collection may also not take account of aspects of a person such as handedness (if data are all collected from the same side of the body, for example), or asymmetric impairments (for example a person with arthritis in their ‘dominant’ hand).

Generally, designers wishing to find data about end-users have to be prepared to search for information within the huge amounts available, and also ensure relevance to their needs. They would have to check the date of the research (due to the effects of secular growth over generations), the nationality of the population studied, whether the data are estimates or actual values, as well as having to consider whether the measurements given are useful for the actions and/or measurements needed for the design (Cushman & Rosenberg, 1991). Data presented are often the 5th, 95th and 50th percentile values, with the standard deviation, for men and women separately, for a given population. Anthropometry is generally collected from groups of people and presented in tables of data (see Pheasant, 1999; Dreyfuss, 1978; Metric Handbook, 2001; Neufert, 1988) or as diagrams with data written alongside (for example Childdata, 1995; Adultdata, 1998; Olderadultdata, 2000; PeopleSize, 1998).
Designers appear to be willing to use anthropometric and ergonomics information, but do not do so in reality (Erbug, 1999). Ergonomics information is increasingly available, but might not be used as it is not necessarily in a form that is easily accessible by designers (Erbug, 1999). The available anthropometry may be incorrect or invalid for the purposes that the designer needs it (Molenbroek & Zhang, 2000), and there is a lack of suitable anthropometry from disabled people (Feeney et al., 1999). There are some data available for older end-users (Institute for Consumer Ergonomics, 1981; Molenbroek, 1987; Steenbekkers & van Beijsterveldt, 1998; Olderadultdata, 2000), and disabled people (Fenwick, 1977; Boussena & Davies, 1987; Goswami, Ganguli & Chatterjee, 1987; Hobson & Molenbroek, 1990). However, these sources may not be as readily available or easy to access if they are not in texts or sources frequently used, for example, or the sources may not be relevant to the design (for example irrelevant dimensions given, wrong side of the body quoted, and so on).

Lack of understanding of ergonomics and anthropometry may prevent designers from utilising the available data. Currently designers need assistance to be able to understand difficult-to-use tables (Molenbroek & Zhang, 2000) and interpret guidelines and existing research (Clarkson et al., 2000), which may explain why ergonomics data are not more widely used. Molenbroek and Voorbij (2001) reflect that anthropometry is presented in a format that is not useful to designers, who prefer graphics to figures. Diagrams, such as those found in PeopleSize (1998) with the dimensions of the body parts written alongside the parts they refer to, are easier to read and understand than tables, but do not highlight multivariate issues. Educating designers in basic ergonomics, how to use the data, and when to use it may help (Erbug, 1999), as well as educating ergonomists in designers’ preferred presentation of such data. Such education would best be fitted into schooling and higher education, rather than training once employed as designers, due to time restrictions (Vanderheiden & Tobias, 2000).

2.4 The design process and incorporating end-user information

Brennan and Fallon (1990) describe the traditional product design process as activity to change a statement of requirements (the client brief) into a detailed plan and description of the product. It requires that the designer recognises the need for the new product, considers what the need is and what problems exist, generates concepts to solve the design problem, analyses and assesses the various concepts, and then designs the final product. This is an iterative process, with designers going back to concepts, and assessing and testing as needed until they come up with a viable solution. It is thought that designers arrive at the final solution, either by a new insight, by
redeveloping existing designs, by using their previous experience of similar problems, by
guessing, or by trying various possible solutions until the best is found.

The pattern to product design discussed by Brennan and Fallon (1990), and also Cushman &
Rosenberg (1991), is detailed in Figure 1. For many designers the process may continue into
installation, maintenance, and so on. This is not the only route from brief to product however,
with iteration of design and feedback from prototyping and testing being used to improve the
design. For further examples of the design process, and discussion of different routes, the
interested reader is directed towards work by Roozenburg and Cross (1991), Vora and Helander

Initial brief given by client

Product planning

Concept development

Marketing

Evaluation

Manufacturing

Testing & redesigning

Figure 1: The design process

In reality the design process is generally vague and imprecise, and influenced by the personal
traits of the designer (Smyth, 1987; Cross, 1983). Ashton (1995) concurs that the design process
is not always a smooth progression but often random, testing different solutions until the optimum
compromise is found. Therefore it is not surprising that non-designers may have problems
understanding what the design process involves, and therefore not being able to provide data to
support such a process.

It has been found that information about end-users is currently used too late in the design process
for changes to be made without excessive costs in time and money (Johnson & Johnson, 1989;
Porter & Porter, 1999; Bruder, 2000). Most designers do not involve end-users at all in the design
process (Johnson & Johnson, 1989; Sharrock & Anderson, 1994; Molenbroek & Zhang, 2000), or
else only involve a few users, who may not reflect the variety of needs of the target user group
(Hasdogan, 1996). Ergonomics needs to be considered early in the design process, with initial
design considerations being about the target user group (Molenbroek and Zhang, 2000). Bruder
(2000) discusses that, increasingly, usability is determining product success or failure, as end-
users no longer accept difficult-to-use products: the lack of understanding of this reflects fallacy 4
(Section 2.3). Information about preferences, physical characteristics and capabilities of end-users
is needed as early in the design process as possible (in order to reduce time wasted on redesign later in the design process, and the cost of post-design or post-manufacture alterations). Ideally, such information should be included in, or requested as part of, the initial client brief, and consideration should form one of the first stages of the design process.

Soares and Kirk (2000) conducted a study into wheelchair design, in order to produce a user-centred design method that would consider all the users involved in the different stages of the design process. They surveyed 11 wheelchair designers, 98 physiotherapists and occupational therapists, 43 rehabilitation engineers, 187 wheelchair users, and 99 carers of wheelchair users. They found that it was important to involve users and carers as much as possible during the design process (including finding out about users and carers) in order to develop profiles of users and the tasks that they carry out involving the wheelchair. Involvement was desirable throughout the design process, from the initial planning, through investigation of the problem, to the prototyping and testing of the finished designs. It was suggested that end-user involvement through end-user profiles, contact with and consultation of end-users, and focus groups with end-users, would all help to inform the design process at the various stages.

Eckert, Cross and Johnson (2000) found that “communication between different members of a design team is a notoriously difficult problem, especially at the early stages of the design process”, and, presumably, communication with end-users is also difficult. Misunderstandings due to problems of communication can result in incorrect design information being passed on to different members of the design team, resulting in errors and problems with the design that may not be discovered until a much later stage, when changes to the design may prove too costly or be impossible. Designers should, where possible, design products with the needs of all potential users as the starting point for the design. In reality it seems that designers focus on the product specification as given in the brief (Cross, 1983). However, the design process and the consideration of end-users are not always within the designers’ control. A designer given a brief for a product by a client must meet the client’s specification, whilst also allowing their own creativity to be apparent, within the boundaries of any legal and technical restrictions. In between all the given constraints, the designer must find a viable and acceptable solution that will make money. Designers may be reluctant to use information about end-users as they may feel that the effort needed to find the required information is not possible within the given time and money constraints, and may increase the price of the final product as a result (Porter & Porter, 1999). Also, designers do not always notice ‘poor’ (meaning unsuitable) designs, due to them most
commonly being assessed by their fellow designers (Savage et al., 1998), who are not necessarily typical end-users. This may suggest, in the opinion of the author, that end-user involvement to assess designs may reduce the likelihood of such ‘poor’ designs being manufactured.

Kahmann (2000) stated that during the analysis of the problem it may be beneficial to observe users as they interact with existing products in real and novel situations in order to find out what people currently do and have problems with. Involving end-users during the evaluation of a product, whether with concepts, models or prototypes, means the designer can get direct feedback about users’ responses to the product. It is concluded that communication to designers or within the design team needs to meet the specific requirements of the designer or team, but no suggestion is made in the paper for how this should be done.

2.5 Communication of design information

It has been found that information about users, in order to be used effectively, needs to be presented to designers in a format that is geared towards their information needs (Porter & Porter, 1999), and it is suggested that this should be visual or graphical whenever possible. Whilst designers work primarily with visual information (Smyth, 1987; Hasdoğan, 1996) most anthropometry is presented in the form of tables of numbers. Such data may not appear to be immediately relevant to the work of the designer (Porter & Porter, 1997). Providing data in a format that does not fit in with the way that designers think and work will result in it not being used to maximum benefit for consumers.

Perry and Sanderson (1998) discussed communication between designers within design teams. The role of ‘artefacts’, that is representations of design issues such as objectives, functions, form, materials, and so on, as a method of communication was discussed. The artefacts used by the two case study groups (the design of a pump and of a building) investigated were largely visual. Artefacts that both groups used were: pencil and paper drawings, CAD drawing tools and models, whiteboard/notice board, prototypes/models (cardboard). Other methods of communicating design ideas were things like telephone, fax, camcorder, and the use of a test rig for the pump design group. It can be seen that the majority of these artefacts and communication methods are visual, methods of showing each other and the client how the design is progressing. The paper discusses communication between “clients, model users, managers of users or clients, suppliers, technical experts, other designers” but does not discuss communication of and with end-users, other than the ‘model users’. The ‘model users’ are not mentioned again in the paper other than in
this quotation, and no details are given as to whether these 'model users' were real end-users or not.

Kuffner and Ullman (1991) discussed the information needs of mechanical design engineers. Again, the information sources that the engineers used were primarily visual: design sketchbooks with drawings to describe the product from concept to blueprint. During their research, three professional mechanical design engineers were asked to make modifications to existing designs. They were each given the blueprints and specifications of the completed design, and access to an expert in the existing design. Their subsequent questions and conversations were videoed and analysed. Of the different types of queries and problems that each designer experienced, 31% were asking the 'expert' about the functionality of the object. It was suggested that the reason for this is that functionality information is not normally included in standard design documentation. It may be (in the opinion of the author) that such information is more likely to take the form of written text and notes, rather than graphical sketches and images.

Toames, Oates and Armstrong (1998) discussed the translation of visual to verbal information and vice versa within the design process. They discussed communication within design teams and the emphasis that different members of the design team place on either visual or verbal information, and therefore the need to translate between the two methods of communication. Again, it is of concern that no mention of communication with end-users was made. The need for efficient communication between the client and the designer is discussed, but it is not suggested that the client is the end-user in the majority of cases, but rather the person commissioning the design. It is mentioned that design is rarely an individual process, but involves many people, therefore making efficient communication essential. The paper does mention the fact that the designer and client both need to be confident that the product will communicate its uses to the purchasing public, but does not suggest that asking the public what they would like or to comment on early prototypes is a way to discover this!

Modelling, whether by use of drawings, mock-ups, or prototypes, has always been important in the design process for the communication and development of ideas (Cross, 1983; Kodali, 1990). The introduction of computer-aided design packages allows two- and three-dimensional modelling, and the use of such tools is now widespread. Making alterations to a design becomes more expensive and time consuming as the design progresses. Using computer-aided design packages allows for many design options to be explored and evaluated in the virtual environment.
for considerably less than the cost of producing traditional models and prototypes. Iterative
design (whether virtual or real) within the design process can also help prevent costly alterations,
especially if end-users are involved at each iteration. However, models, whether physical or
virtual, are only ever simplifications of the real object, and do not always predict problems with
the finished design (Cross, 1983).

Hasdoğan (1996) stated that the designer's expectations and the end-user's might not match. The
designer's expectations and the end-user's might not match. The paper discusses how using a 'model' of end-users could resolve this mismatch. A model in this
sense is any method of thinking about end-users, whether via an empirical physical model such as
using anthropometric data or CAD software, through to scenario-based cognitive models such as
user stereotypes and metaphors. The paper goes on to discuss the results of surveys of designers
from 55 companies, including formal questionnaires and open-ended interviews (it is unclear how
many individual designers responded). Five designers used CAD human models, with one using
anthropometry manikins, and 22 used tables of ergonomics information. In comparison 60 used
only personal experience and imagination, 50 used self-modelling, 20 used sketches of usage, and
50 used scenarios of usage, with only approximately 25 using representative end-users. Reported
reasons for not using physical data such as anthropometry were that it lacked information about
peoples' preferences and behaviours, and the data available were often not relevant to the
population being designed for. Designers' knowledge of CAD human modelling software at the
time was limited, and those who did use it felt that it was open to misuse and required some prior
ergonomics training. Where designers considered end-users in different possible design scenarios,
for the most part they used themselves and their colleagues as 'users', rather than employing
actual end-users. No reason is given for why this may be. However, given that designers have
easy access to their colleagues and associates, it would seem logical that testing with them can be
relatively quick and cost-free. In contrast, user-trials would involve members of the public being
found, contacted, requested to attend, and require ethical consideration and approval, and so on.

Sumner (1995) conducted a case study of user interface designers (no published details of how
many designers) by means of workplace observations, field notes, and open-ended interviews with
designers over a three-year period. The study investigated what computer design tools designers
used, when and how they were used throughout their every day work. It was found that designers
have two major aims – to develop the design and to communicate it to all those involved. As
such, designers were increasingly utilising computer-aided design software packages to represent
and communicate the design ideas. Designers were found to be using a collection of different
packages in order to represent the design in different ways. Although Sumner's (1995) work concerned primarily interface designers, the findings are still relevant to all designers who use computer-aided design packages not only as design tools but also as a means of communication. It seems likely that the use of computer-aided design tools will increase in the future. Combining such tools with human-modelling systems may enable the consideration of users at concept stages, where currently many designers overlook users.

Trueman (1991) concluded in a non-empirical examination into design practice and profit that information was required by all those involved in the design process, and at all stages, and that the information would take different forms: text, graphical, and so on. It was stated that before choosing a computer-based system to assist in the design process, it was important to choose the most appropriate form of information and decide how the information should be made available and who will be using it. It was also concluded that the 'human factor' in design is becoming increasingly important, and that for design teams and clients this may be the difference between success and failure of the design. Feeney and Bobjer (2000) state that real-life situations and use of video film can be used to demonstrate how different users interact with products in order to enable designers to see how people really behave with products. However, no empirical data or evidence is put forward in this paper to support this suggestion, and it is not noted that interactions recorded in a laboratory setting may not necessarily be the same as those performed in private.

Erbug (1999) conducted a survey (with no published details) into preferences and usage of ergonomics software packages. Use of such packages could give an advantage to the designers using them, but many packages were lacking in relevant information and detail. It was found that the ergonomics information that designers require is:

- dynamic, not static data
- details of good and bad existing products
- details of standards and regulations
- accident analysis
- end-user profiles and descriptions
- anthropometry
- details of behaviours and responses to products and situations

Current computer-based resources are too narrow, and need more data and wider application (Erbug, 1999). Computer-aided human modelling packages, such as SAMMIE or JACK, offer anthropometric data and joint constraints within virtual human models and workplace models.
However, such a system requires training and some ergonomics knowledge, and does not serve as an accessible database of anthropometry. Vanderheiden and Tobias (2000) concurred that computer-based ergonomics design tools would be more useful if tailored to the industry using it.

It is proposed by the author that visual information, such as sketches, diagrams and computer-aided design models are more attractive, usable and relevant to designers, encouraging them to consider the needs of all users. In order for ergonomists and designers to understand the needs of each other in the design process, including the presentation of data and the data that is required, more research is needed into the types of information and the preferred presentation methods needed for design professionals.

2.6 Legislation

Few products that are designed are novel, with the majority of design work being the redesign of existing products (Margolin, 1997). Such redesign can occur due to a desire to alter the appearance or functionality of a product to keep up with fashion or technological advances, or due to changes in product legislation and safety laws that affect the design and performance of the product (Cross, 1983; Margolin, 1997).

The current British legislation affecting consideration of the needs of disabled people is the Disability Discrimination Act (DDA) 1995. Goldsmith (1997) states that this was modelled on the Americans with Disabilities Act (ADA) of 1990, and included aspects from British Standards BS5619 (1978), concerning the design of housing for the convenience of disabled people, and BS5810 (1979) a Code of Practice for access for the disabled to buildings. These earlier standards had improved consideration of the needs of disabled people, but were not without their problems.

The Code of Practice, BS5810 (1979), included a plan for the layout of a toilet cubicle that was used extensively in plans for new buildings. It was a unisex toilet, but only specified transfer from a wheelchair on one side or the other only. The widespread adoption of the toilet layout succeeded in raising awareness of the need for such facilities, but its success was limited by who could use the design - people unable to transfer from whichever side had been chosen could not use the facilities without assistance (Goldsmith, 1997). BS5810 also did not provide any data for bathrooms, shower areas, sinks, dining areas, tables, work-surfaces, seating and storage, and did not suggest alternative sources for such information for the interested architect (Haigh & Feeney, 1986). There were also issues concerning the layout and ease-of-use of the document, and no
detail was provided to inform architects of the consequences to disabled people if they failed to provide adequate access.

The Americans with Disabilities Act concerns employment, public transport, buildings, and telecommunications. The Act is supported by the ADA Accessibility Guidelines (ADAAG, 1991), which contains detail about guidelines, recommendations and actual measurements to assist designers in the implementation of the Act. The guidelines include details of sizes for everyday items such as controls, kitchens, bathroom and toilet facilities, alterations, information and communication systems, and vending machines. On the other hand, the British act (DDA) is grievance-led (Goldsmith, 1997), and employers' willingness to comply with the Act depends on personal attitudes to disabled people and knowledge of the legislation (Jackson, Furnham & Willen, 2000). The DDA does not contain guidelines for the necessary changes to be made in order for the requirements of the Act to be met (Goldsmith, 1997). The Act provides no practical details for architects and designers to follow, it simply states that buildings and public areas must be accessible. Confusion about the terms of the Act may also occur in that it is difficult to define what are the “unacceptable” features that could result in a grievance claim (Goss, Goss & Adam-Smith, 2000). As such, the Act could allow successive changes to be demanded to the same building or service, and still not result in it satisfying all people (Goldsmith, 1997).

Another criticism of the DDA (in the opinion of the author) is that it primarily focuses on the needs of disabled people with respect to architectural design and employment discrimination. No direct reference is made to the design of products, with ‘goods’ being loosely covered by Part III, which details how providers of services must not discriminate against disabled people in the provision of that service. Whilst the ability to move about in public independently and with ease is of considerable importance to disabled people, the ability to lead an independent home life is also highly desirable. With the law as it currently stands there is no legal requirement for product designers to consider the needs of older and disabled people. The Act is still to be fully implemented, and not everyone is convinced it ever will be (Bellerby, 2000), and so, whilst the DDA has raised awareness of disability issues, it has not necessarily improved the situation as yet (Robertson, 2001). The legislation may change in the future, forcing designers to ‘design for all’, but it is more likely that the drive for change will come from market forces (Rogers et al, 1997).

There are differences not only in the legislation of different countries affecting the provision of consideration of the needs of older and disabled people, but also in the way that different
governments encourage and emphasise the need for consideration of minority groups by designers. For example, it is standard for Swedish buildings to have level-access showers, easy-push light switches, and even in-toilet bidet systems, which are prime examples of ‘design for all’. Emphasising consideration of all users during design, whether by legislation or funding, could, in the opinion of the author, result in improved usability for all. However, government regulation often results in a split of opinion: in a study of designers Vanderheiden and Tobias (2000) found that those designers who were against regulation felt that it would merely result in ‘extremes’ that people would design to, but would not ensure consideration of people outside these extremes. It is believed by the author that this would still be an improvement compared to current practices.

2.7 Conclusions

Considerable work has been carried out into the needs of end-users with regard to information and information technology, but there is less evidence of research conducted to investigate the information needs of design professionals. Specifically, little is known about the information that designers need about end-users, what sources of information they currently use when designing, and any problems experienced with existing data sources. The literature did not provide any real information about why designers do not involve end-users. It is possible that perceived cost (in time and/or money), or the lack of specification by clients, could account for the contradiction between designers being aware that design can be improved by end-user involvement, and those actually involving users.

Designers should include anthropometric data and ergonomics information in their designs. Failure to do so can cause discomfort, frustration, and even injury in some cases. It is clear that the information that designers need and want may not match that which is available to them, and that existing data may not be relevant or in a format that is preferable. There is clear evidence that designers prefer visual formats for data, but not all data that could be of use to them is presented in this way (for example, percentile data is typically in tables).

It is felt that how designers consider end-users in the design process, the use of visual and other types of data, and the need for cost- and time-effective end-user information needs to be further investigated and addressed (via a survey of design professionals). The role and impact of legislation is also not clear within the product design profession.
Chapter 3. Survey of design professionals

3.1 Introduction
In order to assess the current state of design knowledge and practice with respect to ‘design for all’ in the United Kingdom, it was necessary to conduct a survey of design professionals. Such a survey would also be useful to discover whether the proposed computer-based design tool would be of benefit to designers, what information about end-users it should contain, and what form that information should take, to best assist designers. This information would be used to inform the development of the tool.

3.2 Aims
The main aims of the survey were:

- to investigate current practice of ‘design for all’ and how it could be encouraged and supported within the design community
- to discover the procedures and information used by designers to meet customer requirements
- to find out how computer technology is used in the design process
to discover any other critical issues affecting consideration of older and disabled people, and consideration of ‘design for all’, at the current time. The results would feed into the development of the computer-based design tool, ensuring it contains information of relevance to designers, in a usable format.

3.3 Rationale for survey of design professionals

For the survey of design professionals, it was important to allow the opportunity for free discussion of the issues, and not to bias designers’ answers. Opinions and views why ‘design for all’ was not considered were of as much relevance as reasons for consideration, and in some ways more interesting in enabling possible ideas and ways of counteracting any negative points raised. In order to minimise non-participation and to ensure good relations with designers and companies alike it was important to keep interviews short. It was also useful in the design of the survey to build on existing literature with regard to designers’ preferences for visual information, and their feelings about end-user involvement, the role of the client, the use of ergonomics information and computer-aided design packages.

3.4 Sampling

In order to obtain a broad range of views from a cross-section of design professionals, 50 individuals were selected for the interview survey. The sample was divided as follows: 10 small design companies/consultancies (less than 5 designers), 10 large design companies/consultancies (5+ designers), 10 designers of specialist equipment for older and disabled people, 10 companies with in-house design teams, and 10 other professionals involved in the design process (including transport designers and architects). The sample was not intended to be fully representative of the percentage of designers working within different company types and sizes. A variety of sizes of design groups were included in order to encompass any differences in research capabilities and resources available to the smaller and sole-trader companies and the larger companies. Designers of specialist equipment for older and disabled people were included in order to assess any differences between the information and techniques that they used when designing and those used by designers of mass-market products. Architects and transport designers were included, as they already have to consider the needs of older and disabled people due to legislation. It was hoped that the number of women working within the industry would be reflected in the sample, however, despite contacting the Crafts Council and asking female
designers, it proved impossible to obtain national figures for the percentage of women working within industrial design.

Details about design companies and consultancies were obtained from public lists of designers, such as the Design Directory (1997/1998), and lists on web sites, such as the Royal Institute of British Architects (RIBA) web pages. Designers specialising in design for older and disabled people were contacted using information provided by collaborators with knowledge of specialist design, and from assistive-product catalogues obtained from Disabled Living Centres. Individuals were then selected from these lists, with the sampling method dependant on the number of contacts on each list, and the type of design work undertaken. For example, only the contact details of companies mentioning product design explicitly were taken from the web-based lists, whilst only those architects mentioning specialist work with older and/or disabled people were noted from the RIBA web pages.

3.5 Design of interview questionnaire

The main aim of the questionnaire was to collect detailed information about the design process and the information needs of designers, particularly with respect to 'design for all' (see Section 3.2). It was decided to conduct 30-minute telephone interviews using a semi-structured questionnaire, to meet with the designers’ time constraints, and also to avoid practical difficulties such as travelling to different geographical locations. Postal questionnaires were not possible given the unstructured nature of the majority of questions, and to avoid the likely poor response rate (Sinclair, 1998).

For the design of the questionnaire it was necessary to consider and prioritise the important issues to be covered and how best questions could be phrased in the time available. The author referred to Sinclair (1998) for basic questionnaire design protocol. Questions were devised by the author, and discussed with the other members of the project team. In particular, the questions on computer usage were discussed in detail with the project team member directly responsible for the development of the computer-based design tool.

The layout of the questionnaire was not as critical as in a postal questionnaire, but the wording was still of importance, and it was essential that the meaning of each question made clear verbally. The order that the questions were presented was for guidance only. Flexibility existed to allow the
interviewer to check off questions that were covered out of sequence by the participant, rather than keep stopping the participant in mid-conversation.

The questionnaire was also designed to be as generic as possible across the sample groups to allow for comparison of data between groups. It was divided into four main sections, each with relevant questions reflecting the main themes of the investigation. The four main sections were personal and company details, current design practice, computers, and the future (discussed in Sections 3.5.1 to 3.5.4). The sections were chosen to add coherence to the questionnaire and to allow issues to be addressed out of order without causing confusion to the interviewer.

The majority of questions were open-ended discussion questions to allow more information about peoples' personal opinions and ideas to be gained without prompting by the interviewer. The remaining questions were a mixture of simple dichotomous (“yes-no”) questions to obtain factual information, and probing questions to discover the reasons for the response. The final interview questionnaire is in Appendix 1.

3.5.1 Personal and company details
Participants were asked for their job title and position and how many years they had been involved in design. This was to give background information about the types of people who participated in designing, and their experience level. For example, were juniors being given the task of participating or did higher management feel it important to participate themselves? It was thought this might provide some indication of how important ‘design for all’ issues were within companies. Participants were also asked if they had been involved in the design of any specific products for older and/or disabled people as appropriate. Finally, they were asked what they understood by the terms ‘design for all’ or ‘universal design’, in order to assess knowledge and understanding of these terms.

3.5.2 Current Practice
This section of the questionnaire concerned current design practice, and included the design process, information requirements and sources of anthropometric data used (if any). These questions were to investigate the information needs of design professionals during designing, and to highlight any problems/good points of current sources of such information, specifically anthropometric data. Participants were also asked how they felt about the consideration of end-users during the design process, and whether/how they involved end-users in the design process
themselves. These questions were to ascertain the perceived importance and value of consideration and involvement of end-users in the design process, and how many companies actually involved end-users directly. Participants were also asked whether they had ever, or would ever, consider designing modular products with different components for people with different abilities. This is one way to address potential conflict of needs between people with different abilities. Finally participants were asked for their opinions on why it is that currently few designers take special care to consider older and disabled people in the design of mass-market products. This was a very important question as it was hoped that designers themselves could provide insight into why the profession as a whole seemed to be excluding the needs of these sectors of the population.

3.5.3 Computers
Questions for this section were formulated in close collaboration with members of the project team concerned with the production of the computer-based design tool. Participants were asked what sort of computers and computer-aided design packages they used and whether they had/used any software relating to anthropometric data. This would allow insight into the types of computer-aided design software currently in use, and highlight any problems/good points of such. The proposed computer-based design tool was described to participants and they were then asked whether they would be interested in the proposed tool, and what they would like to be able to do using such a tool. They were told that it would include a computer-aided design tool that could evaluate a given design in terms of usability in relation to a stored catalogue of data from 100 individuals. It was felt by the computing experts on the project team that it was important to know if the participants would wish to be able to tailor the system themselves, and therefore to know how easy to make it to re-write sections of the software code.

The computer questions were not as detailed as the designers of the computer-based design tool originally suggested, due to time constraints, and it was expected that few designers would possess in-depth knowledge about the computers they used. It was also important that the interviewer understood these questions, therefore it was decided that any designers who were especially knowledgeable or interested in the detailed side of the software would be asked if they would be willing to speak to the researcher concerned with the development of the tool. Relevant contact details were then passed on.
3.5.4 The Future

Participants were asked for their views on how, and in what ways, all designers could be encouraged to consider older and disabled people during the design process. This was to determine how people viewed the future of their profession and what they would be willing to do in order to increase the consideration of these sectors of the population.

The same questionnaire structure was used for all the sample groupings (large and small companies, product designers, transport designers, architects, specialist designers), with amendments made as appropriate. The questions asked were also made as generic as possible to the process of designing, whether it was applied to a house, car, or kettle. A house, a car, and a kettle were the examples given to the relevant designers (architects, transport designers, and product designers respectively) if they needed prompting or directing to a specific design in order to focus their thoughts. Differences in questionnaire structure for the difference sample groups were as follows:

- Questionnaires for designers and architects were largely identical, with the only differences being the alterations to the examples given.
- Transport designers and architects were not asked if they had ever designed modular products (with different components for people with different abilities), as this was not thought to be relevant to the types of ‘products’ that they were designing.
- The questionnaire for students only included those questions that they would be able to answer given their limited commercial design experience.

3.6 Ethical considerations

It was not necessary to obtain specific ethical approval for the survey from Loughborough University, as general guidelines for such research were followed. The main issues for consideration in the survey of design professionals were confidentiality, both personal and in terms of corporate identity. All measures were taken to keep participant responses anonymous.

3.7 Piloting

Four designers were interviewed face-to-face in order to pilot the content and wording of the questionnaire. They were made up of final-year Design and Technology students who had been on one-year industrial placements with product designers, and consultant designers. The industrial collaborators for this research (see Section 1.4) were also contacted and asked for their opinions about the questionnaire. The procedure used was the same as that for the actual investigation.
(details given in Section 3.9), but at the end participants were also asked for their opinion of the interview questionnaire.

The piloting resulted in changes to the structure of some of the questions, and a reduction in the length of some of the preamble. This was to prevent the attention of busy participants from wandering whilst the questions were being read, and remove the need to remember lots of information for consideration in the answer. Some dichotomous questions ('yes-no') were also changed and made into open-ended questions to make them more open to participants’ opinions, rather than forcing the participants to agree or disagree with the interviewer’s preconceived ideas. It was felt that this would result in a more accurate reflection of the designers’ real views.

Piloting was also carried out for the letter and project details (Appendix 1) to be sent to all participating design individuals prior to the interviews taking place. This was to ensure that the wording and layout would make the information quick and easy for the participants to understand. It was especially important that the value of the contribution that the participants would make was emphasised, and that the accompanying consent form was read, understood, and completed. The letter and project details were also checked by members of the project team and two practising product designers, and amendments were made as necessary. Those who took part in piloting the questionnaire and other documentation were not included in the investigation sample.

### 3.8 Equipment

In order to assure the confidentiality of participants’ responses, and to prevent either the interviewer or the participant from being distracted, the telephone interviews were conducted in a quiet room, and efforts were made to avoid interruptions. Interviews were conducted using a BT Freehand speakerphone, allowing the interviews to be tape-recorded using a Sony TCM-459V Dictaphone. Full-size tapes were used in order to reduce costs and to allow for transcription using an Optimus CTR-109 portable cassette recorder.

### 3.9 Survey procedure

1. The selected companies were contacted to ask if they would participate and all contact details were checked.
2. Those unable to participate were removed from the sample frame, and others contacted to try and replace them.
3. Letters were sent to all participants, detailing the research aims, what participation would involve, a consent form and list of the main areas covered by the questionnaire. The letter included a request to sign and return the consent form along with a preferred date and time for participation (Appendix 1).

4. Those who did respond to the initial letter were contacted by follow-up telephone calls in order to arrange interview times. This process had to be repeated many times, with some requiring further faxing through lost details and consent forms. Unfortunately nine participants pulled out after several follow-up calls had been made (see Section 3.11.1). It was thought that by making the effort to contact people personally by telephone the likelihood of participation would be higher than just sending letters to firms without any other contact being made.

5. Once interviews were arranged, participants were telephoned at the designated time and date for the interview to take place.

6. Interview conversations began with the participant being asked whether they had read and signed the consent form. If it had not been previously returned to the interviewer, participants were asked to do so.

7. Interviews then commenced, and the tape recorder was switched on. A code number was used to identify participants in order to ensure anonymity of responses.

8. Interviews were then conducted as described in Section 3.5. As already discussed, the order of presentation was flexible to prevent stifling of conversation, whilst keeping track of those questions still unanswered and issues raised.

9. Notes were made during the interviews to supplement those that were made from the tape-recording of the interviews.

10. On completion of the interviews the participants were thanked for their help, and a reminder was given to return the signed consent form if necessary.

11. The tape-recordings were then listened to and the notes made during the interviews were augmented and reiterated. The tapes allowed for additional information to be noted than may not have been possible during the interviews, and allowed for verification of any notes made during the interviews, to check for discrepancies or errors made. The tapes were erased once the note-taking was complete.

12. Data were entered into an Excel spreadsheet for ease of comparison of answers across participants.

13. Once all interviews were complete and all notes updated and recorded, the results were studied and lists of themes and issues raised were compiled.
3.10 Data analysis
Qualitative data were assessed and quantified with regard to the number of repeated themes emerging across all the participants (methods such as this, and other methods for assessing qualitative data, are discussed by Maxwell, 1996). It became clear that participants were putting forward the same ideas and reasons, and this enabled counts of the number of times each view was expressed, in order to reflect the occurrence of such views and opinions. These were then calculated as percentages of the total responses, to provide quantitative data. Due to the small sample size, however, the results are most frequently given in terms of the percentage, with the number of participants of the sample who responded in that way given in brackets afterwards. Also due to the small sample size, it was not possible to compare the results for the different groups of design professionals, as was the original intention (Section 3.4). Qualitative data, in the form of comments and quotations, are also included to highlight relevant issues and the feelings that the designers had about them.

3.11 Results
Interviews took place in April 2000. The results are presented according to the four sections of the questionnaire (Section 3.5.1 to 3.5.4) with the questions printed in Italics above the results as appropriate. The results are not necessarily presented in the exact order of the questionnaire.

3.11.1 Personal and company details
In total, 70 people were contacted by telephone in the initial round of calls to check whether people would be willing to participate. 29 agreed to take part, but despite efforts by the author the remainder were unable to participate in the study. Reasons for non-participation are detailed in Table 1.

<table>
<thead>
<tr>
<th>Reason given</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not in at time of call and subsequent calls/no reply to messages left</td>
<td>9</td>
</tr>
<tr>
<td>Agreed but then pulled out due to lack of time</td>
<td>9</td>
</tr>
<tr>
<td>Felt that own work was not relevant to the project</td>
<td>7</td>
</tr>
<tr>
<td>Unwilling</td>
<td>7</td>
</tr>
<tr>
<td>Call sent round to various departments without any help</td>
<td>2</td>
</tr>
<tr>
<td>Provided alternative names when refusing</td>
<td>2</td>
</tr>
<tr>
<td>Concerns about confidentiality</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1: Reasons for non-participation (n=38)
As a result of the number of people unable to participate it was decided to expand the sample to include final year design and technology students, all of whom had been on industrial placements the year before. Three students responded, taking the total number of participants to 32 (27 men and 5 women). The broad range of design conducted by companies is shown in Figure 2, and the breadth of experience (the number of years of experience in the design profession) is given in Figure 3. It was difficult to know if the 14% (5 out of 32) of the sample that were female accurately reflected the percentage within the whole industry. The sample shown compares to the intended sample of 20 people from design companies/consultancies, 10 designers of specialist equipment for older and disabled people, 10 companies with in-house design teams, and 10 other professionals involved in the design process (including transport designers and architects). In the final sample, there were 16 product/industrial designers (this was the design type stated by the individuals), 6 designers of specialist equipment, 4 designers from in-house teams, and 6 other design professionals, including architects, transport designers, and final-year industrial design students.

Figure 2: Types of design professionals interviewed (n=32)
3.11.2 Current Practice

16% (5 out of 32) of designers reported that they had never designed anything that had needed specific consideration of older or disabled people. 28% (9 out of 32) had not really heard of 'design for all' or universal design, although three of these were prepared to take a (accurate) guess at the meaning. The remaining respondents (72%) considered 'design for all' and universal design to generally be that which tries to encompass as wide a section of the population as possible. The products that had been designed with older and disabled people being considered tended to be those concerned with activities of daily life, with baths, showers, taps, telephones, seats, and kettles all being mentioned.

The design process used varied between respondents (students were not asked this question). Broadly, all designs started with a briefing stage, involving discussion with the client/commissioner as to what was required, followed by initial concepts. These concepts were then revised through collaboration with the various parties concerned, and the plans then progressed to such issues as feasibility, further concepts, development, model-making and prototyping, and production itself (where applicable).

The primary information needs of the design professionals varied widely between companies (Table 2), with manufacturing issues and user profiles being the most frequently mentioned. It can be seen that the number of responses is greater than the number of participants, which is due to the fact that 29% (9 out of 31) who responded (one participant did not respond) mentioned two

---

Figure 3: The frequency of 'number of years as a design professional' of the interviewees (n=32)
types of information needed, and 16% (5 out of 31) mentioned three different information needs. For the majority the first reference point for information when given a brief was the client (Table 3). Students were not asked this question.

<table>
<thead>
<tr>
<th>Information needed</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing issues: costs, processes, materials, etc.</td>
<td>12</td>
</tr>
<tr>
<td>User profiles and anthropometric information</td>
<td>11</td>
</tr>
<tr>
<td>User &amp; management objectives &amp; expectations</td>
<td>9</td>
</tr>
<tr>
<td>Varies depending on product to be designed</td>
<td>7</td>
</tr>
<tr>
<td>Whatever manufacturer/client thinks is important</td>
<td>3</td>
</tr>
<tr>
<td>Previous solutions/existing products in market-place</td>
<td>3</td>
</tr>
<tr>
<td>Standards</td>
<td>3</td>
</tr>
<tr>
<td>Clear brief from client detailing needs and expectations, and all necessary information</td>
<td>3</td>
</tr>
<tr>
<td>No response</td>
<td>1</td>
</tr>
<tr>
<td><strong>TOTAL RESPONSES</strong></td>
<td><strong>52</strong></td>
</tr>
</tbody>
</table>

Table 2: Information needs in the design process (n=31)

<table>
<thead>
<tr>
<th>First reference for information</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Client</td>
<td>18</td>
</tr>
<tr>
<td>Research (books, journals, www, archives)</td>
<td>7</td>
</tr>
<tr>
<td>Varies for different products</td>
<td>2</td>
</tr>
<tr>
<td>Marketing department</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 3: First reference point for information in the design process (n=29)

The standards used routinely during the design process are detailed in Table 4. It can be seen that again, the number of responses is greater than the number of participants. 21% (6 out of 29, students were not asked this) used two standards routinely, with 14% (4 out of 29) using three standards and 3% (1 out of 29) using five standards routinely during designing. The type of standards used did vary between designers, depending on the type of design they did: the two architects used building regulations and access standards, with the transport designer using rail and aviation standards.
<table>
<thead>
<tr>
<th>Standards used routinely</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>British Standards</td>
<td>8</td>
</tr>
<tr>
<td>Ergonomics/Health &amp; Safety Executive</td>
<td>7</td>
</tr>
<tr>
<td>Specific to design: building regulations &amp; materials regulations, Rail standards, Aviation standards, access standards, water electrical standards</td>
<td>7</td>
</tr>
<tr>
<td>None specifically</td>
<td>5</td>
</tr>
<tr>
<td>Any relevant</td>
<td>5</td>
</tr>
<tr>
<td>Technical and IEE</td>
<td>4</td>
</tr>
<tr>
<td>ISO9000</td>
<td>4</td>
</tr>
<tr>
<td>European Standards</td>
<td>3</td>
</tr>
<tr>
<td>Internal checks and processes used</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 4: Standards used routinely during the design process (n=29)

Q. Do you currently use any of the available sources of anthropometric data about users?

The majority of the sample (77%) used anthropometric data from the sources detailed in Table 5. 23% (7 out of 31; one respondent was omitted to be asked) did not use any anthropometric data during the design process. These seven were two product designers from small companies, one industrial designer, one in-house designer, one architect, one student, and one specialist designer. The architect argued that the relevant measurements and details had been learned and so did not need to be looked up during the design process. The total number of anthropometric data sources used was greater than the 24 designers who used them. 62.5% (15 out of 24) of designers using any anthropometric sources used just one source of data, 25% (6 out of 24) used two sources and 12.5% (3 out of 24) used three sources.

<table>
<thead>
<tr>
<th>Source used</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Books (USA, Dutch, others)</td>
<td>7</td>
</tr>
<tr>
<td>Own collection/expert</td>
<td>5</td>
</tr>
<tr>
<td>Pheasant (1986, 1996)</td>
<td>5</td>
</tr>
<tr>
<td>Standards (various)</td>
<td>2</td>
</tr>
<tr>
<td>BSI charts &amp; leaflets</td>
<td>2</td>
</tr>
<tr>
<td>PeopleSize (1998)</td>
<td>1</td>
</tr>
<tr>
<td>Selwyn Goldsmith (1984, 1997)</td>
<td>1</td>
</tr>
<tr>
<td>ChildData (1995)</td>
<td>1</td>
</tr>
<tr>
<td>AdultData (1998)</td>
<td>1</td>
</tr>
<tr>
<td>World wide web sources</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: Sources of anthropometric data used during the design process (n=24)
Q. Who would use such data? (students were not asked this question), and How do you/they find it using these data?

It was reported that when anthropometric data were used, in most cases all employees used it (not just specialist human factors staff). 82% (18 out of 22) of participants reported 'all staff' using anthropometric data (four sole-traders and 14 company employees). Only 14% (3 out of 22) stated that only the designers in the company used such data, and 4% (1 out of 22) that a human factors specialist only used these data. When asked how they found it using anthropometric data, 54% (15 out of the 28 who responded) stated that the anthropometric data they used were fairly easy to use, although not all of it was relevant and some learning was needed in order to understand the data correctly. 29% (8 out of 28) stated that these data were 'very helpful' and 'easy to use'. However, due to time constraints it was not possible to discuss exactly how data were used or understood. Problems experienced using anthropometric data included data being 'dry and skewed', having 'gaps', being too specific, irrelevant or unrepresentative, being time consuming to use, and a general 'lack of confidence' in the figures.

Q. What would be your preferred format for such data?

28 out of the 32 respondents gave a preference for the preferred format of anthropometric data. Some form of computer software or web-based data was preferred by 50% of respondents (14 out of 28), but 29% (8 out of 28) stated that their preferred format was data in books. The remaining six respondents preferred drawings or charts of data.

Q. Some people feel that the best time to consider the user is at the beginning of the design process - Do you feel that this is possible? Why/why not?

81% (26 out of 32) of respondents felt that it was possible to consider the end-user early in the design process. Those who did not feel it was possible gave the reason that they often did not know who the end-user would be, as the client commissioning the design was not an end-user or did not provide details of the intended end-user. Those who did consider end-users felt that it was important to consider users all through the design process, and include consideration as early as possible.

Q. What sort of information about users is of most use to you?

The type of information needed about end-users varied widely between designers, and the designs themselves. 41% (13 out of 32) mentioned specifically that the information required varied with the different projects, for example for some projects "some aspects may be irrelevant". Physical
parameters, preferences and expectations, anthropometrics, own experience, and lifestyle were all mentioned as being information of interest about end-users.

Q. Do you involve end-users during the design process? and How do you involve them?

84 % (27 out of 32) of respondents involved end-users in the design process, with user trials being the most popular method. However, two respondents did mention that it was rarely possible, but was done so whenever feasible (if enough time and money was available to run trials, for example). Some of the respondents involved end-users in more than one way (Table 6).

<table>
<thead>
<tr>
<th>Method of involvement</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>User trials</td>
<td>14</td>
</tr>
<tr>
<td>Focus groups</td>
<td>7</td>
</tr>
<tr>
<td>Collection of end-users opinions &amp; comments</td>
<td>6</td>
</tr>
<tr>
<td>Observations</td>
<td>5</td>
</tr>
<tr>
<td>Questionnaires</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6: Methods of involvement of end-users in the design process (n=27)

Q. How many people are involved, and at what stage in the design process?

The number of end-users involved during the design process varied, with ten being the most frequent number: this was the response given by 33 % of those who answered this question (7 out of 21). The larger companies tended to involve more users (up to hundreds). The timing of end-user involvement is detailed in Figure 4. It can be seen that majority of participants (62 %) reported end-user involvement occurring later in the design process, at the prototyping stage. It is encouraging that 52 % (11 out of 21) of respondents reported involving end-users during the concept stage or all through the design process.
Q. Have you ever undertaken to research a user group and involve users even if the client brief has not specified it? Why/Why not?

Only 34 % (10 out of 29) had ever involved end-users if the client had not requested it in the brief. The main reason for not involving end-users was the lack of money if the client was not paying for the work to be done. However, those who had researched and involved end-users without the client specifying it reported that it was felt to be essential in order to get the necessary information, and may even be mentioned to the client in order to get them to include it within the brief.

Q. Do you personally test/use the finished products/designs? (students were not asked this)

90 % (26 out of 29) of those asked reported that they had tested or used their own products, although 19 % of those who replied positively (5 out of 26) did mention that they only ever tested the products but had not used them. 10 % (3 out of 29) had personally never used or tested any of their own designs; two designed specialist equipment for older and disabled people so did not see the relevance of testing products themselves, and saw no need to use such products.

Q. What feedback do you get about customer satisfaction? (students were not asked this)

Lack of feedback (very little or none) about product success/problems was reported by 21 % of respondents (6 out of 29), and the feedback largely consisted of details of how the product was selling (for 28 %, or 8 out of 29, this was the only information received). Two of the remainder got feedback from clients only, four received feedback direct from end-users, and seven of the
remainder received varying amounts of information from each client. Only two respondents mentioned that direct end-user feedback was thought to be of considerable importance within their companies, and that great efforts were made to get such feedback and information. Both these participants were from small design consultancies.

Q. Have you ever considered designing modular products, with different components for people with different abilities? Why/why not?
46% (11 out of the 24 to whom the question applied) stated that they had or would consider designing modular products, with different components for people with different abilities. The reasons given by the remaining participants for not designing modular products were that it had never arisen as part of the brief, and that it would be more likely to have modularization in terms of assembly and construction, not in terms of usability.

Q. Few people currently take special care to consider the needs of older and/or disabled people in designs (for mass-market products). Do you have any ideas why this may be so?
In response to this question, several clear trends were seen. 43% (13 out of 30) felt that the main reason was that older and disabled people were perceived as being a minority group, although this was acknowledged to be changing. 20% (6 out of 30) felt that it was down to the client to insist that the population were considered, as the designers could not consider them if the client did not allow them the scope to do so. 20% (6 out of 30) felt that it was difficult for designers to empathise with older and disabled people and therefore to consider their needs, and also that it was difficult to consider the full range of problems that could be experienced by older and disabled people. The remaining 17% (5 out of 30) felt that the main reason was one of cost, with the cost of consideration being seen as too high with the expected profit seen as too low. Two respondents appeared to misunderstand the question and responded that consideration of older and disabled people was sensible given the growing market and that consideration would make products easier for all users.

3.11.3 Computers
All but one respondent (30 out of 31) used a computer-aided design package. One other respondent was not asked any computer questions, as they were not actually involved directly in designing. Details of the numbers of packages used are given in Figure 5, with the computer-aided design packages used being listed in Table 7. The total number of different packages used was 28, with 77% (23 out of 30) of participants using more than one computer-aided design
package within their company. It was not possible to find out any details about three packages (each used by one company), so these have been left out of the table, as spellings and package types could not be checked. The majority of packages (68%) used were 3-dimensional modelling systems, with only one human modelling package being mentioned (SAMMIE). Two-dimensional drawing packages accounted for 20% of the types of package used.

Figure 5: Number of computer-aided design packages used by design professionals (n=30)

Q. What sort of computer(s) do you use?

26% of respondents (10 out of 29, 3 did not answer this question) used more than one type of computer, with the types of computers used detailed in Figure 6. It can be seen that personal computers (PCs) were most frequently used, with few designers using more specialist machines, such as Unix and Sun workstations.
<table>
<thead>
<tr>
<th>CAD program used</th>
<th>Frequency</th>
<th>Type of software</th>
</tr>
</thead>
<tbody>
<tr>
<td>AutoCAD</td>
<td>8</td>
<td>3D modelling</td>
</tr>
<tr>
<td>ProEngineer</td>
<td>7</td>
<td>3D modelling</td>
</tr>
<tr>
<td>Ashlar-Vellum</td>
<td>7</td>
<td>3D modelling</td>
</tr>
<tr>
<td>ProDesigner</td>
<td>5</td>
<td>3D modelling</td>
</tr>
<tr>
<td>SolidWorks</td>
<td>5</td>
<td>3D modelling</td>
</tr>
<tr>
<td>Adobe suite (2D Photo-editing)</td>
<td>4</td>
<td>2D graphics</td>
</tr>
<tr>
<td>Algor/Finite Element Analysis</td>
<td>2</td>
<td>2D graphics</td>
</tr>
<tr>
<td>Coral Draw (2D)</td>
<td>2</td>
<td>2D graphics</td>
</tr>
<tr>
<td>FastCAD</td>
<td>2</td>
<td>3D modelling</td>
</tr>
<tr>
<td>FormZ</td>
<td>2</td>
<td>3D modelling</td>
</tr>
<tr>
<td>MicroStation</td>
<td>2</td>
<td>3D modelling</td>
</tr>
<tr>
<td>SDRC Ideas</td>
<td>2</td>
<td>3D modelling</td>
</tr>
<tr>
<td>SAMMIE</td>
<td>2</td>
<td>Human modelling</td>
</tr>
<tr>
<td>3D Studio</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>3D Viz</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>Alias</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>AutoTrack</td>
<td>1</td>
<td>2D graphics</td>
</tr>
<tr>
<td>Mechanical Desktop</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>ProMechanica</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>QuarkXPress (2D Desktop publishing)</td>
<td>1</td>
<td>2D graphics</td>
</tr>
<tr>
<td>Rhino</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>SolidEdge</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>VectorWorks</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>Unigraphix</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td>XCAD Pro 4.2</td>
<td>1</td>
<td>3D modelling</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>62</td>
<td></td>
</tr>
</tbody>
</table>

**Table 7**: Computer-aided design packages used by design professionals (n=30)

![Figure 6: Types of computers used by respondents (n=29)](image)

**Figure 6**: Types of computers used by respondents (n=29)
Q. Do you use any software relating to anthropometric data?, Who uses it/them?, Are the tools used in the development of all products?, and How do you/they find using this?

32% (10 out of 31, one person not asked) had some sort of software containing anthropometric data (those mentioned included: “AutoCAD library”, “2D percentiles on figures”, “DesignAid”, and SAMMIE). Of the ten having software containing anthropometric data, the software was used by all members of the design team in six companies. However, the other four companies owning such software did not use it at all, and reported that they purchased it thinking it would be useful, but it had not turned out to be so. Of those companies that did use software relating to anthropometric data, two used it for all projects, two used it for those projects that required it, one used it for major projects only, and one used it for seating designs only. Those who used the software reported that it was generally acceptable, although only “basic anthropometry” was provided.

Q. If a computer modelling tool that included data from older and disabled people as well as able-bodied people, for use as a design tool were available, would you be interested in using it?

All but one respondent (one other was not asked) were interested in such a proposed computer-based design tool, although 13% (4 out of 30 who responded positively) did add the proviso that it depended on the usefulness and cost of the package.

Q. Would you yourself use it or would another member of your team use it? and Do you think you would have time to learn to use such a tool?

All 30 of the respondents who were interested in the proposed computer-based design tool felt that whoever was directly involved in designing would want to use the tool. 15% (4 out of 30) felt that they would not have time to learn to use the tool, needing it to be intuitive and very easy to use. 63% (19 out of 30) of the respondents also added that they would wish the tool to be easy to use, and would make the time if it were beneficial for them to do so.

Q. What do you think you would want to be able to do using such a computer-based design tool?

The responses to this question varied, with 13 responses consisting of more than one usage. The 30 participants who were interested in the computer-based design tool reported wanting different information within the tool:

- 30% (9 out of 30) wanted reach range data and/or space envelopes
- 27% (8 out of 30) requested general anthropometric data
- 23% (7 out of 30) asked for manipulateable data and three-dimensional manikins

62
• 20% (6 out of 30) wanted quick access to up-to-date data
• 17% (5 out of 30) would like data on hand and grip size
• 10% (3 out of 30) requested data on lift strength
• 10% (3 out of 30) wanted to know grip strengths
• 10% (3 out of 30) simply wanted 'as much data as possible'
• 10% (3 out of 30) requested data about minority groups
• 10% (3 out of 30) wanted to know about buying habits
• 10% (3 out of 30) wanted recommended height of handrails and other items
• 7% (2 out of 30) wanted stature data
• 7% (2 out of 30) requested information on basic restrictions and constraints
• 7% (2 out of 30) asked for legislation and guideline information
• 3% (1 out of 30) asked for access data
• 3% (1 out of 30) requested data on spine curvature
• 3% (1 out of 30) wanted to know sight lines

Other issues raised were:
• the wish to have a tool that would run automatically, with “diagnostic” evaluations of concept designs, identifying for example “bad postures” within the concept (2 respondents)
• provision of graphics and data that could be used in presentations to clients (2 respondents)
• the wish to have a tool that could bolt onto existing computer-aided design packages (1 respondent)
• an expert system to guide the designer through the relevant questions to highlight the necessary areas for consideration (1 respondent)

During the interviews it was decided that any participants who seemed especially knowledgeable about computers and the software requirements that they had, would be put in contact with the researcher working on the development of the design tool. However, only one person appeared very knowledgeable about the computing side of the design process. Due to the fact that their conversation with the author was tape-recorded, the tape was passed on to the relevant researcher to listen to before it was erased.
Q. Here is a list of alternative types of information that such a tool could present (Appendix 1). Answer yes or no as to whether you would want each type of information.

Of the 28 participants who responded to this question,

- 93% (26 out of 28) of the respondents wanted to be able to access simple anthropometric data
- 86% (24 out of 28) wanted graphical representation of problems experienced
- 86% (24 out of 28) were interested in having possible solutions provided, but five others were unsure, fearing that it might be irritating and prescriptive, and three feeling that it was desirable but maybe not possible.
- 82% (23 out of 28) were interested in seeing details about the statistical data, sample sizes, ranges, where the information had come from, and so on

Only 18% (5 out of 28) of participants did not feel that being told the percentage of end-users accommodated by the design would be beneficial. Of these, three said that it depended on which specific population was being considered, whilst a further three raised the same concern about percentage accommodated being dependent on which population was being considered, whilst agreeing to the information in principle. One respondent made the additional comment that it would be useful to have the percentage of the disabled population accommodated subdivided into groups with certain problems or severity of problems, to increase the information provided by such an assessment. Only 4% (1 out of 28) of participants did not want ergonomics guidelines to look up, feeling that such guidelines were restrictive to the design process.

Other information requested (by one participant in each case) was:

- environmental information and parameters
- examples of successful cases of 'design for all' designs
- specific information about disabilities
- sources of further information provided
- case studies as examples of successful modularisation
- examples of successful consideration of older and disabled people

Q. Would you wish to tailor the tool to the person who would be using it? For example, a trained ergonomist could interact with detailed data, whilst an untrained designer could view simpler guidelines with out complex detail?

Feelings on whether the respondents would want to tailor the tool themselves were divided, with 45% (14 out of 31) stating that they would be interested in tailoring the tool themselves, but a further 45% said that they would not wish to tailor the tool themselves (Figure 7). Reasons given
for not wanting to tailor were usually a wariness of altering computing software and their personal computing abilities. Reasons for wanting to tailor the tool concerned the fact that all designers work differently and all design projects vary as to where the emphasis of such a system needs to be placed.

![Circle chart showing opinions on tailoring the tool](image)

**Figure 7:** Opinions of whether designers would wish to tailor the proposed computer-based design tool themselves (n = 31)

### 3.11.4 The Future

*Q. We are hoping to encourage all designers to consider the needs of older and disabled people more in designs. How do you think we could encourage people?*

This question resulted in several main responses (one participant chose not respond). The different suggested methods of encouraging designers to consider the needs of older and disabled people were:

- **29%** (9 out of 31) felt that it was a case of convincing the manufacturers and clients of the market sector that was currently being ignored, and encouraging them to include consideration within their briefs.
- **23%** (7 out of 31) were of the opinion that the changing demographics and increased buying power of older and disabled people will result in a consumer-led change.
- **19%** (6 out of 31) thought that the best encouragement would be to make anthropometry data and ergonomics information more accessible to designers.
- **16%** (5 out of 31) suggested recommendations, and examples, of ‘design for all’ as “best practice”.
- **10%** (3 out of 31) felt that legislation and enforced standards were needed.
Q. Here is another list, of possible information sources which could be of use to designers if they were to consider older and disabled people more (Appendix 1). Please answer yes or no as to whether you would consider each to be a useful tool in encouraging ‘design for all’.

- All respondents felt that it would be an improvement to have anthropometric data presented in a ‘preferred’ format, although there was no agreement on what this format should be.
- All felt that a CAD system to aid designers would be beneficial, with five respondents specifically mentioning the fact that they wanted a system that could be compatible with, and interact with, current CAD packages.
- 94% (30 out of 32) felt that checklists to assess products would be useful (those who did not, considered it to be a matter for internal checks).
- 91% (29 out of 32) thought procedures for evaluating products would be useful, although it did depend on the appropriateness of the procedure to the product.
- 88% (28 out of 32) felt that they would have time to undertake training into consideration of the needs of older and disabled people. Four designers were not positive about this. 25% (7 out of the 28 who responded positively to the question) were also unsure about making time available. 21% (6 out of the 28) of respondents felt that such training should form part of the education of designers, not once they were working in practice.
- 56% (18 out of 32) felt that legislation was a bad idea, as it was a ‘blunt instrument’, and would be impossible to cover all aspects and would be restrictive.
- 44% (14 out of 32) felt that legislation would be a good idea, but felt that it would be difficult to implement and enforce.
- 25% (8 out of 32) felt that it was more important for the clients to see the need for such consideration than themselves.

3.12 Discussion

All respondents seemed open and honest when discussing the issues, such as the impact of clients and the lack of time and other resources for considering older and disabled users. Due to the anonymous nature of the survey and the results, which was made clear to all participants, it is not expected that many would have felt the need to make false claims.

3.12.1 Time within the design process

Lack of time featured frequently in reasons for not considering or involving end-users, as did the role of the client in providing time, money and scope to allow (and insist upon) consideration. The fact that some designers actually do raise such issues with clients suggests that maybe design
professionals have their own role to play in influencing clients and manufacturers. Kahmann (2000) also found that it was acknowledged that the design process is bound by time constraints.

Time was also a major factor in gaining access to designers in the first place to ask their views on these issues. Without talking to designers and understanding their needs and concerns, it is impossible for ergonomists to assist fully with providing data and help to designers. 38 of the 70 designers contacted declined to participate, with nine specifically citing lack of time as the reason for non-participation. It is worth noting that there is the possibility that those who agreed to take part were more interested in the topic of study and therefore willing to make the time to participate. It is always an issue with surveys and questionnaires, that non-participation, either through choice or being unavailable, results in some degree of bias to the results (Sinclair, 1998). It is hoped, however, that by questioning as wide a variety of designers as was possible within the time available that any bias would be minimised. It is also felt that the fact that clear trends emerged within certain areas of the results and opinions, that a representative view of the design profession was obtained.

A curious finding is that 63 % (19 out of 30) of the designers specifically mentioned that they would be able to make the time to learn to use a new piece of software if it was thought that it would be helpful to them and their business. Despite this, the same designers did not always see that making the time to involve end-users directly would also be helpful and improve designs. This suggests that designers are either not fully aware of the benefits of end-user consideration and involvement, or else prefer to explore technical aids more readily, for whatever reason. Staff training on universal design was seen as being needed by the designers, but they felt it should be brief and economical, and would be best fitted into design education. The need for training, and the lack of time for it, was also found by Vanderheiden and Tobias (2000). Of their 29 respondents, 50 % felt that training was essential but not available at the current time, and 52 % mentioned lack of time to learn about ‘design for all’ being a considerable problem.

3.12.2 ‘Design for all’ improves design for all

It was encouraging that 72 % (23 out of 32) of design professionals had heard of ‘design for all’ or were able to deduce the meaning easily. This suggests that the philosophy is known about, but begs the question as to why the ideas are not being implemented more often. Failure to design in this way cannot be blamed on ignorance.
Three designers expressed the view anecdotally that ‘good designs’ would be usable ‘by everyone anyway’. Such an attitude removes the need for separate consideration only if it is true, and if all designs are “good”. Many people do sometimes experience difficulties with the products we interact with regularly (Keates & Clarkson, 2000; Soares & Kirk, 2000), which suggests that, therefore, many designs are not ‘good designs’. It has also previously been stated that designers do not always notice ‘poor’ (unsuitable) designs, due to lack of end-user testing (Savage et al, 1998). This brings the discussion full-circle to the original starting point for suggesting the need to consider all users more carefully, to make designs more usable. The products where consideration did occur were some of the every day items involved in activities of daily life (Section 4.5), such as kettles, showers, toilet seats, and telephones, suggesting that some designers and clients are beginning to realise that such products will be used by older and disabled people as well as the able-bodied.

23 % (7 out of 31) of the design professionals reported that market trends were changing due to changing demographics, and therefore that ‘design for all’ will become a necessity in the future. However, 17 % (5 out of 30) cited perceived costs and lack of market value for reasons for currently not considering older and disabled people. These findings are supported by the work of Vanderheiden and Tobias (2000) who found that universal design was seen as being too specialised and resulted in increased design and manufacturing costs by between 79 % and 83 % of the 29 design professionals they studied. Keates, Lebbon and Clarkson (2000) also found similar concerns, reporting that most designers felt that they would implement universal design only ‘if it was easy to do’ and did not increase costs.

### 3.12.3 Anthropometry and the Fundamental Fallacies

The idea of the use of intuitive ergonomics reflects one of Pheasant’s (1996) ‘five fundamental fallacies’, in that people believe they can consider other people’s needs and dimensions without actually referencing any explicit data concerning such people. 23 % (7 out of 31) of participants did not use any sources of anthropometric data, suggesting to the author that they did not feel that they needed to. One participant did actually state that they felt able to ‘intuit’ the ergonomics requirements of a design and the end-users.

Designers obtained most anthropometric information from books such as Dreyfuss (1953, 1959, 1960, 1967, 1978), Selwyn Goldsmith (1984, 1997), and Pheasant (1986, 1996, 1999) which were generally regarded as acceptable. However, it is often the case that data are not relevant to the
population concerned (for example, use of data from USA soldiers for the UK civilian population), are out of date (use of 1960s data), are static data, or are only 5th, 50th, and 95th percentile. This suggests that the data may be being used, but in some cases is not necessarily going to result in better products being designed. It is not clear whether participants used anthropometric data correctly, for example considering the differences in age, population, static versus dynamic, and so on, as this was not explicitly asked in the questionnaire and was impossible to judge during a telephone interview. 29% (8 out of 28) of participants stated that anthropometric data sources were ‘very helpful’ and ‘easy to use’. However, 18% (5 out of 28) of participants did mention that data could be ‘dry and skewed’, have ‘gaps’, be too specific, irrelevant or unrepresentative, time consuming to use, and a general ‘lack of confidence’ in the figures. It seems that this 18%, and possibly some of the other participants, were aware of the seventh fallacy (Section 2.3), and did not think that anthropometric data is necessarily easy to use and understand. It is interesting to note though that these five participants (who were aware of the possible inaccuracies of using such data) still used the data. It may be that there was no choice due to access to more relevant, accurate and reliable data.

Information concerning the costs, technicalities, and manufacturing processes were considered to be the most important first information needed in the design process by 45% (12 out of 31) of designers. It is therefore interesting to note the discrepancy between this and the fact that 81% (26 out of 32) felt that it was possible to consider end-users from the beginning of the design process, with 31% (10 out of 32) stating that it was essential. This highlights the difference between ‘thinking’ about users, and actually having information about the users to inform this thought. This is a similar issue to the one raised earlier concerning intuitive ergonomics: designers feel that they are considering end-users, when in fact they may not actually have any evidence as to what the users really want or who they really are.

3.12.4 End-user involvement

The number of participants (84%, 27 of the 32) involving end-users in the design process is encouraging for the ‘design for all’ approach. Such involvement of end-users must help to increase the usability of products, as long as the involvement is structured to produce useful information that can be incorporated into the design. However, 41% (13 out of 32) of respondents did not get information direct from end-users themselves, getting the information instead either from the client or from other sources (experts, marketing departments). It is not
known whether this information is accurate, detailed, or relevant either to the designers’ information needs or to the consumers’ usability needs.

End-user involvement occurred generally late in the design process, at the prototyping or modelling stage in 62% of cases (13 out of the 21 participants who provided details concerning this). This finding was not surprising; other researchers have found the same picture (Johnson & Johnson, 1989; Porter & Porter, 1999; Bruder, 2000). Testing at this stage allows for limited changes to be made to the design if problems arise, and if trials are only carried out using finished products the scope for change is almost negligible. The amount of end-user involvement was encouraging, although the numbers involved were generally low; the most common number of end-users involved was ten. Hasdoğan (1996) corroborated this finding, reporting that where consideration of end-users occurred for the most part designers used themselves and their colleagues as ‘users’, rather than employing actual end-users.

Observations of users interactions with existing products accounted for 38% (5 out of 27) of end-user involvement in this study, which means that the end-users were not actively playing a role in assessing the early stages of any new products in these cases. The 16% (5 out of 32) who did not involve end-users at all in the design process reflect the findings of Johnson and Johnson (1989); two of the designers in their study reported that very little pre-operational testing was conducted either by themselves or end-users.

Once the design was completed and in the market place, end-user involvement decreased sharply. Only 14% (4 out of 29) of participants reported getting direct feedback from end-users, whilst 21% (6 out of 29) received little or no feedback at all. Johnson and Johnson (1989) reported similar findings. Their designers reported getting very little feedback about the product other than faults, and then only by being told about them by the marketing department or client, not from the end-users themselves.

3.12.5 The influence of the client

A significant finding is that clients have a lot of influence on the majority of designers. 34% (10 out of 29) of the designers did try and influence the clients, suggesting that maybe all designers should try harder to encourage clients to consider the needs of older and disabled people more. However, it is important that top-level information about aims and objectives received from the commissioning client can often be vague (Smyth, 1987). Education of clients as well as designers
may be the key to greater consideration of older and disabled people. Currently few designers are willing or able to consider such issues without the support of the client commissioning the design. Vanderheiden and Tobias (2000) had similar findings, and reported that 71% of their respondents felt that top management support for design for all was essential, but only 19% indicated that this was fully available to them. Where successful universal designed products exist, they usually had support from top management and clients, rather than being brought about by the designers (Keates, Lebbon & Clarkson, 2000).

Changing what the clients demand in the brief may, in time, come about as a result of the changing population demographics, thereby forcing consideration of older and disabled people during mass-market design. Keates, Lebbon and Clarkson (2000) concur that persuading top management of the need and benefits of universal design may be the best way to encourage it. However, despite this being a slow process, it is still important to increase awareness of ‘design for all’ issues in order to allow clients and designers to adapt, and have useful information available.

The challenges for ergonomists and promoters of ‘design for all’ lie not just in making relevant and useful anthropometric and end-user data available to designers in a usable format. In addition the clients, manufacturers, and design professionals need to be convinced that they all should consider the needs of older and disabled people. Optimistically, 28% (12 out of 21) of respondents said that they considered end-users as the first information needed on receipt of a brief for a design. However, 48% (14 out of 29) stated that the client provides all initial information (with no guarantee that this information would include data about users). The way to improve the situation is to highlight the fact that consideration will in fact result in increased market size, and therefore potential for greater sales. This point was also raised by Vanderheiden and Tobias (2000), who found that knowledge of market forces and changing demographics were likely to influence the number of designers considering ‘design for all’/universal design (as did Rogers et al., 1997; Clarkson et al., 2000; Jordan, 2000; Keates, Lebbon & Clarkson, 2000).

From a different perspective, Mossink (1990) stated that ‘the implementation of human factors largely depends on the personal interest of the designer’. Designers do not work as systematically as ergonomists. Important factors in the consideration, or not, of ergonomics during the design process are things such as the attitude of the designer towards ergonomics, the commitment of the client commissioning the design, and knowledge of the costs and benefits of consideration. It is
interesting to note that 17% (5 out of 29) of participants mentioned that they would always encourage a client to allow consideration of older and disabled end-users, even if it was not in the original brief. This is an example of the designers' personal interest and feeling about 'design for all' influencing the design process.

3.12.6 Legislation

Another interesting point arising from the designers' feelings on how to encourage the use of 'design for all' practices is the conflict between those who favoured legislation and enforced standards, and those preferring 'best practice' guidelines only. The divide between the 16% (5 out of 31) of respondents who favoured 'design for all' as best practice, and the 10% (3 out of 31) who thought legislation would be needed (see Section 3.11.4), reflects a more fundamental difference over whether designers should be forced or given the choice. This split in feeling over legislation was also reflected in the findings of Vanderheiden and Tobias (2000), who found that whilst 70% of the 29 designers surveyed felt that general accessibility regulations were important, the other 30% did not.

There is still a general feeling of 'design as creation', to be done without interference from external sources, which unfortunately includes the end-user's wishes and needs. It seems likely that those in favour of enforced consideration are those who already feel strongly that 'design for all' is a good thing and are likely to be practising such consideration themselves already. However, it is the view of the author that it may be that those designers who are in favour of recommendations only (i.e. not legislation) would disregard such recommendations, if they do not feel 'design for all' is important enough to be made essential.

Several of the designers mentioned the Disability Discrimination Act (1995) as a source of legislation to demand consideration of older and disabled people, but as was discussed previously (see Section 2.6), the DDA is non-prescriptive and does not specifically refer to product design at all. It is likely, however, that products for the world-wide market may begin to be affected by the Americans with Disabilities Act (1990), which contains guidelines and recommendations for many types of environment and some products.

3.12.7 The use of software tools and packages

The software packages containing anthropometric data available at the moment (such as PeopleSize, 1998, and SAMMIE) had not proved to be widely used or seen as useful tools, even
though 40% (14 out of 28) said that they favoured data in such a format. This is an interesting discrepancy. Either current sources are not known about, or else they do not adequately address designers’ information needs. This finding may be supported by Hasdoğan (1996), who found that those designers who did use human-modelling systems felt that it was open to misuse and required some prior ergonomics training. Erbug (1999) also found that ergonomics CAD packages were lacking in the necessary information and detail, and that current computer-based resources were too narrow, needing more data and wider application.

Designers favour an electronic source of data that can work in conjunction with their current computer aided design packages. However, the fact that 28 different CAD packages were in use within this sample of companies suggests that matching the proposed computer-based design tool to all existing systems is an impossible task. It is easier and faster to communicate via visual means: graphics and simulations rather than text or tables (Erbug, 1999). Also, CAD models can address some problems of communication, between for example designers and technicians, during the design process, although communication may still be difficult at the concept stage (Eckert, Cross & Johnson, 2000).

The findings of Erbug (1999) reflect the findings of this research, namely that the ergonomics information that designers require is dynamic, not static, data with details of good and bad existing products, details of standards and regulations, accident analysis, end-user profiles and descriptions, anthropometry, as well as details of behaviours and responses to products and situations. Vanderheiden & Tobias (2000) suggested that design tools to assist with universal design would be most useful if tailored to the industry using it, and specific examples of ‘best practice’ and profitable designs that had incorporated universal design would help in encouraging further consideration. Again, the findings of this study support this argument. Interestingly for the development of the proposed computer-based design tool (see Section 1.4), Vanderheiden and Tobias (2000) also found that the majority of their participants were in favour of some method of indicating how many people were accommodated by a change in design. 61% of respondents felt that such information was essential, with another 25% feeling that it was very important.

3.13 Critique of the methodology

On completion of the survey of design professionals and analysis of the findings, it was important to reflect on the methods employed, and the impact that these may have on the results and subsequent research in this area. As such, the issues raised are discussed here.
One of the main points to highlight is that the sample of design professionals was small, and not necessarily representative of the design profession as a whole. This could well be said to affect the ability of researchers to generalise from these results to the wider design community. However, it is felt that there is some confidence in the general nature of responses as, given that the survey consisted of mainly open-ended answers, consensus was still found in the responses of the design professionals interviewed. Clear 'categories' of answers were seen for some of the main topics being discussed (for example, "how best should 'design for all' be encouraged?", and so on), suggesting that the views expressed would be similar to those held by other design professionals.

The use of open-ended questions in the survey proved to be very useful and worked well in eliciting detailed responses. The survey may have taken longer to complete by having such questions, but this was outweighed by the benefits of allowing the design professionals a free response. Again, given that the designers interviewed showed a consensus of views across topics indicates that the use of open-ended questions was both appropriate and valuable in this context.

An important issue in the survey was the problem of contacting design professionals and getting them to participate. The approach of 'cold-calling' potential participants rather than meeting them face-to-face was taken due to the time and money constraints of the project. The possibility of conducting focus groups was also discounted for the same reasons as face-to-face interviews. However, with hindsight and for future research, a more 'hands-on' approach might be more successful. For example, better use could have been made of existing contacts within design companies and consultancies: it could be expected that by taking the time to meet with the designers at their place of work, they may gain more understanding of the project and get to know the researcher, and therefore be more willing to make time to participate. Such arrangements would require a longer project time-scale, and considerable effort on the part of the researcher contacting and organising visits or meetings, but there is the potential of 'reward' in terms of participation and interest. Building contacts within design companies could also have served to increase the likelihood of design professionals being interested in involvement throughout the course of the project, for example when the prototype computer-based design tool was being developed and feedback from designers was required.

A final issue for consideration for possible future research was the inclusion of student designers in the sample. Three final-year industrial design students who had completed a year in industry
were included in order to increase the sample size. However, it could have been of interest to increase the number of students included, in order to enable comparison of the views and opinions of those currently in design education, with those design professionals who were long established in their careers. This may have been particularly interesting given that ‘design for all’ and similar philosophies are relatively ‘new’, and therefore it might be expected that the ideas and opinions of it as a design practice could vary between younger and more established designers.

3.14 Conclusions

‘Design for all’ is widely known or understood, but it not widely practised. Lack of time, lack of client backing, lack of money and a lack of awareness of the possible market are reasons given for this. Time is needed (and lacking) for training in ergonomics, preferably as part of design education, rather than ‘on the job’. Time must also be a consideration for the proposed computer-based design tool, as designers have limited time for learning new systems.

The use of computers and computer-aided design tools is widespread, and there is a preference for data sources that complement these working methods. The information provided by the proposed computer-based design tool needs to complement the work of designers. It was requested that the design tool specifically included details of the sample that the data had been obtained from, anthropometry, graphical representations of problems experienced, reach ranges, and grip strength. These data are currently available in tables and books, and are used by design professionals, but are not felt to be ideal and are open to problems with interpretation, application, relevance, and reliability. Information should be provided in a visual format, up-to-date and relevant to the work of designers. The proposed tool also could be used as a method of communicating ideas and the need for, and/or benefits of, ‘design for all’ to clients.
Chapter 4. Review of literature on older and disabled people

4.1 Introduction
As the proposed computer-based design tool (see Section 1.4) is intended to assist designers in considering the needs of older and disabled people, it was necessary for the author to gain some understanding of issues concerning ageing and disability. It was also important to investigate the literature on designing with respect to older and disabled people, and any problems that such people have with existing designs. The literature review discusses current research into disability, ageing, the ageing population, the classification of disability, activities of daily life, and the role of design in maintaining independence.

4.2 Disability
4.2.1 Definitions
According to the World Health Organisation (1980), impairment, disability and handicap are defined as follows:
• Impairment is any loss or abnormality of psychological, physiological or anatomical structure or function
• Disability is any restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal
• Handicap is a disadvantage for a given individual, resulting from an impairment or disability that limits or prevents the fulfilment of a role that is normal for that individual

These definitions have become widely accepted, although there are some who disagree with their usage, due to the fact that the definition of disability refers only to the consequences of the impairment, not to any influence of environment or social factors (Harrison, 1993; Grundy et al, 1999). As such, the definitions are at odds with how many disabled people view their situation. The able-bodied see the problems that disabled people experience as being due to functional limitations, whereas the disabled themselves focus on the failure of the physical and social environment to enable them (Oliver, 1993). The WHO (1980) classification system is also apparently not widely known and used within the medical community (Harrison, 1993).

4.2.2 Prevalence

Measures of the prevalence of disability vary depending on how disability is defined and which population is being assessed. It is also possible that some people will not be counted if they do not regard their functional limitations as a disability, and other people may be counted more than once, if they have problems that fall into different classifications. However, a few examples of estimates of prevalence are given here as a guide for the reader.

McGlone (1992) estimated from survey results (conducted by the Office of Population Censuses and Surveys) that there were 6.2 million disabled adults in Great Britain, with more than two-thirds of them aged 60 years and over. Sandhu & Wood (1990) reported that 11.6% of the UK population are disabled (it is not clear what the source of the data for this estimation was). Vanderheiden (1990) states that over 30 million people in the USA have disabilities or functional limitations, either from birth, accident and illness, or through old age. However, the type and severity of impairment varies widely. In a survey of 978 wheelchair using adults in the United Kingdom, Fenwick (1977) found that in England and Wales in 1973 there were 2.7 per 1000 women using wheelchairs, and 1.8 per 1000 men.
4.2.3 Causes

The causes of disablement are many, some problems are congenital (experienced from birth); others are acquired (whether through accident or illness). Some are constant, with the same degree of disability being experienced over time, whilst others can vary in severity from day to day, or even hour to hour in some cases. An example of the latter is arthritis, the symptoms of which (in some cases at least) can vary depending on the weather and the amount of activity done in the preceding hours and days. Symptoms of diseases such as rheumatoid arthritis and multiple sclerosis also have remissions and acute phases, with different abilities being affected at different times. Accidents, injuries, and diseases can all have a disabling effect on the individual concerned. The interested reader is directed to Aylward, Dewis and Henderson (1998), and Vanderheiden (1997) for descriptions of some of the main causes and symptoms of disabilities.

Vanderheiden (1997) proposes a model for disability, which incorporates the same definitions as given by the World Health Organisation (1980), and is shown in Figure 8. This model shows the ‘cause and effect’ relationship between physical impairment and disability, and the impact of the design of products and environments in causing disadvantages to those with physical impairments. In this way it can be seen that the emphasis of the model is to encourage changes to the design of products, environments and so on, to prevent any disadvantage.

Not all disabilities are caused by injury or disease. Increased age results in many physiological changes (Borkan, Hults & Glynn, 1983; Vercruyssen, 1987; Kroemer, 1987; Fisk, 1993; Haigh, 1993; Baumgartner et al, 1995; Pheasant, 1999; Carmeli et al, 2000) which can lead to disability, and such changes can be harder to classify than specific disabilities. Changes can also be cumulative and vary greatly between people. Some individuals may experience impairment in many areas, others may have differing degrees of impairment in one area alone, and yet some people may experience the physiological changes but not to a degree to cause severe impairment. Physiological changes due to age include: a reduction in the speed of visual and cognitive processing, a loss in muscle mass and strength, changes in body composition, and reduction in joint flexibility. These changes occur to a lesser or greater degree in all older people, and so are discussed briefly in the forthcoming paragraphs.

As people get older the accommodation of the eye decreases as the lens becomes more crystalline and less flexible. This means that it becomes harder to bring objects at different distances in to focus. Visual acuity is also reduced, with details taking longer to resolve, and the size of detail
that can be resolved decreases. Other age-related changes in visual ability include a reduction in
the size of the visual field, an increase in the time taken for adaptation to darkness, and loss of
depth perception (Charness, 1985).

![Diagram]

Reduced ability: Below the 'norm'

Inability to access: Unable to access standard product(s) and/or environments

Disadvantage: Inability to live a 'normal life'

Figure 8: Model for disability (Vanderheiden, 1997)

The maximum instantaneous force that a person can exert decreases by between 15% and 40%
between the ages of 20 and 60 years, as does the maximum sustainable force (Charness, 1985).
The reduction in muscle strength is due to the loss of muscle fibres and the deterioration of the
nerves carrying impulses to the muscles. Muscle mass and strength decrease with age (Lindle et
al, 1997) increasing the probability of individuals experiencing problems in performing activities
of daily life that were previously taken for granted. Lindle et al (1997) made comparisons of the
muscle strength of the knee extensor muscles in 654 people aged between 20 years and 93 years.
It was found that age reduced the muscle strength, which could affect such activities as climbing
stairs, bending to reach low cupboards, getting up out of chairs or the bath, and other activities
requiring knee strength.
Asmussen and Heebøll-Neilsen (1962) measured the isometric muscle strength of 360 men and 250 women aged 15 to 60 years. They studied 25 muscle groups using strain gauge dynamometers, and found that isometric strength of the hands and arms reaches a maximum by the time a person is 20 years old, and decreases over the age of 40 years. For trunk and lower limb muscles, isometric strength increases to a maximum at about 30 years of age for men and 25-30 years for women, and then decreases immediately. Carmeli et al (2000) also investigated muscle strength and functional abilities of older people in order to study the effects of a 12-week exercise programme on performance. 12 men and 16 women aged between 78 and 87 years of age took part, with 29 people aged between 75 and 83 years of age in the non-exercising control group. It was found that muscular strength was improved in those aged 79-83 years, and that exercise improved performance in a 3-minute distance-walking test. This suggests that older people can improve and prolong some of their abilities by keeping fit and active, whenever possible.

Viitasalo et al (1985) studied muscle strength of 180 men aged 31-35 years, 51-55 years, and 71-75 years of age. Muscle strength was measured using dynamometers for grip, trunk extension/flexion, knee extension and elbow flexion. It was found that the percentage decline of muscle strength from youngest to oldest groups was: knee extension 47 %, hand grip 42 %, trunk extension 42 %, trunk flexion 35 % and elbow flexion 35 %. Kallman, Plato and Tobin (1990) investigated muscle loss and decrease in grip strength with age in 847 people aged between 20 and 100 years of age. It was found that grip strength increases up to 30-40 years of age, and then decreases after 40 years of age. It was found that, whilst grip strength was strongly correlated with muscle mass, it was even more strongly correlated with age, suggesting that other factors are responsible for loss of grip strength with age, not just loss of muscle mass.

Body composition and size can change as a person ages. Borkan, Hults and Glynn (1983) studied 1212 men between 22 and 82 years of age, to investigate the effect of ageing on stature and arm span. It was found that, of the 7.27 cm difference in stature between the younger group and the older group, 4.27 cm was accounted for by shrinkage due to ageing. The other 3 cm was attributed to secular growth (that the younger generation is generally larger than the older generation). Baumgartner et al (1995) investigated body composition in 316 men and women aged between 60 and 95 years. Body composition was assessed using x-ray absorptiometry and isotope dilution. It was found that skeletal muscle decreased with age, and total fat mass and percent body fat decreased with age in women only.
Joint flexibility is also affected by age. Bassey et al (1989) investigated shoulder joint abduction in 1000 men and women aged 65 years and over. It was found that the range of shoulder movement was 30° less than that of younger participants, and for men each additional 10 years amounted to a 10° reduction in flexibility. Vandervoort et al (1992) studied the mobility of the ankle of 214 men and women aged between 55 to 85 years old. It was found that age and gender had significant effects on passive resistance torque and voluntary strength. Passive torque increased with age, and strength decreased. It was also concluded that functional ankle movement is limited with age, but can be improved by exercise to strengthen weak dorsiflexor muscles.

It is a common misconception that older people are all the same, when in fact they are not, and do not all suffer from the same problems (Kahmann, 2000). Some physical and psychological changes do occur with increased age, but there is no common trend dictating the onset and speed of any degeneration. It is also important to distinguish between decrements in old age that are caused by the normal ageing process, and those caused by other illness or disease (Kahmann, 2000). In summary, the effects of ageing occur in all people to a lesser or greater degree, and as such it is important that such changes and their effects are considered by those designing with older end-users in mind. Disability, whether caused by age, accident, illness or genetics results in a wide range of abilities and problems that affect the way that people interact with daily activities, products and environments.

4.3 Classification of disability and severity of disability
Duckworth (1983) states that formal classification of disability occurs for two main reasons: for precise descriptions of patient health status for ongoing medical treatment, and for descriptions of social security benefit applicants. Harwood et al (1994) add to this the ability to assess the outcomes of existing healthcare and assistance. Classification provides methods by which diseases and their consequences (and the people suffering from them) can be identified, categorized and evaluated. However, the method selected must depend on the reason for carrying out the classification, for example what it is to find out, and why. Population surveys of the disabled can help governments and service-providers to be aware of the numbers affected and their needs (Harrison, 1993). The traditional medical approach is classification in order to give names to disorders and diseases and not to provide information about the effects on people’s lives, what care they need, or other such factors (Duckworth, 1983).
There are many ways of differentiating between the severity of disabilities, but not all methods are helpful in all circumstances. Some classification methods exist to enable the provision of Social Service payments to individuals, others to determine the medical assistance required, and others for the collection of population statistics. The different ideologies behind the different classification systems can affect the level of detail used, the number of classes, and the distinctions between similar categories. As such, the given disability, and severity of disability can vary with the method of assessment.

Misuse of any classification system is possible through either incorrect application of objective and reliable criteria or by usage to classify people for purposes that the system was not designed for. Such misuse can result in stigmatisation, discrimination, loss of benefits, or confusion on the part of the person being classified (Duckworth, 1983). Measures of disablement need to be valid and reliable, especially if the level of care or benefit a person receives depends on a one-off assessment. Measures should accurately measure what they are claimed to be measuring, and the measurement method should be suited to the elements being assessed (Duckworth, 1983). At all times it must be remembered that disability is a continuum (Vanderheiden, 1997), however people are classified on that continuum.

4.3.1 Classification of disability

The International Classification of Disability (ICD) and the International Classification of Impairments, Disabilities and Handicaps (ICIDH) use systematic assignments to categories. This is the World Health Organisation’s (1980) preferred method of assigning people to categories. They advocate that an individual’s handicap cannot be discovered from a simple examination of their impairments or abilities: the process is more complex. The ICD has broad categories of disease, such as ‘congenital abnormalities’ and ‘mental retardation’, that can be broken down to more and more detailed levels. For example, ‘congenital abnormalities’ includes ‘anencephalus and similar abnormalities’, and this in turn includes ‘anencephalus, craniorachischis, iniencephaly’, and so on. It is possible that an individual may be classified in more than one section, with classification made on the basis of medical and pathological observations (Duckworth, 1983). The ICD has a medical focus, and is primarily used by health professionals, and is an exhaustive systematic description of disease phenomena (Duckworth, 1983).

The ICIDH separates impairments, disabilities and handicaps, in a model shown in Figure 9. The ICIDH can be used to show the consequences of impairments for medical professionals, policy
planners and sufferers themselves. Within the groups, impairments and disabilities are divided into main categories with sublevels. For example, the nine disability categories include behaviour disabilities, communication disabilities, and locomotion disabilities, and the nine impairment categories include intellectual impairments, language impairments, and skeletal impairments. Within the 'intellectual impairments' category are subcategories including impairments of intelligence and impairments of memory. The levels continue in increasing detail and specificity, with 'impairments of memory' including categories for amnesia and impairment of thinking, amongst others. Handicaps are categorised within groups that reflect the circumstances that the person may encounter. For example, orientation handicaps, mobility handicaps, occupational handicaps, social integration handicaps, and so on. This method allows the impairments and disabilities to be fully inclusive, with the severity of the handicap to be included (Duckworth, 1983). ICIDH is useful for categorising problems that do not belong to clear medical definitions, and is used by those working in rehabilitation, the provision of benefits, and health care workers.

Figure 9: ICIDH route for impairment, disability and handicap
(Duckworth, 1983)

The ICIDH is currently being reworked, with disability being renamed 'activity', with increments of 'activity limitation' to designate problems, and handicap becoming 'participation', with assessment of 'participation limitation' (Grundy et al, 1999). It is felt that it is important to also
assess the required care, physical functioning, social capabilities and so on, not just the clinical diagnosis (Duckworth, 1983). It must be remembered that the ICIDH is a method of classification, but not of measuring severity of disability (Harwood et al, 1994). A criticism of the ICIDH is that the environment (both physical and social) is treated as a neutral influence in the effect that impairment has on a person. This results in the idea that the individual needs to change, through rehabilitation and other techniques, in order to overcome any handicap. This ignores any impact that changing the environment can have in enabling a person (Barnes, Mercer & Shakespeare, 1999).

Is classification of disability by ‘label’ helpful though? If someone is given a label, it can make them behave and feel the way that they perceive someone with that label should (Barnes, Mercer & Shakespeare, 1999). Classification can result in discrimination against groups, but can also be used to get needed assistance if used correctly and in sufficient detail (Duckworth, 1983). Classification methods need objective and reliable criteria for assigning categories, and the categories should be exhaustive and mutually exclusive. It is much more complex than just saying that someone has ‘arthritis’ or ‘multiple sclerosis’ (Harrison, 1993), and it must be noted that the same impairments do not always lead to the same severity of experience of disability (Harwood et al, 1994). Lenker and Paquet (2001) discuss that sampling based on disability type ignores the fact that there is great functional variation within a group with the ‘same’ disability, and that functional limitations caused by a disability can vary over time. Vanderheiden (1997) notes also that classification systems can ‘miss’ people, for example, if one classifies by visual impairment and mobility problems, it is not possible to deal with those with multiple impairments. All classification methods have a limited usefulness in that they are only relevant to the situation and people they were devised for (Duckworth, 1983).

4.3.2 Severity of disability

McWhinnie (1982) devised a survey device for assessing the disabled population, whereby the impact of ill health was measured by impact on, and reduction of, ability to perform activities of daily life. Two sorts of assessment were used. Time-based assessment concerns the number of workdays lost due to impairment. However it can be difficult to specify what ‘normal’ is for comparison, as it is highly subjective and influenced by personal factors such as coping and adaptation. The second assessment was function-based, which can be useful for policy planning and to show trends, but is still affected by the perception of what is ‘normal’. However,
assessment in terms of essential activities of daily life can provide an indication of problems even if no medical diagnosis has been made.

The Office of Population Censuses and Surveys (OPCS) method of assessing disability (Martin, Meltzer & Elliot, 1994) is based on a large sample of 14308 interviews with private householders. Briefly, severity scales were drawn up from agreed judgements of severity made by 45 judges who were involved in care and rehabilitation, or disabled themselves. The severity of disability scales consisted of a series of statements of activities, with each given a numerical value to reflect the judged severity of disability that would prevent the activity being completed. Severity scales were devised for each of: locomotion, reaching and stretching, dexterity, seeing, hearing, continence, communication, personal care, behaviour, intellectual functioning, consciousness, digestion, and disfigurement. Individuals were assessed on their ability to accomplish statements for each of the scales. For example, the numerical value for the first statement that the person is unable to do is recorded in each of locomotion, reaching and stretching, and so on. The three highest non-zero scores are then added and weighted according to highest + 0.4(second highest) + 0.3(third highest). This weighted severity score is then used to look up the severity category in a given table, ranging from 1 (least severe) with a weighted severity score of between 0.5 and 2.95, and 10 (most severe) with a score of between 19 and 21.40. Grundy et al (1999) list a number of studies that have used the OPCS scales. A criticism was the fact that the scales were not validated by comparison to a previously accepted classification measure prior to use.

Lenker and Paquet (2001) discuss sampling methods for disabled people, based on different aspects: type of disability, mobility aids used, and functional independence levels. The latter approach is similar in nature to that of the OPCS scales. It is suggested that participants are assessed according to how much assistance, or not, they require to complete tasks. A scale going from ‘needs complete physical assistance’, through ‘needs some physical assistance’, ‘independent with use of an assistive device’, to ‘independent’ is proposed.

4.4 The ageing population

In an audit of disability and dependency in old age, McGlone (1992) discussed the fact that the percentage of the population aged 60 years and over is increasing every year due to improvements in health care, lifestyle and social security systems. Wilson (2000) also discussed this in her book on understanding old age, as did Walker & Maltby (1997) in their book on ‘Ageing Europe’. In the United Kingdom in 1993, 20.6 % of the population were aged 60 years old and over, and it is
estimated by Walker and Maltby (1997) that this percentage will rise to 25.3% by the year 2020. It is predicted that, worldwide, by 2020 the number of people aged 60 years and over will be 1000 million (World Health Organisation, 1998).

Many of those people currently aged 50-75 will have access to disposable income (Walker & Maltby, 1997), which, in the author’s opinion, makes them a section of the potential market that designer’s would be foolish to ignore. Ward (2001) concurs that the “new old”, those who grew up in the 1950s and 1960s, have a disposable income, coupled with high expectations of the quality and effectiveness of the products they buy and use. Indeed, in proposing a model for inclusive design, Clarkson et al (2000) discuss the fact that designers who do not consider the needs of older and disabled people are missing out on a lucrative ‘older’ market (and some of the same authors reiterate the point in Keates, Lebbon & Clarkson, 2000). Rogers et al (1997) made the same point about older people having increasing disposable incomes, in a paper on task analysis as a method for encouraging designers to consider older end-users. As more people begin to buy their own specialist and assistive products to replace the mass-market products that they can no longer use, it may be that market forces encourage designers to consider older and disabled people in mass-market product designs, not just in specialist applications (Jordan, 2000; Vanderheiden & Tobias, 2000).

4.5 Activities of Daily Life

4.5.1 What are Activities of Daily Life (ADL)?

Katz et al (1963) first created the Index of ADL to provide a guide to chronic illness, for studying the ageing process, and to assist with rehabilitation. They classified patients in terms of the performance of six activities: feeding, bathing, continence, transferring, toileting, and dressing. Patients were graded from ‘independent in all areas’, through ‘dependence in one or more area’, to ‘dependence in all areas’.

Since this first index was created, the study of ADL has increased to cover all those activities that are essential for independence, and its assessment can be used to reflect the ability of the individual to live in their own home with or without assistance. ADL can include using the toilet, eating, walking, dressing, bathing, and grooming, although these can vary between studies. Instrumental ADL (IADL, Clark, Czaja & Weber, 1990) include activities such as cooking, shopping, using transport, taking medication, using the telephone, housekeeping, doing laundry, and managing money. These activities are important to a person’s ability to live independently,
but not as fundamental as ADL such as toileting, walking and eating. A person may live quite independently but require someone to do their weekly shopping, whereas someone who needs assistance to use the toilet cannot be said to be living as independently, as they will probably require the assistance of another person many times a day.

Assessing a person's ability to perform ADL has been one method used to ascertain the level of handicap a person experiences as a result of their impairments. Various indices exist for the assessment of ADL: simple checklists can be used to assess abilities in the situations where certain problems may be more likely (Duckworth, 1983). Assessment of ADL can help medical professionals such as occupational therapists to decide what assistance a person needs in their everyday lives, and the level of care that needs to be provided. However, it must be remembered that assessing ADL can be a subjective activity. Observing a person can lead to differences between observers' ratings of how easily or well a person achieved a task, and checklists of 'succeed / fail' may not take into account coping strategies or alternative methods of completing a task. It is also not clear whether a person who fails certain tasks is necessarily more impaired than another person who fails different tasks. Aspects such as the person's wish to complete that activity (which may affect their effort and determination to persevere and succeed), and whether a person has assistance (which may result in them not attempting tasks that they might be able to achieve, but instead they get the assistant to aid them) need to be considered when assessing ADL.

4.5.2 Studies of time spent on ADL

Powell Lawton (1990) discussed the lack of a national UK database about how older people perform ADL and the amount of time spent on such tasks. The paper reports previous findings by the author and other researchers. One item discussed is the amount of time spent performing activities during the day, for example, considering fundamental ADL, most time was spent eating (a mean of 77 minutes per day), with cooking second highest (mean of 69 minutes per day) and then housework (68 minutes per day). It is noted that no details were provided in the data, for example, it is not known what 'housework' actually involved, or the problems experienced.

Modrick, Meyers and Papke (1995) also detailed the length of time spent on various ADL tasks, by 40 retirees in this case. 80% reported being in excellent or good health, and although 40% reported a chronic health condition only 5% described themselves as having poor or very poor health. The survey was conducted in order to provide details of the activities undertaken during retirement and as people adapt to the physical effects of ageing. Activities were divided into
'passive' (for example reading, watching television, and church attendance) and 'active' (household tasks, maintenance/decorating, exercise, skills/crafts, recreational travel, paid/volunteer work, and care of dependants). It was found that 'household tasks' took up the most time, taking up 45.85 hours per week, and were undertaken by 88 % of people. ‘Watching television’ was the next highest at 19.43 hours per week, with 82 % of participants watching. However, the study does not indicate whether the length of time spent on these tasks was of an expected level, or whether it was taking people longer to complete a task, as might be predicted if they experienced difficulty with the task. There is also no mention of whether participants ever did two activities at the same time (for example watching television whilst ironing) or how this was accounted for within the study.

Ashworth, Reuben and Benton (1994) compared the amount of time that 44 healthy older people (mean age 70 years) and 46 younger people (mean age 27 years) spent on ADLs. Participants were asked to complete a 24-hour diary of their activities, which were scored for functional activity levels and energy levels. The levels used ranged from 0=sleeping (0.8-1.2 kcal/min) to 5=heavy (7.0-12.0 kcal/min). Where more than one activity was reported at any one time, the highest energy level of activity was recorded, and the diaries were assessed by what activity was being done on the hour and the half-hour. This may lead to some inaccuracies as to exactly how long participants were performing specific tasks. The actual tasks assessed are not detailed, instead being assigned to categories of basic ADLs (bathing, feeding, toileting, and so on), instrumental ADLs (shopping, cooking and so on), advanced ADLs (exercise, hobbies, working, and so on), sleeping and driving. It was found that the older participants spent more time performing basic and instrumental ADLs than the younger group, but spent less time in physical activities or sleeping. The older women spent more time on basic ADLs than the younger women did, and also more time on instrumental ADLs than either the younger women or older men.

4.5.3 Studies of problems with ADL

Dawson, Hendershot and Fulton (1987) analysed the results of an extensive earlier (1984) survey of people living in the community in the United States. Dawson, Hendershot and Fulton (1987) focused on the 11,497 respondents who were aged 65 years and over. Participants were recorded as 'having problems' with activities, if they responded positively to questions in the form of 'because of a health or physical problem do you have difficulty ______ing?'. It was found that 9.8 % of people had problems bathing, 7.1 % preparing meals, 11.3 % shopping, 4.3 % toileting, and 6.2 % dressing. Avlund and Shultz-Larsen (1991) assessed what activities 734 70-year olds...
did and what they were able to do. Participants were asked if they performed a number of tasks, and were then asked if they could perform those tasks (even if they did not), and how easy or difficult these tasks were. It was found that women performed activities such as cooking, preparing food, doing housework and washing clothes, significantly more often than the men, but the men did tasks such as repairing the car, painting, minor plumbing work, gardening and driving more than women. It was found that, overall, nearly all participants performed all the basic ADLs, but no instrumental ADLs were performed by all participants. With regard to what participants were able to do, nearly all performed basic ADLs without any assistance, albeit sometimes slower and with more tiredness than experienced when younger, but fewer completed instrumental ADLs without assistance. Such reliance on others to perform instrumental ADLs suggests a considerable impact on the day-to-day independence of the people. The list of activities that participants were asked about is not exhaustive however, and is obviously designed for the population of the study ('shovelling snow' is one of the activities assessed, which is appropriate to the Danish people surveyed).

Sonn and Grimby (1994) investigated the prevalence of assistive device usage in Swedish older people. Study was made of 371 people aged between 70 and 76 years, and 595 people aged over 76 years. Their aim was that this would provide a broad indicator of the problems that were experienced with certain ADL, with problems then necessitating the use of an assistive device. It was found that one fifth of people aged 70 years used an assistive device of some sort, with the proportion of the population increasing to almost one half of all participants by the age of 76 years. 31 % developed a need for an assistive device between the ages of 70 and 76 years. Assistive devices to aid bathing and mobility were those most frequently mentioned. Hill et al (2000) conducted a survey of stair usage by 157 people aged between 65 and 96 years. All participants were living in their own homes, and the study investigated the causes and prevalence of older people falling on stairs. As part of this survey it was found that 34 % of participants had two handrails on the flight of stairs. From general experience, the majority of domestic stairs have only one handrail, and so the inclusion of a second handrail suggests that these people needed some extra assistance with using the stairs, and may have had an extra rail fitted as a result.

Clark, Czaja and Weber (1990) studied the prevalence of ADL difficulty in 60 people aged between 55 and 93 years of age. Video cameras were used to record the movements of participants in their own homes, and when out shopping, over a two day period. A self-constructed task-analysis program on computer was then used to analyse the videotapes. Actions,
postures, grips, objects and locations were all coded for each task. All the objects that people interacted with were measured; the force needed to open doors or turn taps on, the weight of items lifted and carried, the sizes of handles and control knobs, and so on. The most frequent movements were lift/lower and push/pull (accounting for 60% of all actions), with leaning and reaching accounting for 21% of all postures, and bending accounting for 14% of postures. 95% of tasks included the upper body (the hands and/or arms).

It was concluded that there are certain movements that are common to many ADL. These were: being able to lift/lower, push/pull, use a precision grip, stand for more than a few seconds, and reach. It was suggested that a system that incorporated assessment of these elements alone would be sufficient to predict severity of problems with ADL. A person able to do these things could be predicted to be able to complete most ADL tasks. However, it is not clear whether different levels of performance of movement were included. For example, someone may be assessed as being able to push and pull and grip, but have very little strength in these movements. No mention is made of whether such a person, on the basis of their ability to perform the required movements, would be predicted as being able to complete ADL (that in reality they may have problems with).

Also, in the Clark, Czaja and Weber (1990) study it was found that 45% of people were unable to prepare meals, 53% were unable to shop, 12% were unable to do their laundry, 32% were unable to dress themselves, 28% were unable to bathe unaided, 28% were unable to groom themselves, and 28% were unable to transfer. These tasks were then broken down into component movements that could be analysed, for example reach, lift, and grip. These task descriptions were then to be used to design a computer system that would be able to assess the ADL/IADL performance of any given individual. It is unknown (no literature has been found) if this proposed computer system was ever designed and whether it was effective or not.

Kirvesöya, Väyrynen and Häikiö (2000) conducted a study into task-surface heights with 55 older Finnish men and women (no details are given as to the ages of the participants). They investigated participants’ reported preferences for different heights of shelves in a mock-up kitchen, and different heights of adjustable chairs. It was found that reaching the top shelf of a kitchen wall unit was difficult for all participants, and recommendations were made based on participant preferences that the lowest kitchen shelf height should be 300 mm, with a preferred work-surface height of 850 mm. The chairs rated as most ‘suitable’ were those either with or without arms, with the seat height set at 450 mm.
4.5.4. Coping behaviours and implications for ADL assessment and design

A study conducted for Government Consumer Safety Research (2000) assessed the difficulties that 250 disabled people had when using everyday consumer products, and included the collection of information on the coping strategies that people employed. It states that coping strategies are those behaviours that disabled people use to complete a task, which a non-disabled person attempting the same task would not need to. Such strategies as sliding rather than lifting heavy items, and to lean on, for example, work surfaces when completing kitchen tasks, are highlighted. It was found, for the example of the kettle, that participants used a range of coping strategies. These coping behaviours included using a jug to fill the kettle (15 participants), using both hands to lift and pour (13 participants), sliding rather than lifting the full kettle (7 participants), and only part-filling the kettle to keep it light enough to carry (25 participants).

Powell Lawton (1990) discussed the fact that people may use different methods to accomplish the same tasks in order to maintain independence. The concern was that direct observation measurements of these tasks during ADL assessments might lead the observer to conclude that if the person is not performing the ‘required’ behaviours they are not completing the ADL. It was suggested that researchers should consider the use of assistive devices when assessing ADL, and not give a lower assessment of a person’s ADL abilities because they accomplish a task in a non-traditional way. This argument has some merit. However, from a design viewpoint, it would seem important to emphasise the fact that if a person accomplishes a task by using a coping strategy or assistive device, they can only do so because of the strategy or device. The design of the product or task alone is not conducive to them completing the activity. A policy of acknowledging and encouraging adaptation as a solution to counter increasing impairment could work against the ‘design for all’ ideal. If observers discount those people who have adapted their behaviour (whether or not the new behaviour is actually detrimental to the continuing progression of impairment), then the number of people with recorded ADL problems will decrease. This could then result in designers being less likely to consider the needs of such people, as they will see the problem as being less significant than it is. In effect, this would mean that those people adaptable enough to cope in ingenious ways would be penalised for their adaptability. Coping should not be seen as being good enough.

It is important to understand what people have difficulties doing and why, both in terms of the disability and the design of the products and environments involved. It is also interesting to investigate any ways in which people compensate or adapt to their disabilities and the designed
environment. Some of these adaptations may provide information useful to designers concerning design changes that may be necessary in order to remove the need for such adaptation or coping strategy. Impairments do not have to mean that tasks become impossible, as long as the environment and the products used allow the person to utilise their full capabilities.

4.6 The role of design in maintaining independence

"The primary goal of many older individuals is to maintain an independent lifestyle" (Fisk, 1999).

Performing ADL is essential to the continued independence of older and disabled people. The majority of older people wish to remain living in their own homes (Lansley, 2001). Independence is beneficial to self-esteem and also to reduce the financial cost of caring for people. To keep a person in a nursing home or sheltered accommodation costs them and the tax payer money. This may be saved by designers and architects considering the needs of these people more carefully, and including them in the population at large through their designs (Duckworth, 1983). There are many everyday activities that cause problems to older and disabled people and reduce their independence. Access to shops, public buildings and areas, and homes can be difficult for the disabled (Which?, 1989), with obstacles such as steps, heavy doors, out of reach shelves, and items on the pavement. A few studies have been selected to illustrate the problems that older and disabled people experience.

Petzäll (1993 & 1995) investigated the use of transport by older and disabled people. In 1993 the use of buses by 30 ambulant disabled people was studied. Eight participants were classified as 'seriously ambulant disabled', 11 were 'less seriously ambulant disabled' and 11 'slightly ambulant disabled'. Observations were taken of participants getting on and off a mock-up bus with the seats, steps and handrails set at different heights and distances apart. Recommendations were then made for the height and depth of steps, positioning of handrails, seat heights, distance between seats, arm rests and grab rails. In 1995 Petztäll conducted a second study, into the design of entrances of taxis for older and disabled people. 17 participants were involved, aged between 35 and 80 years, with six being wheelchair users and 11 ambulant disabled. Participants were observed getting in and out of different sizes of mock-up cars, and recommendations were made for the doorway width and height, seat position, door-sill height and door angle. It is not clear whether these data have been made generally available to designers in any form other than the published papers. The 1995 paper states that the Swedish Board of Transport has used the results during work on regulations for public transport usage by disabled people.
McClelland and Ward (1976) investigated the ergonomics of toilet seats, in order to obtain anthropometry and postures adopted, as such data was not previously available. A total of 166 people took part, including a small number of people aged 60 years and over. Unfortunately, due to the small sample size the data from older people was not included in the analysis. It is unclear whether these data would still have been made available to any designer who wished to consider the anthropometry of the older participants. In 1982 McClelland and Ward looked again at toilet seats, and conducted trials with 205 participants, ranging from 29 to 50 years old. Different angles and styles of toilet seat were tested to see which was most comfortable and easiest to get up off. It was found that the height and angle of the seat had an effect on ease of use, but the shape of the seat did not. The recommended height of the toilet seat was 0.4 m. The current British Standard for toilet pan heights is 0.4 m (BS 5504-3, 1977).

Rogers, Gilbert and Fraser Cabrera (1997) looked at automatic teller machine (ATM) usage in older people. They conducted telephone interviews with 44 men and 56 women, aged 61-81 years. They also conducted structured individual interviews with 24 of the telephone participants (8 never used ATMs, 8 used ATMs at least once a month, 8 used ATMs at least once a week), aged 62-80 years. The aim was to assess ease of ATM usage, and reasons for using or not using such machines. The responses to the structured interviews were open-ended and allowed participants to express any concerns or opinions that they had. Factors that arose as reasons for not using ATMs were not knowing how to use the machine (8.5 %), inaccessibility (17 %), and fears over security (33.9 %). The study includes discussion of the implications for design and location of ATMs, namely to increase the perception of safety and security, and also guidelines for training to decrease reluctance to use, and problems experienced when using them.

Poor product design affects everyone, not just older or disabled people. Older and disabled people are considered to be minority groups outside the boundary of the ‘normal’ population. Due to this their needs are often ignored by designers of everyday products (Rogers et al, 1997). As a result of their needs not being considered, such users have to adapt to using inadequate products, or else invest in assistive devices or specialist products, which are often expensive.

Three-quarters of visitors to Disabled Living Centres nationally now buy their own products, whereas people used to get them on loan from Social Services (Harding, 1999). Specialist products for older and disabled people are therefore becoming big business. People can increasingly buy products (such as grabbers for reaching and adapted kitchens and bathrooms)
from High Street stores such as Argos and B&Q, or from magazine advertisements. However, people may pay more for products bought in this way, or pay for products that are not suited to their needs (Harding, 1999).

4.7 Conclusions

Ability forms a continuum, with those who are fully able-bodied at one end, and those who are severely disabled at the other. In between, there are a large number of people with a wide range of impairments, either congenital, or due to injury, illness or old age. Classification according to impairment or disability alone is not enough; as such labelling does not take into account the variation in abilities of people with the 'same' impairments, but differing severity of disability. It is expected that the majority of people wish to lead as independent and full a life as is possible, and consideration of their needs by designers can help to achieve that.

There will always be those people for whom specialist help is needed, but information about the needs and abilities of those who could be assisted by more user-friendly products is urgently needed. Methods for classifying disability and assessing ADL are useful for providing information to designers, as well as carers and medical professionals. However, the methods used to assess ADL need careful consideration, with regard to the mode of classification, and the reasons for collecting the data.

It is clear that problems experienced with ADL are widespread and cover some of the most basic activities that fit, able-bodied people take for granted (including bathing, toileting, cooking, mobility, and access). However, no information was found regarding older and disabled peoples' explicit wants and desires, or which activities would improve their perceived quality of life. There was also little consideration in the literature of younger disabled people, with the main focus being on older people.
Chapter 5. Survey of older and disabled people

5.1 Introduction
In order to discover the current problems that older and disabled people have with products, environments, and the activities of daily life that they would most like to be able to do, it was necessary to conduct a survey. This would also provide insight into the problems that these individuals have with existing designs. It would also serve to identify the types of tasks that would be appropriate for the main data collection phase of the research, with the collection of physical and capability data from older and disabled people for inclusion in the proposed computer-based design tool.

5.2 Aims
The main aims of the survey were:

- to identify Activities of Daily Living (ADL) that caused the most problems for older and disabled people
- to identify the ADL that they most wanted to accomplish for themselves, and would most improve their perceived quality of life
- to ask participants whether they felt that changes to design could improve the ease of ADL.
5.3 Rationale for the survey of older and disabled people

In order to inform the main data collection phase of the project, during which data would be obtained for use in the computer-based design tool, it was necessary to understand what problems people currently experience with products and environments. As the research forms part of an initiative to extend quality of life, it was thought prudent to investigate those activities that make a difference to peoples' perceived quality of life. In order to reflect this, it was important to cover as wide a range of ADL as possible, both around the home and away from home. It was also desirable to get peoples' opinions on how their lives could be improved by changes to existing designs.

5.4 Sampling

The aim was that a sample of 50 older and disabled people would be selected, with 10 participants in each of five age and ability groups (18 to 62 years with no disabilities, 18 to 62 with disabilities, 63 years upwards with no disabilities, 63 years upwards with disabilities, and wheelchair users aged 18 upwards). Each group of 10 participants was made up of 5 men and 5 women.

People were contacted through groups, including disability groups, colleges and day centres for disabled and older people, and by handing out leaflets asking for volunteers at the Motorbility Roadshow on the 23rd and 24th June 2000 (see Appendix 2). It was felt to be beneficial to conduct as many interviews as possible face-to-face, to enable the interviewer to see the problems that people were describing first-hand. It was not possible, due to time and cost constraints, for the author to travel in order to sample over a wider geographical area. This may have some impact on how representative the sample was. However, it was felt that the sample did not need to be strictly representative, but aimed to include as wide a range of abilities as possible and to see if there was a clear consensus on the issues being examined. Due to problems locating and contacting participants, the final sample of 50 consisted of 30 women and 20 men.

5.5 Questionnaire design

The questions to be included in the interview were devised by the author, and discussed with other members of the project team. The questionnaire was once again shown to the relevant industrial collaborators (Section 1.4), and their input recorded and included in alterations made to the interview questions. A fellow researcher (who used a wheelchair) was also consulted for his input. The questionnaires were to be administered either face-to-face or over the telephone.
Postal interviews were rejected due to the lack of available addresses for individuals, and the likelihood of a low response. For example, anyone with a disability affecting his or her hands would have had difficulty completing a written questionnaire.

As discussed in Section 3.5, the layout of the interview questions was not as critical as in a postal questionnaire. However, the wording was still of importance, and the meaning of each question made clear verbally. The order of questions asked was set out, but the flexibility did still exist to allow the interviewer to check off questions that were covered out of sequence by the participant, rather than keep stopping the participant in mid-conversation to take them back to the next question on the sheet. The questionnaire was divided into seven main sections: general personal details, kitchen, bathroom, general in the house, away from home, work, and leisure (Appendix 2). These were defined by questions concerning either certain types of activity (for example ‘leisure’) or places where activities are carried out (for example ‘kitchen’ and ‘bathroom’). This served to focus the participant on the area of concern and the activities associated with it. The different sections were also useful in that many of the tasks had elements that were part of other tasks. Therefore, even if a person did not perform, for example, any kitchen tasks, they could still be assessed for similar movements performed on tasks in other areas. In this way, reaching and bending during supermarket shopping could be used to reflect ability to reach and bend in the kitchen.

The questionnaire was designed to be as generic as possible in the tasks that were being assessed. Specific questions were devised that would enable the individual to focus on the task being described, but the actions involved were actions that could be required to perform a number of tasks successfully. For example, people were asked how they managed lifting a small dish into the oven. This was a specific question, but reflected the fact that a person unable to do this task was likely to have difficulties with any task involving bending and reaching forward whilst carrying an object (for example selecting goods from low supermarket shelves, books from low library shelves, and so on). Each question was given a scale for the interviewer to mark, according to the person’s response (numerical, from 1 to 5, with 1 indicating that a task was accomplished easily and with no problems, and 5 indicating that a task was impossible). This scale is almost identical to that proposed by Lenker and Paquet (2001) in a discussion of sampling methods. The scale was marked by the interviewer depending on what the participant said about how difficult or easy they found the tasks to be. Additional comments were noted. The
participant was not shown the scale, to prevent confusion and additional information from having to be considered.

At the end of each group of questions from the seven sections, participants were also asked if there was any one thing (at a practical level) that they would like to be able to do but could not achieve. The question was asked in such a way that the person did not answer with desires that could not realistically be met, for example, to avoid a person with no use of their legs saying that they would love to be able to walk again.

5.6 Ethical considerations
It was not necessary to obtain specific ethical approval for the survey, as general guidelines for such research were followed. The main issues were confidentiality and to ensure that the participants were not made to feel unsure or embarrassed by any of the questions regarding physical difficulties. In order to achieve this, the questions took the form of open-ended discussions around the key issues. This allowed the participant to go into as much detail as they felt comfortable doing, without forcing them to consider issues that were too personal.

5.7 Piloting
The interview questionnaire was piloted with five individuals face-to-face. At the end, they were asked for any comments regarding the questions asked, order of questions, or wording used. Their results were included in the final analysis, as no major changes were made to the questionnaire after the piloting procedure. The consent form and information given to participants were also piloted (Appendix 2).

5.8 Survey procedure
1. Participants were contacted and asked if they would agree to take part.
2. Participants were then telephoned to arrange a time for the interview, or the interview was conducted there and then if convenient. Interviews took place at participants' homes, or in social clubs.
3. Participants were asked to sign a consent form. If they were unable to do so the consent form was read to them, and they were asked whether they wished to participate and the form was then signed on their behalf by the interviewer.
4. Participants were informed that they could stop at any time without giving reason for doing so.
5. The interviews were conducted, responses were written down, and the relevant scales were marked. This was to provide qualitative as well as quantitative data for analysis.

6. The participants were asked if they had any questions, and then thanked for giving up their time.

5.9 Data analysis

Data were analysed using a similar procedure as in the Survey of Design Professionals (Section 3.10). For each question a count was taken of the scaled responses, and these are presented as percentage values. All percentage values given are for the full sample of 50 participants, unless otherwise stated. Qualitative data in the form of comments made are noted as well, where applicable. The results are presented largely according to the different sections of the questionnaire.

5.10 Results

5.10.1 Sample and general information

The majority of interviews took place between February and August 2000. A total of 50 participants took part in the survey (30 women and 20 men). Ages ranged from 21 to 99 years and full details of the age and gender of participants is given in Table 8.

<table>
<thead>
<tr>
<th>Age range (years of age)</th>
<th>Number of men</th>
<th>Number of women</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-62 (with disability)</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>63+ (with disability)</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>63+ (without disability)</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>TOTAL</td>
<td>20</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 8: Ages and genders of older and disabled participants (n=50)

56% of the participants were of working age (18-65 years of age), but of these only nine actually worked. The other 44% reported either being retired early or unable to work due to their disability. All those who were working reported having easy access to their place of work, although for one person it was via a side door. They were reasonably happy with their access to work items and the building(s), although three admitted that if they could not reach an item they would ask a colleague for help. The only changes that they reported to be needed included items such as non-slippery floor surfaces when using crutches to move around, and ensuring that the office was laid out in such a way that a wheelchair could be manoeuvred easily around desks, etc.
All those who were working stated that they could still perform their jobs without these changes being made, but felt that such changes would improve the situation further.

5.10.2 Mobility and independence

The most usual method of mobility used by participants is given in Figure 10. It can be seen that more participants were independent at home than when away from home. 36% of participants reported that they were more independently mobile within their own home than when out and about: none reported being less independently mobile at home. Five participants (10%) were reliant on the assistance of another person to push them in a manual chair away from home, which may have some impact on how often they get to go out, and where they go. However, several participants did mention that they used different modes of mobility, for example walking with a stick for short distances but a scooter for longer distance or if they were tired.

Figure 11 shows the percentages of people who were independent, unable to use, or required assistance, for indoor stairs. It can be seen that the majority of the sample were either unable to manage stairs, or else needed the assistance of a person or rails. Those who were unable to go up or down stairs needed a stair lift or avoided having to use stairs. Of the 34% who needed some assistance, 29% (5 out of 17) reported needing two handrails in order to be able to manage stairs. Interestingly, two people who were recorded as being independent using the stairs did add that they crawled or slid on their bottom.

30% of participants reported not being reliant on other people on a daily basis at all, remaining very independent. 60% reported needing assistance in some tasks only, usually involving activities such as cooking, cleaning, gardening, bathing, and shopping. It was, however, of concern that 10% of the participants reported being ‘very reliant on other people’ at home on a daily basis, requiring almost continual assistance in daily activities.
**Figure 10:** Modes of mobility in the home and away from home (n=50)

**Figure 11:** Percentage of participants and ability to manage indoor stairs (n=50)
5.10.3 Kitchen activities

The participants' ability to carry out kitchen activities are shown in Figure 12. It can be seen, for example, that 32% found it impossible to reach a high shelf. Those who did not do these tasks (classified as 'not done') either had assistance or had not tried it themselves, or had been assessed to be unsafe performing such tasks and were advised to no longer do them. Many participants mentioned methods of coping with ADL problems:

- Long-lever taps were used by the 28% of participants requiring 'some help' with using taps
- 20% of participants would only lift very light items into the oven (for example, a tray of chips was mentioned by one person)
- 14% of participants would slide rather than lift a pan onto the hob
- 12% of participants could put washing in and out of the washing machine without assistance but were reliant on another person to hang it to dry
- 10% of participants had 'considerable problems' with washing up, and so had a dishwasher
- Kettle tippers were used by the 6% requiring 'some help' to lift a kettle
- ‘Grabbers’ were used by the 6% requiring 'some help' to reach high items

![Figure 12: Percentage of participants reporting ability to manage selected kitchen tasks (n=50)](image)

**Figure 12:** Percentage of participants reporting ability to manage selected kitchen tasks (n=50)
5.10.4 Bathroom activities

When asked about bathroom activities, it was discovered that five participants did not own a bath, four did not own a shower, and three participants were catheterised so did not use the toilet. Figure 13 details ease of managing bathroom activities. It can be seen that only 4% of participants were able to get in/out of the bath ‘easily’, as opposed to 18% who reported being able to use the shower ‘easily’. Strategies for coping with difficulties with bathroom activities:

- 40% (4 out of the 10 participants who reported having ‘some problems’ using the toilet) had rail(s) nearby to grab onto
- 20% of participants reported having a seat in the shower
- 20% of participants needed ‘some help’ to use the toilet, and had a raised toilet seat and/or a frame around the toilet to hold onto
- 14% of participants needed ‘some help’ using the bath, and had rails fitted and/or a seat
- 14% of participants required ‘considerable help’ using the bath, and had a hoist or lift to get them in and out
- 12% of participants had level-floor showers that could be walked or wheeled into
- 6% of participants needed ‘considerable help’ to use the toilet, and had a hoist to lift them

![Figure 13: Percentage of participants reporting ability to manage selected bathroom tasks (n=50)](image-url)
5.10.5 General tasks around the home and away from home

Figure 14 details the percentage of participants who reported ease of opening and closing windows and doors around the home, and ease of using plug sockets. It appears that the height of window catches affected the ease of opening and closing, with 20% of participants saying they could only manage low window catches. The 12% who found windows impossible to open did so because the catches were too high, or the windows were too heavy. Closing doors and knob handles that required dexterity for turning caused problems with internal doors. Ease of putting plugs into and out of sockets was reported to depend on the height of the socket:

- 8% of people actually had had their homes rewired with all sockets at midlevel
- in total 24% of participants said that they either had, or could only manage, midlevel plugs
- two participants used a multi-socket for frequently used plugs, which could be positioned at a suitable height, and they simply removed and added plugs as appropriate
- one person mentioned using the plugs with a loop on the back for ease of grip and handling

![Figure 14: Percentage of participants reporting ability to manage selected general household tasks (n=50)](image)
Participants lived in a variety of geographical locations, with 62% living in towns, 20% living in cities, and 18% living in villages. This may have had some impact on the type of public transport available to them. Indeed, it was found that only one person living in a village had access to ‘kneeling buses’ (buses that could be lowered to decrease the step from kerb to bus), with the remaining eight reporting that they could not use the standard buses provided. Four people living in towns had access to ‘kneeling buses’, with seven stating that they could not use standard buses, and 11 people were sufficiently able-bodied as to be able to use any bus without problems. Three participants living in the cities reported that kneeling buses were available to them but six people were unable to use the standard buses provided. Three people (two town-dwellers and one city participant) did report that ‘kneeling buses’ were in operation locally, but that scooters could not fit on board, so the buses were not accessible to these people. Two participants were unable to use buses, as they were unable to stand and wait at bus stops for buses to arrive. Figure 15 shows the percentage of participants who reported ease of managing selected tasks away from home, including using buses, trains, cars and cash machines. It can be seen that 28% of participants found it impossible to use buses, and 16% needed considerable assistance to get into a car. Use of trains depended more on the station having a car park available, and the fact that advance arrangement was needed in order for ramps and assistance to be provided (meaning that all train trips had to be planned in advance, no spontaneous trips were possible). 24% of participants had to use trains in this way (all were in wheelchairs), and a further 24% were able to use trains with no need for prior booking (could walk on board).

18% of participants mentioned that they filled their cars with petrol by getting the staff at the petrol station to do it for them. 8% specifically mentioned the fact that one major high-street supermarket has buttons at the pumps that can be pushed for assistance in just such cases, and one other participant said that a different supermarket had payment facilities at the pumps, removing the need to go to the main kiosk building.

Cash machines caused problems or concern for many participants. 22% of participants reported having problems with the height of the machines, with only low-level ones being accessible from wheelchairs. However, problems were still experienced even with the low machines, as the screen was often at the wrong angle so reflected light, rendering the screen impossible to see. One participant did not use the machines due to security fears, and two others could only use them if a car park was nearby.
Figure 15: Percentage of participants reporting ability to manage selected tasks away from home

Most participants agreed that large supermarkets and shops were usually very willing to help whenever possible, either by providing an assistant to push a trolley, or staff simply reaching for high items for people in wheelchairs. However, it was mentioned that sometimes people can be almost ‘too’ helpful, and that sometimes having to ask for help is embarrassing. It was generally felt that supermarkets had improved in recent years, with three participants mentioning the ‘special’ trolleys for wheelchair shoppers and those who cannot bend down to the bottom of conventional trolleys. However, there is still room for improvement, with one participant reporting difficulties with signing card receipts, and another the narrowness of some checkouts.

5.10.6 Leisure activities

Participants took part in a wide range of leisure activities, with only five people saying that they did not really do anything, due to physical constraints. Activities that participants reported taking part in on their own included:

- 18% enjoyed reading
• 12% did knitting or other craft-work
• 12% watched television for recreation
• 10% did gardening

Other activities were group-based, with the following being mentioned:

• 16% regularly attended social clubs
• 10% enjoyed theatre trips
• 6% participated in church activities
• 6% were involved in voluntary work
• 6% enjoyed cinema trips
• 4% frequented public houses
• 4% regularly attended nightclubs

Sporting activities were also enjoyed, with 22% of responses being activities such as walking, cycling, dancing, bowls, swimming, paragliding, and wheelchair racing.

When asked if there was anything they would like to do but were unable to because of the way equipment or environments were designed:

• 14% wanted to go swimming
• 12% wanted to be able to go on holiday or visit friends
• 8% wanted better cinema and theatre access
• 4% wanted access to football and rugby stadia

With regard to gardening, 14% of participants did not have gardens, so gardening was not applicable to them. Of the remaining 43 participants, 21% (9 out of 43) of participants had had their gardens adapted to suit their needs, with better accessibility, rails if needed, raised beds and plants in tubs, to remove the need for bending. However, not all of those with gardens were interested in actively gardening, with 30% (12 out of 43) preferring to simply sit in the garden and relax.

5.10.7 What would participants like to be able to do?

Participants were asked what they would really like to be able to do, given their abilities, on a practical daily level. The responses to these questions (it was asked after each main section of the questionnaire) reflect those things that people most wanted to be able to do, in order to maintain independence and live their lives in the way that they wanted to. The total number of responses was 68, with most participants giving more than one response (38 of the 50 participants)
responded). Responses varied widely, but different participants mentioned several of the same items:

- **32 % (12 out of 38) of participants wished to use the oven more fully, possibly with a midlevel oven, for activities such as baking**
- **18 % (7 out of 38) of participants wanted to be able to use their baths themselves or have equipment to make bathing easier**
- **16 % (6 out of 38) of participants wanted the ability to take holidays, to have access, and receive care when away from home**
- **10 % (4 out of 38) of participants expressed a wish for each of:**
  - Access to the cinema
  - Access to swimming
  - Access to public transport
  - To have a walk-in, level-access shower
- **8 % (3 out of 38) of participants expressed a wish for each of:**
  - To have lower work surfaces to make cooking and food preparation easier
  - To have lower or no kerbs
  - ‘Access to all areas’
  - Access to smaller shops
- **5 % (2 out of 38) of participants expressed a wish for each of:**
  - To be able to reach high cupboards
  - Being able to wash own hair
  - Being able to do the ironing
  - Being able to change light-bulbs
  - Being able to hang clothes on the washing line
  - Being able to reach shop shelves

Other activities mentioned each by one participant were: mopping the floor, a better electric peeler design, a better bottle/jar opener, being able to open the windows, being able to clean the windows, doing the washing-up, a combined bidet and toilet, vacuuming, changing smoke alarm batteries, a swivel on all car seats, doing the decorating, and playing table tennis.

### 5.11 Discussion

It must be noted that the sample of 50 participants were nearly all from the East Midlands region of the UK, and as such may not be representative of the needs, wishes and problems experienced
by older and disabled people countrywide. However, there was a consensus between many of the problems and wishes mentioned by participants, and so it is felt that it is likely that the results broadly reflect the problems, concerns and desires of the wider population.

5.11.1 Activities of daily life

Problems with such activities of daily life such as shopping, cooking, laundry, and using transport all featured highly in this study, as they do in previous research. As an example, Clark, Czaja and Weber (1990) found that 12% of their 244 older (but not necessarily disabled) participants reported problems with doing the laundry, 28% reported problems with bathing, 53% reported problems with grocery shopping, and 45% had problems with meal preparation. These findings can be compared to the results of this research, in which 36% reported problems with, or found it impossible to use a washing machine, 52% reported problems with bathing, 48% reported difficulties when shopping, and 64% had problems or found it impossible to use an oven.

Dawson, Hendershot and Fulton (1987) also found the highest reported percentage of problems were with shopping, bathing and preparing meals. Cooking was the most frequently requested activity that the participants in this research really wanted to be able to do. Clark, Czaja and Weber (1990) classified cooking as an instrumental ADL, rather than a fundamental one, whereas in this study it appears that cooking is fundamental to independence.

The use of assistive devices in the bathroom (20% had a seat in the shower, 26% had rails and/or raised seat and/or frame on the toilet) reflected the findings of Sonn and Grimby (1994), which found that the most prevalent assistive devices were ones to aid bathing and toileting. The need for raised toilet seats also indicates that the work of people such as McClelland and Ward (1976, 1982) into recommendations for toilet seat heights is needed, as this is still an issue. Such usage of assistive devices, as documented by Sonn and Grimby (1994), also raises the fact that, if designers were to more fully consider the needs of older and disabled people, the need and usage of such assistive devices would be reduced.

Reaching high items in the kitchen (and no doubt, in other rooms or in the supermarket) was impossible for 32% of participants, and a further 34% had problems with this activity. These results reflect the findings of Kirvesöya, Väyrynen and Häikiö (2000), who found that two-thirds of their 55 participants reported problems using the top shelf (1840mm) of their experimental kitchen. Kirvesöya, Väyrynen and Häikiö (2000), argued, as this thesis does, that anthropometric data alone is not enough to allow designers to adequately design products and environments for
older and disabled people, and that information about functional capabilities, mobility and problems with activities of daily life is needed as well.

Bus usage led to a number of issues arising, including inability to wait at bus stops, and inability to access standard buses due to step heights and lack of wheelchair access. Petzäll (1993) investigated older and ambulant disabled people using buses, and found that step heights and the provision of handrails were key issues. 'Kneeling' buses (ones that can be lowered by the driver so that the entrance is level with the kerb) were not discussed by Petzäll (1993). However, the design of such buses meant that 14% of participants in this study were able to use buses when they were unable to use standard, non-kneeling buses. Such design changes may well be the answer to increasing accessibility of buses for older and disabled people: the 26% of participants who were unable to use standard buses may well have been better able to access kneeling buses, if available in their area.

With regard to automatic teller machines (ATMs), it was not just the height and location that caused problems for participants. There were also issues of security (for one participant) and several who just never used them (no reason specified). These findings are supported by the work of Rogers, Gilbert and Fraser Cabrera (1997), who found that issues of security and non-usage were common in older people concerning ATMs. The security fears may be due to the exposure of ATMs in the High Street as opposed to inside the bank and talking to the cashier, and the general fear of mugging and attack if one is seen to be getting money out of an ATM.

Coping mechanisms such as sliding rather than lifting items (reported by 14% of participants), and use of assistive devices (such as hoists and kettle tippers) featured often in participants' responses, indicating, as Powell Lawton (1990) suggested, that such behaviours and assistive devices need to be considered when assessing ADL. Information about coping strategies may also be of use to designers, raising awareness of current problems and areas where assistance may be required. In addition to assistive devices in the bathroom, others used included dishwashers, kettle tippers, grabbers, and long lever taps. Coping strategies were such things as sitting to do tasks, sliding items rather than lifting, and asking for assistance when needed, and reflect the coping strategies found by the Government Consumer Safety Research (2000). 24% of participants reported that having all electrical plug sockets at mid-level would be beneficial, and six participants had level-access showers to allow them to continue to enjoy showers. Those participants who were working expressed their ability to adapt and cope with problems such as
cluttered work areas when moving in a wheelchair and slippery floor surfaces when walking with a stick. Changes to existing designs and ‘standard practise’ of room layout and design, may be beneficial to all users, and may become more prevalent as people pay for the changes themselves, and demand higher usability standards from those designing and building homes and offices. The very fact that 56 % of the participants were of working age but only 18 % were actually in full-time work suggests that improved design and accessibility are needed in order to increase this number.

5.1.1.2 Independence

36 % of participants were more independently mobile within their own home than when out and about. Feelings of uncertainty and lack of familiarity with the surroundings outside the home can result in people opting for more assistance away from home. Also, when out and about the distances involved are usually greater than moving around the home, which may be beyond some peoples’ limitations. The increase in the number of motor chairs or scooters used away from home reflects the fact that these chairs are often rather bulky for home use, but offer greater independence and range of distance away from home. Such increased reliance on scooters may be at odds with independence when bus usage is required, however, with buses generally being unable to accommodate scooters (Section 5.10.5). Lenker and Paquet (2001) discussed the possibility of using mobility aid-usage as a method for sampling populations of disabled people. However, from the results here it would suggest that such an approach would not reflect the fact that the majority of participants used different mobility aids depending on where they were (at home or away), the distances to be travelled, and how familiar they were with the terrain.

People are very adaptive in their own home, and can cope amazingly well in their own environment, partly due to control over organisation and arrangement of items such as furniture, but also due to the added confidence of being in a known environment. Most people used more conservative modes of locomotion when outside the home, and several people mentioned behaving differently in areas they were unfamiliar with, and a fear of problems occurring in unknown places. Such fear of the unknown not only prevents people from attempting to go to public buildings or use public transport, but can also prevent people from attending social events. It may be that standardisation of kerb and step sizes, widths of pavements, and the availability of public seating, accessible public toilets, and better sign-posting of such may all serve to reduce anxiety about venturing outside. Visiting friends and social gatherings can lead to problems of accessibility, resulting in embarrassment of the individual, and other members of the group who
may not have considered the problems fully. Sadly, to avoid this possibility, many people reported not going out to unknown houses or places.

Those disabled from birth tend to have stronger coping mechanisms, having had longer to perfect adaptive behaviours and environments as appropriate. Those older people without specific problems reported 'the need to keep active and supple in order to keep degenerative skeletal problems at bay'. However, those who experienced problems from birth were felt to sometimes have less of a voice when it came to demanding better care and provision. Some people with acquired disabilities felt that they personally were more vocal as they had been more independent and vocal before the onset of their disability. It appears (ad hoc) that acquired disabilities were less accepted by the individuals and resulted in a more demanding attitude to Social Services provision.

60% of participants reported generally having 'some reliance' on other people on a daily basis, with 10% reporting being 'very reliant' on other people. Such reliance indicates reduced independence in some or all activities. 10% of all participants reported requiring two handrails in order to be able to use stairs, which reflects one of the findings of Hills et al (2000). They reported, in a study of stair usage by older people, that 34% of households surveyed had two handrails fitted. With regard to leisure activities, a wide variety of activities were undertaken, which is encouraging and exciting as it suggests, that for some people, disability did not affect them unduly with regard to leisure activities. However, for others, they perceived their options for leisure activities to be very restricted (five people; four with substantial mobility problems, and one due to fear). It is unclear whether they were really that restricted or whether it was what was available to them.

The amount of money that individuals are able to spend is a complex issue. The 26% of participants living in council owned or housing association properties generally had all the necessary adaptations, adaptive equipment, and assistive services, provided by the Social Services. However, whilst this may appear to be a very good situation, these people are wholly reliant on such provision and could not afford to purchase products themselves. A couple of participants mentioned problems arising when the Social Services did not assess them to be in need of a certain piece of equipment, or else having to wait many months for alterations to be made.
Those living in private housing did not get provision of all necessary specialist equipment from Social Services, although most people interviewed had received some form of assistance, for example a kettle tipper, or rails provided externally to the property. Participants reported having to pay for any housing adaptations and specialist equipment that they needed, and being able to purchase anything that they feel would be of benefit, whenever they wish to, provided they had sufficient money available. Some specialist items, adaptations and services (such as stair-lifts, bath-lifts, wheelchairs, 'home help', and others) may prove to be prohibitively expensive. It may be that older people do not always have the disposable income that would encourage designers to consider them as part of the 'market forces' or to force change, as predicted by Walker and Maltby (1997), Clarkson et al (2000), Rogers et al (1997), Jordan (2000) and Vanderheiden and Tobias (2000). These researchers predict that market forces will result in change, and consideration of older and disabled people, but this will occur over time. Many of the older and disabled people in this survey reported that they were, or had been, struggling to pay for expensive specialist equipment, or relying on Social Services to provide it. As the older population grows, and the numbers of older people with larger disposable incomes grows, so the market will change and it is likely, in the view of the author, that the predictions of Vanderheiden and Tobias (2000) and others will be met.

It appears from the findings of this survey that improving design will increase independence, at least for some participants. Increasing independence will improve quality of life through old age for older people, and throughout the lives of those with disabilities. Wider availability of 'kneeling' buses, accessible shopping areas, redesign of baths to include those with lower sides and handles as standard, level-access showers more widely included as standard in bathrooms, midlevel cookers, and increased access to public areas (leisure centres, cinema, etc), would all serve to improve the quality of life of many older and disabled people.

5.12 Critique of the methodology

As with the survey of design professionals (Section 3.13) it was useful to reflect on the methodology used in the survey of older and disabled people, and the implications for interpretation of the results. Issues associated with the sample of older and disabled people were briefly mentioned at the beginning of the discussion (Section 5.11). Notably, the sample was intended to provide data to inform the design of the data collection phases, that is to increase awareness of the problems that older and disabled people experience and what they would most like to be able to do. As such, the emphasis in the sampling was to interview people with a wide
range of abilities and problems. Within the sample, a consensus of opinions was found as to what activities caused the most problems, and the types of tasks that people most wanted to be able to do (or do more easily). This suggests that the results, whilst maybe not representing all the possible problems and desires of the larger older and disabled population, reflected the feelings and opinions of a broad cross-section. As such, it is likely that the results include those tasks and activities that would arise if the survey were repeated with other older and disabled people.

There was some concern about the possibility that participants may have over-exaggerated their abilities when asked about completing tasks, in an effort to appear less 'disabled' than they were in reality. This would obviously affect the results and impact on the main data collection phase when participants were to be observed performing certain tasks rather than just asked about their abilities in relation to them. The approach of the author (who conducted all the interviews) was to be friendly and interested in all responses, and to reiterate that there was no 'right' or 'wrong' answer. The aim of the survey was to find out the real issues that affect older and disabled people. Conversely to the problem of participants over-exaggerating their abilities, was the fear that some participants would over-exaggerate the problems they experienced, for example if they felt very strongly that a certain product or activity should be considered and redesigned. Whilst it is not possible to state categorically that no participants responded in a biased way, the author aimed to put participants at ease and stressed the value of all responses, whether positive or negative. It is therefore expected that the results will be a fairly accurate reflection of participants' actual abilities and problems. It should also be noted that approximately half the interviews were conducted with participants in their own homes, which provided opportunities for participants to demonstrate the difficulties they experienced, allowing some verification of problems experienced and tasks conducted. Conducting the surveys with older and disabled people provided invaluable insight into the problems experienced, and the wishes and desires of the participants. Such awareness and empathy with the participants may also serve to increase the likelihood of open and honest responses from participants.

The survey did not include any questions relating to, or taken from, existing rating scales or questionnaires for assessing ADLs or 'quality of life', such as those used by Occupational Therapists or other medical professionals. It was decided in advance that the survey should be very specific to the task-based nature of the proposed methodology for the data collection trials, and the computer-based design tool. Also, the investigation of 'quality of life' within the context of ADL assessment; that is, asking participants what would improve their quality of life as well as
what they have problems with, was a novel approach, not covered adequately by previous survey tools.

5.13 Conclusions
Many older and disabled people still have problems achieving ADL such as cooking, bathing, using transport, shopping, and using public amenities. Good design should be able to improve the situation for many older and disabled people. Examples where design changes have assisted people are level-access showers, wider checkouts in supermarkets, mid-level electrical sockets, and lower Automatic Teller Machines (ATMs). Older and disabled participants in this survey generally had money to spend, or else had equipment provided by Social Services.

Older and disabled participants most wanted to be able to achieve the simple activities of daily life that so many of us take for granted, for example use their cooker more fully, and felt that design changes may assist them in achieving this. Cooking is an activity that involves reaching, bending, and lifting, all of which are elements found in many every day tasks. Cooking is also an activity that would improve the quality of life. As ‘extending quality of life’ is part of the project remit, the tasks associated with cooking were considered to be appropriate for the main data collection phase of the project.
Chapter 6. Pilot Study for collection of data from older and disabled people

6.1 Introduction
The data collection phase would involve the collection of physical and task-capability data from older and disabled people, for subsequent inclusion in the computer-based design tool for estimating percentage accommodated. Based on the information gained in the survey of design professionals (Chapter 3), and the survey of older and disabled people (Chapter 5), ideas about the kinds of tasks to be assessed and the data that design professionals require were formulated. The possible methods for collecting such data also needed to be explored. This chapter initially explores the rationale for the data collection phase of the project as a whole, and then describes and discusses the results of the pilot study to evaluate data collection methods, particularly use of a motion-capture system called CODA (Section 6.4).

6.2 Rationale for the data collection phase
The aim of the data collection phase of the project was to obtain data from individuals with a wide range of ages and physical abilities. These data were crucial for the development of the computer-
based design tool to enable estimation of the percentage of people who would be able to use a concept design (see Section 1.4 for further details).

There was much discussion within the project team as to the benefits of collecting ‘traditional’ data (anthropometry, joint constraints, force capabilities, and so on) as opposed to ‘task-specific’ data (data on abilities, postures and behaviours during the completion of specific tasks). It was felt that, whilst ‘traditional’ data are useful in their own right, task-specific data could be more applicable and useful to designers, in order for them to see who succeeds/fails and why, within a given context rather than data of static postures and dimensions. A task-based approach would also reflect the nature of the multivariate ideal of the project (see Section 1.3). It is not just arm length or stature that determines whether a person can use a product or environment successfully, but the person’s postures, behaviours, coping strategies, and so on. All these variables affect the success or failure of a product or environment, and need to be assessed in order to predict accurately who can use a product, who is designed out, and why.

It was felt that analysis of the postures and methods a person used for task completion, in as realistic a context as possible, would yield valuable multivariate information for design professionals. If the tasks chosen contain generic elements that could be applied to different tasks, products and environments, then it was proposed that the designer could apply the knowledge gained from the task-specific data to new situations. However, the tasks considered had to be those that would fit within the constraints of the software being used for the computer-based design tool. The software technology being used was best suited to tasks involving gross movements, that is, those involving the whole body in postural changes, such as bend, reach and lift. Fine manual dexterity manipulations could not be modelled within the ‘virtual’ environment.

In order to construct the physical representation of the individuals in the computer-based design tool, the following data were also required:

- Anthropometric measurements. These data will be used to form three-dimensional human-models of each individual that has been measured. This provides the designer with visual evidence that people are multivariate: no person is any given percentile for more than a couple of dimensions (Roebuck, Kroemer and Thompson, 1975).

- Joint movements and constraints were also to be collected in order to constrain the movements of each individual human-model to further reflect the abilities of the original participant. The
joint constraints and behaviours could be used, together with the anthropometry of the
individual, to provide details of the capabilities of each individual, which the computer
software tool would then use to assess whether each person could interact with a given
product in the required manner.

- Details of how people perform tasks: their posture during tasks, and their overall behaviour as
  they approach and carry out the tasks. This task-specific behavioural and postural information
  will be used in the computer software tool to help predict how a person would interact with
  similar products and environments to those in which the data were collected. It was felt by the
  project team that the tasks studied did not require participants to use maximal strength, reach,
  movements, and so on, but those that they were comfortable using in every day life. It was
  believed that it would be of more value to the designer to know what people would do, not
  what they necessarily could do, if in reality they rarely, if ever, would exert themselves to
  their maximum capabilities.

In order to reflect the nature of the project remit, which was to extend quality life, activities
identified in the survey of older and disabled people (Chapter 5) that were perceived to be
important for independent living were selected for investigation. These tasks were kitchen-based,
specifically reaching items in an oven and in cupboards. These tasks were similar to those studied
by Kirvesöya, Väyrynen and Häikiö (2000) in a study of Finnish older people (Section 4.5.3).
Such tasks as putting items on to different heights of shelves, are specific tasks, yet contain
elements that are generic to other ADL. Reaching, bending and lifting are found in activities such
as shopping in the supermarket, using a washing machine, getting items in and out of a fridge-
freezer, and so on. The design of the rig and method for investigating these activities is described
in Sections 6.10 and 6.12.5.

6.3 Aim of the pilot study
The main aim of the pilot study was to inform the methods and methodology of the main data
collection phase. As such, the objectives were to
- test and assess methods for collection of postural and task-based data (including use of CODA
  and more ‘traditional’ methods)
- test and assess methods for anthropometric data collection
- design and test rigs for collection of reach range and task-specific data
• allow the experimenters to learn and practise the methods and techniques to be used in the main data collection phase.

There were several important decisions that needed to be made regarding the methodologies to be tested in the pilot study. This section briefly details some that were considered, with the relevant literature as appropriate. However, this is not intended to be a comprehensive review of all methods and literature, but simply to cover the main options that were considered.

6.4 CODA

The Cartesian Optoelectronic Dynamic Anthropometer (CODA) motion capture analysis system consists of markers that can be attached on to objects and people (by double-sided sticky-tape, or Velcro). These markers receive and return signals sent from the CODA detectors (housed in the CODA machine), which in turn use the positions of the markers in space to construct images of the movements of the person or object concerned in three-dimensional space. These potentially can be used to collect data on the postures that people adopt when performing tasks, as long as they are wearing markers and these are within view of the CODA system. It was expected that the method could potentially reduce the length of time needed for analysis of the postural data obtained, and to also reduce the time that participants were required.

There are several questions that arise when considering the use of CODA systems to collect data from older and disabled people:
• How easy is the system to use with such participants?
• How effective is marker positioning? Do the markers move with clothing, are they obscured and undetectable at times, is it safe to affix markers to the skin of older and disabled participants?
• Is the use of CODA systems more efficient than using traditional methods of data capture (for example, video capture), in terms of set-up time and data collection time?
• How accurate and useful are data obtained when compared with data obtained (for the same measures) using traditional methods?

In order to clarify these issues it was decided to include assessment of CODA in the pilot study. A list of potential advantages and disadvantages to the use of CODA was also drawn up, and these form the basis for evaluating the results of the pilot trial.
Potential advantages of CODA

- Enables speedy collection of data.
- Enables extrapolation of anthropometry from data collected for reach range and joint constraints, so removing the need to measure anthropometry on the participant separately.
- Reduces the length of time needed for the collection of reach range and joint constraint data due to the fact that the participant can be asked to move and reach without the need for each position to be held whilst an investigator physically measures distances and angles. This potentially reduces fatigue for participants as they do not have to hold and maintain postures.

Potential disadvantages of CODA

- Difficulty with affixing markers to the skin of older and disabled participants.
- Time needed to set-up the participant accurately with markers. A high level of accuracy of marker placement is needed, as placement will affect the quality of the data obtained.
- Potentially two or more CODA machines are needed in order to achieve accuracy and to prevent markers from being lost from view, at a cost of approximately £110,000 for two.
- Markers can be ‘lost’, for example they can go out of the line of sight of the CODA, resulting in gaps in the data.

6.5 Anthropometry

The majority of anthropometry measurements involve determining the distance between ‘external markers’ on the body, using measuring tapes and anthropometers. These external markers often take the form of bony prominences such as the tip of the humerus, the top of the patella, the acromion of the shoulder, and so on. In order to actually construct a realistic and accurate three-dimensional model of a person in the computer environment from measurements, however, it is also necessary to find out the distances between the centres of their joints (link lengths), as well as the external lengths (which are often end-of-bone points).

In this pilot study, both external and link lengths were measured for hip breadth, upper arm length, and shoulder breadth, in order to establish whether the use of regression equations and external measures yielded accurate link length data. It was expected that prominent bony body markers (for external anthropometry) would be fairly easy to locate by manipulation of the joints, whereas in direct link length measures it is more difficult to locate the centre of the joint. Details of the measurements taken are given in Section 6.12.2. Measurements of external anthropometry can be used to estimate joint centre link lengths, by using regression equations that have been calculated...
for the task. These equations involve calculations of link lengths as an adapted percentage of the stature of the person. Regression equations used in this study were devised by:

Reynolds (1978)

white female elbow-shoulder length = 0.1855 stature + 0.771
white male elbow-shoulder length = 0.185 stature + 1.338

and Pheasant (1996)

elbow-shoulder length (male) = 17.4 % of stature
elbow-shoulder length (female) = 17.2 % of stature
hip breadth (male) = 9.9 % of stature
hip breadth (female) = 10.9 % of stature
shoulder breadth (male) = 21.9 % of stature
shoulder breadth (female) = 21.2 % of stature

6.6 Measuring reach envelopes

The pilot study served as a test of the feasibility of the proposed method for collecting reach range data. Such data is of use to designers in allowing them to assess the reach volume of a person, and therefore where elements of the design need to be placed. Three methods for measuring reach envelopes were initially considered for the pilot trial.

Firstly, Wright, Major Kumar and Mittal (1994) assessed reach range in 133 men and women aged between 65 and 89 years of age. A goniometer was used to measure people when sitting, using the dominant arm for all measurements. For vertical reach the arm was held upright and the vertical rod was moved along the radial line until it touched the fingertip. The distance between the rod in this position and the shoulder joint was measured and recorded as the horizontal fingertip reach of the participant at the 0° radial position. This method was then repeated with the arm extended at the 90° radial position. Horizontal grip reach was determined by the vertical rod being gripped by the participant, and the distance between rod and shoulder joint being recorded. Interestingly, their research found that there was no significant difference in horizontal reach
capability in those under the age of 85 and those over 85 years of age, although vertical reach decreased in both men and women over the age of 85 years (the data for youngest and oldest age groups is reproduced in Table 9).

<table>
<thead>
<tr>
<th>Reach angle</th>
<th>Age group</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>0°</td>
<td>65-69 years of age</td>
<td>593</td>
<td>42.1</td>
</tr>
<tr>
<td></td>
<td>85+ years of age</td>
<td>600</td>
<td>25.6</td>
</tr>
<tr>
<td>90°</td>
<td>65-69 years of age</td>
<td>606</td>
<td>40.8</td>
</tr>
<tr>
<td></td>
<td>85+ years of age</td>
<td>610</td>
<td>26.4</td>
</tr>
</tbody>
</table>

Table 9: Horizontal grip reach (mm) for different age groups, at 0° and 90° (data from Wright, Major Kumar & Mittal, 1994)

Secondly, research conducted for a report for the Centre for Accessible Environments (1999) measured the forward reach of 136 wheelchair users and 164 ambulant people. Participants performed comfortable and maximum safe reaches on to a pivoting board positioned horizontally, then at 30°, 70° and -24°. The board was also moved in each position 30° to either side of the vertical. Measurements were taken to the end of the participant's fist, to simulate a useful grip range. The end of the board was positioned at 750 mm from the floor for wheelchair participants, and at 800 mm for standing participants. Wheelchair participants sat so that the front of the chair was level with the end of the board, and standing participants stood so that the front of their body was 50 mm away from the end of the board. Data are presented in the paper in the form of diagrams, allowing only approximate values to be extracted. For comfortable horizontal reach, the research presents that 90% of seated wheelchair users could reach forward 200 mm, with only 10% being able to reach 450 mm. For maximum horizontal reach, 90% of participants could reach 250 mm, with 10% being able to reach 660 mm.

Finally, Molenbroek (1999) also conducted work into reach range, with 627 older adults (aged 50-94 years) and 123 younger adults (aged 20-30 years). Participants were asked to draw arcs on white-boards. These boards were either placed vertically or horizontally, and the person drew their maximum comfortable arc on each, being able to bend from the hips. The knees were kept locked and the buttocks were against a block to provide a reference point. For those aged 75 years and older (the only data given in the paper), the maximum vertical grip reach was divided in to those shorter in stature than 165 cm, and those equal to or taller than 165 cm. For the shorter group, the mean maximum vertical grip reach was 191 cm (standard deviation 8), for those in the taller group, the mean maximum vertical grip reach was 210 cm (standard deviation 7).
The method used by Molenbroek (1998) to study reach could be easily adapted to meet the needs of the data collection pilot study, with white-boards being relatively inexpensive and easy to mark and record results. Due to the fact that some of the participants in the pilot study would be in wheelchairs it was decided to assess all participants sitting down, and to ask participants not to move their spine whilst reaching, in order to record absolute arm reach, independent of spinal and hip flexibility. A more complex apparatus was proposed for the main trial, should the pilot yield useful data.

6.7 Posture analysis

Posture analysis was essential to the assessment of the task-based capabilities of participants from the video recordings. There were four methods for posture analysis that were considered for the pilot trial. Firstly CODA, which has already been discussed in Section 6.4. Secondly, OWAS (Ovako Working Posture Analysis System, Finnish Institute of Health, 1992), which is a code for observed postures that involves assigning numbers to the back, arms, legs, and the load or effort involved in the task. It was reported that, with practise and training, the postures involved in a working task could be assigned, and the amount of time spent in the various postures adopted can be calculated. The categories for the body parts are broad, for example: back straight, back bent forwards/backwards, back twisted/bent sideways, and back bent and twisted or bent forward and sideways, both arms below shoulder level, one arm at/above shoulder level, both arms at/above shoulder level. This allows for quick classification and identification of undesirable working postures, but does not allow for more detailed classification, or the differentiation of, for example, twisted and bent postures, or to which side of the body the twist or bend occurs. For the purpose of development of the design tool, posture analysis would be used to encode postures in the computer-based design tool, so that the computer could predict whether a person could achieve a posture in order to complete a task. More details were also needed, for example, the direction of any bend of the back or the degree of leg bend a person could adopt.

Thirdly, RULA (McAtamney & Corlett, 1993) is a more complicated procedure for assessing posture, force and muscle activity, calculated from observation of the arms, neck, back and legs. The calculations involve assigning numbers to basic body-part positions, and then adding or subtracting according to the angles of body parts, and any bending or twisting of the body. The technique is not as readily usable as the OWAS method, requiring more learning and time to conduct the calculations, although it is possible that this would reduce with practice. The
proposed computer-based design tool did not require information about force and muscle activity, as these could not be encoded in the computer, so such a complex system was not necessary.

Finally, Posture Targetting (Corlett et al, 1979) is a method by which ten areas of the body are used to show the location of the head, trunk, upper and lower limbs with reference to standard positions. Each body area has a target that consists of a set of concentric circles, with each circle indicating a different angle away from the standard posture. Movements in the horizontal plane are shown on radial lines on the target circle. With training, completion of the targets was reported to take approximately 30 seconds, and was believed to be best suited to recording static postures or repetitive actions. It was found that experimenters were able to accurately record static posture from slides after one hour of training. The technique allows more detail and grading of severity of poor postures, but is not as suited to dynamic changing movements of the kind that would be the most relevant data for the proposed computer-based design tool.

Traditional methods of recording postures include taking static photographs (or freeze-frames of video recordings) and measuring angles of deviation of limbs from relaxed positions, from the rear and side planes. These angles can be measured using goniometers. Alternatively subjective methods can be used to assess the posture, either real-time (usually requiring repetitive tasks) or using still camera shots or video recordings.

Posture analysis techniques such as OWAS and RULA are designed for identifying poor working postures, whereas the aim of the data collection research was to provide enough detail to enable the complete posture of the person to be reconstructed, either by another person or by the computer-based design tool. On discussion with the researcher responsible for developing the computer-based design tool, it was decided to adapt the concepts of the OWAS and RULA posture analysis systems, to create one specific to this study. Details of the posture analysis system devised are given in Section 6.13.1.

6.8 Classification of disability
The assessment of severity of disability was largely to assist with sampling, and to ensure as wide a range of severity of disability as possible within the sample. The Office of Population Censuses and Surveys (OPCS) method for classifying disability (Martin, Meltzer & Elliot, 1994) is covered in Section 4.3.2. After discussion with the project team it was felt that the OPCS scheme could be adapted to assess the severity of disability of participants during the main data collection phase.
Due to the types of activities being investigated, it was not necessary or beneficial to use the whole OPCS scale. Items such as continence, hearing, communication, intellectual functioning, consciousness, digestion, and disfigurement, were less applicable to the ADL tasks that participants would be asked to complete as part of the data collection phases. Ethical concerns may also have arisen over participants being made to feel uncomfortable by the intimate nature of some of the questions. Therefore, only questions regarding locomotion, reaching and stretching, dexterity, and personal care were selected for inclusion in this study.

Due to the adapted OPCS system only using four of the possible sections to classify severity of disability, the maximum weighted score was only 18.55, severity of 9. This was less than the maximum severity score of 10 obtainable using the full OPCS scoring system, and for this reason it was necessary to adapt the scoring system to take into account the use of fewer sections. A new category system for finding the severity scores from the weighted scores, with increments of equal amount between each category, was devised, as follows:

Severity score = weighted score range
10 = 16.696 to 18.55 (most severe)
9 = 14.85 to 16.695
8 = 12.986 to 14.84
7 = 11.14 to 12.985
6 = 9.276 to 11.13
5 = 7.43 to 9.275
4 = 5.566 to 7.42
3 = 3.72 to 5.565
2 = 1.86 to 3.71
1 = 0.5 to 1.85 (least severe)

The OPCS scales were used to draw up a questionnaire to be administered to all participants. The questions were designed to estimate severity of disability of the participants based on the scoring statements used in the OPCS system. Scores were then used to assign severity. The list of statements that participants were assessed against is given in Appendix 2.

Following the investigation into literature and existing methodologies, rigs for collection of reach range and task-based data were designed and constructed, and methods for assessing severity score, posture analysis and anthropometry were devised. In order to test and evaluate these, to inform the design of the main data collection phase, a pilot study was conducted.
6.9 Participants

The data collection pilot study involved eight participants. Given that the main data collection phase would involve older people, disabled people, and able-bodied people, it was decided to recruit: 2 older people (63 years upwards), one man, one woman; 2 people in wheelchairs, one man, one woman; 2 ambulant disabled people (able to walk with assistance but not reliant on a wheelchair), one man, one woman; and 2 able-bodied people, one man, one woman.

Participants were recruited from advertisements put out over the Loughborough University website notice-board page, and by re-contacting people who had previously taken part in the survey of older and disabled people. Participants were paid for giving up their time to take part in the study, and reimbursed if they had needed to get a taxi to the location where the trials were run.

Due to the nature of some of the disabilities that participants could have, it was felt that it was vital to keep the length of participation to a maximum of two hours. It was expected that this would minimise the amount of possible strain and fatigue that the participants would experience.

6.10 Equipment

Equipment used included:

- A Harpenden anthropometer - for the anthropometric measurements, in conjunction with a standard cloth tape measure and a 30 cm plastic ruler.
- Stadiometer and sitting-height table for anthropometric measurements.
- A Baseline goniometer - used for the measurement of joint angles.
- A kitchen rig mock-up, consisting of two IKEA “IVAR” shelving units, placed back-to-back and fixed in position using masking tape (see Figure 16). The open shelves were set at heights equivalent too the lowest shelf of an oven (14 cm high), standard work-surface height (90 cm high, BSEN1116, 1996), and the lowest shelf of a kitchen wall cupboard (60 cm high, BSEN1116, 1996) and 89 cm wide (see Section 6.12.5 for details of the use of this equipment).
- A plastic beaker and baking tray - used to contain the weights used for the lifting and placing tasks, and weighted using bags of rice (see Section 6.12.5).
- Two CODA MPX 30 motion capture systems (see Figure 17), along with the relevant connections to a standard personal computer, and the markers and receivers for the CODA to detect. The equipment was on loan for the duration of the study. The markers and receivers were affixed to participants using household double-sided sticky-tape.
- A 6' by 4' white-board for obtaining reach contours, by seating participants adjacent to the board leant against a wall, and marked using four coloured white-board pens.

Figure 16: Photograph showing the ‘kitchen’ rig, with the shelves set at heights applicable to the bottom shelf of a wall cupboard (60 cm), a work surface (90 cm), and the bottom shelf of an under-surface unit (14 cm).

Figure 17: Photograph showing set-up of the CODA systems within the trials room: one was placed on a tripod, the other on a table. Participants were stood facing one machine, with the other perpendicular.
6.11 Ethical issues

Milgram (1963) showed that in a laboratory situation people may feel that they must do what they are told to do, even if they object to the task they are being asked to complete. This work found that people would administer what they thought to be lethal-level electrical shocks to others. The participants were seen to be genuinely distressed by the fate of the person they thought they were shocking, but all still obeyed the experimenter and continued to administer the shocks (in reality the person was not being shocked at all, but was played by an actor instructed to react as if in pain). This and subsequent trials have shown that people will go to extreme lengths if a person seen to be in authority (in this case, the experimenter) instructs them to do so. For this reason it is very important to ensure that the participant does not feel pressurised to do anything that they are not happy to do. In the context of the proposed research, given that older and disabled people may have conditions that make some movements uncomfortable or painful, either immediately or as the result of subsequent irritation or swelling, extra care must be taken to prevent participants attempting activities that will cause such pain.

The proposed pilot study will concern ADL, which by their very nature should be performed on a daily basis. As such, participants were asked not to attempt any activities that they had never done before or that they had ceased to do due to pain and discomfort. Participants were free to stop any activity at any time without giving any reason, and were reminded of this throughout the experiment. Participants were also informed that they could miss out any parts of the study that they did not wish to attempt, and the experimenters did ask participants if they wished to stop if at any time they appeared to be struggling, tiring or in pain. The experimental activities were designed to identify areas of difficulty with activities of everyday life without participants being placed under unnecessary stress to complete them.

This study required that ethical approval was obtained from the university, and the submission of the relevant forms and details was undertaken. The research was approved and the forms, along with details of actions taken to reduce the likelihood of ethical problems, are contained in Appendix 3.

6.12 Procedure

6.12.1 Greeting and questionnaire

On arrival participants were greeted and given an information sheet detailing what would happen in the trial, and containing contact details for future reference (see Appendix 4). Participants were
then asked to read and sign the consent form. They were also asked to consider the optional
consent form concerning use of photographic material in public outputs (Appendix 4). The OPCS
scales discussed in Section 6.8 were used to draw up a questionnaire, which was then
administered. This questionnaire also included personal information, history of any disability, and
recording of responses to questions regarding tasks, such as ability to get up from lying down,
reach to tie shoelaces, and bending to touch toes (see Appendix 4).

6.12.2 Anthropometry and joint constraints

Participants were weighed using standard bathroom scales (or asked if they knew their weight if
they were unable to stand on the scales). Anthropometric measurements were then taken using
standard methods and postures, as detailed in Table 10. However, in practice participants were
measured in whatever posture that they could attain that was similar to the standard posture for
that measurement. It was decided that these data would provide a more realistic idea of the
person’s normal posture and capabilities. The definitions of the measurements are taken from
Pheasant (1990), Dempster (1955) and Gray (1995). The methods used to locate estimated joint
centres were determined using the work of Dempster (1955), and these in turn give measures of
‘link length’.

Table 10: Anthropometric measurements taken, equipment used, and the method used for taking
the measurement.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Equipment</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature</td>
<td>Stadiometer</td>
<td>Measured vertically from the floor to the top of the head (no shoes). The person stands erect, looking ahead, arms hanging loosely at the sides.</td>
</tr>
<tr>
<td>Arm length</td>
<td>Tape measure</td>
<td>Measured horizontally from the acromion to the tip of the middle finger. The arm is straight with palm vertical.</td>
</tr>
<tr>
<td>Upper arm length</td>
<td>Anthropometer</td>
<td>Measured from the acromion to the tip of the elbow. Person stands erect, one hand on hip, thumb towards the back, fingers in front. Wrist kept in a straight line with the forearm.</td>
</tr>
<tr>
<td>L/R (external measure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elbow to shoulder</td>
<td>Anthropometer</td>
<td>Measured from the mid region of the palpable bony mass of the head and tuberosities of the humerus to the midpoint of a line between the lowest palpable point of the medial epicondyle of the humerus and a point 8mm above the radiale (radio-humeral junction). Person stands erect, one hand on hip, thumb towards the back, fingers in front. Wrist kept in a straight line with the forearm.</td>
</tr>
<tr>
<td>L/R (link length)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

129
<table>
<thead>
<tr>
<th>Measure</th>
<th>Equipment</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure</td>
<td>Equipment</td>
<td>Method</td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Chest height</td>
<td>Anthropometer</td>
<td>Measured vertically from the seat surface to the height of the nipple in a male subject, and to the height of the bust point (tip of bra) in a female subject.</td>
</tr>
<tr>
<td>Chest depth</td>
<td>Anthropometer</td>
<td>Measured horizontally from the rear vertical plane to the nipple. The measurement is taken after exhalation.</td>
</tr>
<tr>
<td>Head height</td>
<td>Anthropometer</td>
<td>Measured vertically from the bony tip of the chin to the top of the head.</td>
</tr>
<tr>
<td>Eye to top of head</td>
<td>Anthropometer</td>
<td>Measured vertically from the outer border of the eye socket to the top of the head.</td>
</tr>
<tr>
<td>Buttock knee length</td>
<td>Anthropometer</td>
<td>Measured horizontally from the most posterior part of the buttock to the front of the knee. The person sits erect with thighs horizontal and lower legs vertical.</td>
</tr>
<tr>
<td>Abdominal depth</td>
<td>Anthropometer</td>
<td>Measured horizontally from the rear vertical plane to the maximum protrusion on the front of the relaxed lower abdomen. The person sits erect, arms hanging loosely at the sides.</td>
</tr>
<tr>
<td>Thigh depth - sitting</td>
<td>Anthropometer</td>
<td>Measured vertically from the seat surface to the upper, uncompressed, surface of the thigh where the thigh depth is greatest. Thighs are horizontal.</td>
</tr>
<tr>
<td>Knee height</td>
<td>Anthropometer</td>
<td>Measured vertically from the floor to the top of the knee.</td>
</tr>
<tr>
<td>Shoulder breadth (external measures)</td>
<td>Anthropometer</td>
<td>Measured, from behind, horizontally between the mid region of the palpable bony mass of the head and tuberosities of the humerus. The person stands erect, arms at the sides and shoulders relaxed.</td>
</tr>
<tr>
<td>Shoulder breadth (link length)</td>
<td>Anthropometer</td>
<td>Measured, from behind, horizontally between the acromial processes. The person stands erect, arms at the sides and shoulders relaxed.</td>
</tr>
<tr>
<td>Hip breadth (link length)</td>
<td>Anthropometer</td>
<td>Measured horizontally between the maximum projections of the greater trochanters at the head of the femur. To ensure a bony measurement is obtained, pressure is applied to the soft tissues covering the trochanters. The person stands erect, looking ahead, arms hanging loosely at the sides.</td>
</tr>
<tr>
<td>Hand length L/R (link length)</td>
<td>Ruler</td>
<td>Measured from the wrist crease directly below the pad of muscle at the base of the thumb (thenar eminence) to the tip of the middle finger. The hand and fingers should be held straight and flat.</td>
</tr>
<tr>
<td>Hand grip length L/R</td>
<td>Ruler</td>
<td>Measured from the wrist crease directly below the pad of muscle at the base of the thumb (thenar eminence) to the centre of a rod gripped in the hand.</td>
</tr>
</tbody>
</table>
Joint constraint measurements were taken using a goniometer (details given in Table 11). Participants were asked to move their arm joints (shoulder, elbow, and wrist) to the maximum that they could comfortably achieve, and not to force any joints. Measurements taken were tailored according to the individual and, as stated previously, any movements that were impossible or that the participant did not wish to attempt were not included.

Table 11: Joint constraints measured using a goniometer, and the method of measurement.

<table>
<thead>
<tr>
<th>Joint</th>
<th>Angles</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder</td>
<td>Extension /</td>
<td>Person sits erect with shoulders relaxed and the arm by the side and</td>
</tr>
<tr>
<td></td>
<td>flexion</td>
<td>fingers pointed. For extension the shoulder is raised, for flexion the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>shoulder is lowered. Measured at the midpoint of the palpable junction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>between the proximal end of the clavicle and the sternum at the upper</td>
</tr>
<tr>
<td></td>
<td></td>
<td>border (jugular notch) of the sternum.</td>
</tr>
<tr>
<td>Shoulder</td>
<td>Abduction /</td>
<td>Person sits erect with shoulders relaxed and the arm by the side and</td>
</tr>
<tr>
<td></td>
<td>adduction</td>
<td>fingers pointed. For abduction the shoulder is moved backward, for</td>
</tr>
<tr>
<td></td>
<td></td>
<td>adduction the shoulder is moved forward. Measured as the deviation of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>the midline of the shoulder.</td>
</tr>
<tr>
<td>Upper arm (Glenohumeral)</td>
<td>Extension /</td>
<td>Person stands erect with the arm by the side and fingers pointed. For</td>
</tr>
<tr>
<td></td>
<td>flexion</td>
<td>flexion the arm is moved forward, for extension the arm is moved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>backward. Measured at the mid region of the palpable bony mass of the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>head and tuberosities of the humerus.</td>
</tr>
<tr>
<td>Upper arm (Glenohumeral)</td>
<td>Abduction /</td>
<td>Person stands erect with the arm by the side and fingers pointed. For</td>
</tr>
<tr>
<td></td>
<td>adduction</td>
<td>abduction the arm is moved away from the body, for adduction the arm is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>moved across the body. Measured at the mid region of the palpable bony</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mass of the head and tuberosities of the humerus.</td>
</tr>
<tr>
<td>Upper arm (Glenohumeral)</td>
<td>Medial /</td>
<td>Person stands with the upper arm by the side, elbow flexed to 90°</td>
</tr>
<tr>
<td></td>
<td>lateral</td>
<td>parallel to the sagittal plane of the body. For lateral rotation the</td>
</tr>
<tr>
<td></td>
<td>rotation</td>
<td>arm is rotated away from the body, for medial rotation the arm is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rotated into the body.</td>
</tr>
<tr>
<td>Elbow</td>
<td>Flexion /</td>
<td>Upper arm is supported with the lower arm and hand horizontal, palm up.</td>
</tr>
<tr>
<td></td>
<td>extension</td>
<td>For flexion the lower arm is bent upward, for extension the lower arm is</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bent downward.</td>
</tr>
<tr>
<td>Elbow</td>
<td>Pronation /</td>
<td>Forearm and hand are supported with the hand in a thumb-up neutral</td>
</tr>
<tr>
<td></td>
<td>Supination</td>
<td>position. For supination the hand is rotated outward, for pronation the</td>
</tr>
<tr>
<td></td>
<td></td>
<td>hand is rotated inward.</td>
</tr>
<tr>
<td>Wrist</td>
<td>Extension /</td>
<td>Forearm is supported with the hand horizontal, palm down. For</td>
</tr>
<tr>
<td></td>
<td>flexion</td>
<td>extension the hand is bent upward, for flexion the hand is bent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>downward.</td>
</tr>
<tr>
<td>Wrist</td>
<td>Abduction /</td>
<td>Forearm is supported with the hand horizontal, palm down. For</td>
</tr>
<tr>
<td></td>
<td>adduction</td>
<td>abduction the hand is moved inward, for adduction the hand is moved</td>
</tr>
<tr>
<td></td>
<td></td>
<td>outward.</td>
</tr>
</tbody>
</table>
6.12.3 Reach range

Reach range was measured using an adapted version of the equipment used by Molenbroek (1998). It involved a vertical white-board, with participants seated on a chair that was moved so as to position their right shoulder at 0°, 30°, 60° and 90° to the board (Figure 18). Participants were asked to keep their upper body still and not to lean forward, so that the only movement came from the shoulder joint as the reach arcs were drawn. The shoulder was used as the reference point. Seated participants were asked to grip a marker pen so that the nib pointed out of the back of the grip. They then drew arcs of comfortable grip-reach on the board, and repeated the process with the chair at each of the four positions. Only one arm (the right one) was used for the reach task, to reduce time and also due to limitations in the equipment available.

![Figure 18: Reach measurements being drawn on the white board by a participant, shown in the 90° position](image)

6.12.4 CODA measurements

The participant was then marked-up for the CODA phase. This involved the markers that the CODA systems detect being stuck onto the person’s clothing, by means of double-sided sticky tape. After discussion with previous users of the CODA system, and observation of other researchers using the system, the CODA markers were placed on external anthropometric locations. The position of the markers on the sternum and on both sides of the body is shown in Figure 19. The two CODA systems were set up at 90° to each other, in order to provide coverage of the front and side of the participants, and to try and minimise the occurrence of markers being
The participant was first asked to wave a marker located on a pen (for ease of grip) as if they were washing a large window, with sweeping movements which equated to their grip reach envelope, for between 20 and 40 seconds. They were asked not to bend their back or knees during this process, in order to reflect the posture adopted in the measurements of reach range using the white-board.

Participants were then asked to repeat the maximum comfortable joint movements for the shoulder, wrist and arm for the measurement of joint constraints, although this time they did not have to hold the posture whilst the measurements were taken. Data for joint constraints were collected in 5-second periods, performed in their natural pairs, as detailed in Table 11. For example, abduction and adduction of the wrist were performed consecutively, in the same 5-second data collection period.

![Figure 19: Position of CODA markers on the body of participants.](image)

**6.12.5 Task-based data collection**

Finally, a marker was affixed to the side of the kitchen rig so that its position could be detected by the CODA. Participants were first given an empty plastic beaker (with markers affixed), and
asked to place it, using one hand but in any way they felt comfortable doing, on the middle shelf, bottom shelf and top shelf of the kitchen rig (Figure 16). As participants performed these tasks the CODA systems acquired the movement data. The process was then repeated using the beaker with rice in it, weighted equivalent to a small can of beans (125 g); and then repeated using both hands to hold a baking tray weighted with rice to be the same as a tray of oven chips (250 g). These weights were used to simulate the weights encountered and lifted in "everyday life", not to test the person's maximum capabilities.

Participants were asked to approach tasks in any way that they wanted as if they were at home. They could sit, stand or lean, whichever was relevant to the way they would normally do such tasks. A wheeled kitchen trolley was available for those who normally used one. Participants were also videotaped as they carried out these task-based activities, as an alternative method of recording and analysing postural and behavioural information.

6.13 Data Analysis

It must first be noted that very few useful data were obtained from the CODA analysis. It is thought that this was due to markers going out of view (so making readings impossible) and also due to reflections and interference (which were not predicted before the trials took place). The reflections might have been due to lighting in the room, exacerbated by the metal on crutches and wheelchairs. It was not possible to cover all the metal without hindering the participant using these mobility aids. For these reasons, comparison of the CODA data and data collected using traditional means has been difficult, and in many cases impossible.

6.13.1. Posture analysis and task-based activities

Due to the lack of CODA data it was not possible to conduct any postural analysis. Not enough data from the markers on the body parts were available to construct an image of the person in any static posture, let alone when changing posture and moving. Instead, using the system based on OWAS and RULA (Section 6.7), posture analysis was conducted by watching the videotapes of participants performing the task-based activities. Several iterations of possible coding systems were developed, with two experimenters coding ten participants in order to determine the ease of use of the coding system, to highlight any ambiguous postures or codes, and to allow assessment of inter-rater reliability for the coding system. The postures were obtained by studying videotapes taken at right-angles to, and behind the participants during the kitchen tasks. At the point of completion of a task, for example the point at which a two-handed weight was put on to the top
shelf, the video was paused and the posture recorded. In this way the different postures obtained on completion of each task were recorded for each participant. The method involved assigning numbers to different body parts: the head, the legs, the back, whilst also including assignment for details of neck and body twist, degree of leg and back bend, the position of the target relative to the body, and the alignment of the person relative to the target (Appendix 4). This resulted in a list of numbers to indicate the positions of the various body parts, enabling the person’s posture to be re-enacted by the computer-based design tool, and therefore used in the computer-based estimation of what that individual could do.

6.13.2 Anthropometry
The CODA data for anthropometry were calculated for each participant by examining the graphs of the distances between marker positions, for example, the distance between the markers on the right ankle and the right knee, to give the ankle to knee length. However, for each participant there were six files of data (this is how it was saved by the CODA system), all of which contained different actual figures for the distances between markers. It would have taken considerable time to extract all of the distances: it took nearly two hours to extract all these data for one participant. Also, it became evident that there was no way of knowing which reading to compare to the traditional data; multiple readings on the same dimension were available for each participant and the variations in measurements proved to be so large as to make the data rather ridiculous.

External anthropometry, as well as estimated joint centre-joint centre lengths (link lengths), were collected from all participants for upper arm length, shoulder breadth and hip breadth. The direct external anthropometry was then subjected to the relevant regression equations (Pheasant, 1996 and Reynolds, 1978; see Section 6.5). Measures of direct internal link length anthropometry, and predicted internal link length anthropometry were compared by means of t-tests. In this way it was possible to assess which method of collecting link length data would be most useful for the main data collection phase.

6.13.3 Reach range
It was not possible to extract any useful reach range measures from the CODA system, due to missing data caused by markers going out of view and being ‘lost’. Figures 20 and 21 illustrate the problem of the data obtained from CODA: the grey lines indicate missing data, the black lines are data where all markers were in view and recorded. Figures 20 and 21 show data for one participant, during the reach phase of the data collection, when only markers on the shoulder,
elbow, wrist, fingertip, and pen were analysed. In Figure 20, the dark line indicates that two markers were in view (one at either end of the black line drawn), in Figure 21 three markers were visible (at each end of the black line, and at the apex of the line). The computer software that CODA uses attempts to 'extrapolate' the possible position of the 'lost' markers, hence the grey lines joining 'guessed' markers' positions. Attempting to extract a measure of dynamic reach range from images such as this is impossible, due to the fact that there simply is little or no actual data available.

Figure 20: Image of visible (black lines) and 'guessed' (grey lines) data from CODA software (1)

Figure 21: Image of visible (black lines) and 'guessed' (grey lines) data from CODA software (2)
6.13.4 Joint angles

Study of the data acquired by the CODA systems for joint constraints only yielded useable data for a very small number of participants (between 13% and 50% of participants for the different joint angles measured, see Table 15, Section 6.14.4). Due to the difficulties encountered with extracting joint constraint data from the CODA system, a statistical comparison of these data with those collected using traditional methods was not possible.

6.14 Results

The pilot study took place in February 2001. The results are presented according to the different parts of the trial: anthropometry (external, internal, predicted internal), joint constraints, and posture analysis.

6.14.1 Participants

Participants are described in Table 12.

<table>
<thead>
<tr>
<th>Subject number</th>
<th>Gender</th>
<th>Age</th>
<th>Mode of Locomotion</th>
<th>History of Disability</th>
<th>Severity score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Female</td>
<td>72</td>
<td>Ambulant (aid of stick/frame)</td>
<td>Polio as child, stroke in 1998</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
<td>42</td>
<td>Wheelchair dependent</td>
<td>Multiple sclerosis since 1989</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>33</td>
<td>No disability</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Female</td>
<td>74</td>
<td>No disability</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
<td>77</td>
<td>No disability</td>
<td>N/A</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
<td>41</td>
<td>Ambulant (aid of stick/frame)</td>
<td>Multiple sclerosis since 1990</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Male</td>
<td>28</td>
<td>Wheelchair dependent</td>
<td>Folic acid deficiency</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Female</td>
<td>22</td>
<td>No disability</td>
<td>N/A</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 12: Descriptive data for participants (n=8)

6.14.2 Anthropometry

Table 13 shows the anthropometric data obtained for a typical participant (Participant 1), and compares that for ‘direct measures’ using anthropometers and measuring tapes, and ‘CODA measures’, where the data were obtained from the CODA system. Due to positioning of the markers, measurements using the CODA were not available for stature, abdominal depth (standing and sitting), thigh depth (standing and sitting), ankle height, foot length, sitting height, sitting shoulder height, head height, eye-to-top-of-head, chest height, chest depth, buttock-knee length, knee height, arm length and hand grip length. All data obtained from the CODA analysis are
included in Table 13 to allow for visual comparison of all available data. The percentages presented represent the amount of time the CODA markers were in view, and are presented in brackets in the same order as the dimension name. For example, for shoulder-elbow, the percentage for the shoulder marker is given first, then the percentage for the elbow marker. The percentage time that markers were in view ranges from 0% (marker never in view, no distance graph can be calculated from such data) to 100% (marker in view at all times). A distance calculated from two markers, neither of which was in view for the whole data collection period, will not be as accurate as a reading from two markers that were in view for the whole time.

It can be seen that there is little or no useful comparison to be made between data obtained using traditional measures and data collected using CODA analysis. Examples of the gross inaccuracies (taken from Table 13) are the extremes of the measurements reported for shoulder-to-elbow length: the measurement obtained using an anthropometer was 270 mm, whilst the CODA system yielded measurements ranging from 54.07 mm to 5154 mm. The variation between data obtained from CODA and by use of anthropometers, and within CODA data, suggests that the use of the CODA systems in these circumstances was not useful or sensible.
<table>
<thead>
<tr>
<th>Measure</th>
<th>Traditional methods (mm)</th>
<th>CODA measures (mm) (measurement, % time 1st marker in view, % time 2nd marker in view)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder to elbow (acromion to wrist crease)</td>
<td>270</td>
<td>188.74 (36% 2%) 5154.70 (33% 23%) 54.07 (59% 100%) 221.34 (2% 7%) 538.75 (30% 35%) 207.04 (47% 74%)</td>
</tr>
<tr>
<td>Elbow to wrist (R) (point of humerus to wrist crease)</td>
<td>225</td>
<td>275.08 (17% 18%) 23174.07 (23% 7%) 272.9 (100% 0%) 284.66 (7% 82%) 911.68 (35% 33%) 86.97 (74% 12%)</td>
</tr>
<tr>
<td>Knee to hip (internal link length)</td>
<td>420</td>
<td>470.44 (48% 23%) 295.77 (57% 61%) 538.71 (100% 0%) 73.58 (7% 1%) 789.73 (30% 16%)</td>
</tr>
<tr>
<td>Ankle to knee (internal link length)</td>
<td>324</td>
<td>78.63 (55% 70%) 293.01 (8% 57%) 377.82 (100% 100%) 54.18 (100% 7%) 507.96 (72% 30%) 101.80 (22% 0%)</td>
</tr>
<tr>
<td>Hip to shoulder (internal link length)</td>
<td>364</td>
<td>446.48 (23% 24%) 655.54 (16% 30%) 38.96 (9% 47%) 534.59 (1% 33%)</td>
</tr>
<tr>
<td>Hand length (tip of middle finger to wrist crease)</td>
<td>195</td>
<td>8381.73 (17% 17%) 750.24 (33% 32%) 702.25 (7% 20%) 48.46 (0% 0%) 839.56 (82% 31%)</td>
</tr>
</tbody>
</table>

Table 13: Comparison of the anthropometric data collected from Participant 1 using traditional methods and using CODA (n=1).

6.14.3 Comparison of external anthropometric measures, and measured and calculated link lengths

The regression equations described in Section 6.5 were applied to the external anthropometry data in order to give predicted internal measurements. These were then compared with the direct measurements of internal link lengths. T-tests were conducted to compare the predicted internal measures (Pheasant, 1996 and Reynolds, 1978) with direct internal measurements. Table 14 shows the mean and standard deviation values for the different methods. It can be seen that only
hip breadth produced a statistically significant difference when direct internal measurements were compared to the predicted internal measurements using Pheasant’s (1996) regression equations.

<table>
<thead>
<tr>
<th></th>
<th>Direct internal</th>
<th>Predicted internal (Pheasant, 1996)</th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Shoulder-elbow (L)</td>
<td>6</td>
<td>300</td>
<td>18</td>
</tr>
<tr>
<td>Shoulder-elbow (R)</td>
<td>5</td>
<td>288</td>
<td>24</td>
</tr>
<tr>
<td>Shoulder breadth</td>
<td>6</td>
<td>321</td>
<td>33</td>
</tr>
<tr>
<td>Hip breadth</td>
<td>6</td>
<td>305</td>
<td>39</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Direct internal</th>
<th>Predicted internal (Reynolds, 1978)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Shoulder-elbow (L)</td>
<td>6</td>
<td>300</td>
</tr>
<tr>
<td>Shoulder-elbow (R)</td>
<td>5</td>
<td>288</td>
</tr>
</tbody>
</table>

Table 14: Comparison of direct internal and predicted internal anthropometry measurements: mean, standard deviation, and significant differences, where N is the number of participants measured (* = significant at the 0.05 level, ** = significant at the 0.02 level)

6.14.4 Joint constraints

As already discussed, data obtained from CODA were sparse due to lost markers and interference. From the data available it was only possible to extract 22 joint constraint readings for the eight participants, when 112 readings were expected (Table 15). No readings at all were obtained for measures of shoulder abduction, shoulder adduction, elbow pronation or elbow supination, due to the nature of the movement (for example, joint twisting motions) and the positioning of the markers on the body.

It can be seen from Table 15 that CODA only yielded one measurement for the majority of the joint constraint angles, and the maximum number of measurements obtainable were for elbow flexion for four out of the eight participants. This lack of data means that no meaningful statistical comparison of data from CODA and traditional methods could be made.
Table 15: Joint constraint angles obtained using CODA and traditional means (n=8).

<table>
<thead>
<tr>
<th>Participant</th>
<th>Shoulder extension</th>
<th>Shoulder flexion</th>
<th>Upper-arm extension</th>
<th>Upper-arm flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CODA</td>
<td>Traditional</td>
<td>CODA</td>
<td>Traditional</td>
</tr>
<tr>
<td>1</td>
<td>26</td>
<td>25</td>
<td>8</td>
<td>34</td>
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<tr>
<td>2</td>
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<td>41</td>
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</tr>
<tr>
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</tr>
<tr>
<td>8</td>
<td>18</td>
<td>18</td>
<td>6</td>
<td>54</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Upper-arm abduction</th>
<th>Upper-arm adduction</th>
<th>Upper-arm medial rotation</th>
<th>Upper-arm lateral rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODA</td>
<td>Traditional</td>
<td>CODA</td>
<td>Traditional</td>
</tr>
<tr>
<td>1</td>
<td>100</td>
<td>55</td>
<td>47</td>
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<tr>
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<tr>
<td>8</td>
<td>156</td>
<td>16</td>
<td>24</td>
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</table>

<table>
<thead>
<tr>
<th>Elbow extension</th>
<th>Elbow flexion</th>
<th>Wrist extension</th>
<th>Wrist flexion</th>
</tr>
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<tbody>
<tr>
<td>CODA</td>
<td>Traditional</td>
<td>CODA</td>
<td>Traditional</td>
</tr>
<tr>
<td>1</td>
<td>10</td>
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<td>74</td>
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<td>0</td>
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<td>165</td>
<td>85</td>
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<tr>
<td>8</td>
<td>4</td>
<td>135</td>
<td>148</td>
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<table>
<thead>
<tr>
<th>Wrist abduction</th>
<th>Wrist adduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>CODA</td>
<td>Traditional</td>
</tr>
<tr>
<td>1</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
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<td>23</td>
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<td>8</td>
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</tbody>
</table>

6.15 Discussion

The findings of the data collection pilot study and the implications for the main data collection phase are discussed in this section. They will inform the methods, equipment and procedures to be used for the collection of data in the main data collection phase. The discussion is divided according to the different methods investigated.
6.15.1 CODA

The potential advantages and disadvantages to using CODA (Section 6.4) are shown below in italics, with comments to qualify or refute each as a result of the pilot study.

Potential advantages

- Enables speedy collection of data. Collection was certainly faster using CODA compared with traditional methods, but was not instantly usable and understandable. Considerable further work was needed to remove extraneous data, and sort through the inaccuracies caused by the covering of markers and reflections of marker signals. Lost signals resulted in the loss of much data. Whilst useful data were collected for joint constraints for some participants on some angles (for example, participants 2, 3, 4, and 8 for elbow flexion, and participant 8 for shoulder flexion), no useful information on postures and behaviours was extractable, due to considerable disruption of the signals.

- Enables extrapolation of anthropometry from data collected for reach range and joint constraints so removing the need to measure anthropometry on the participant separately. Joint constraints that involved rotation (upper-arm medial rotation and upper-arm lateral rotation) could not be extracted, due to the positioning of the markers. It is possible that using additional markers could be a solution to this problem. Joint constraints not involving rotation were obtainable, but only for participants where markers had not been obscured or other interference had not occurred. Which participants and which joint constraints it was possible to extract varied, as can be seen in Table 15. It was theoretically possible to extract anthropometry measures from CODA data but, as with the collection of other data by CODA, anthropometry measurements could only be extracted where markers had not been obscured or ‘lost’.

- Reduces the length of time needed for collection of reach range and joint constraint data due to the fact that the participant can be asked to move and reach, without the need for each position to be held whilst an investigator physically measures distances and angles. This reduces the fatigue for participants as they do not have to maintain postures. The use of CODA does not require participants to remain stationary in a posture for the time necessary to use a goniometer for measuring joint constraints. CODA could also reduce the number of movements required if anthropometric data could be collected from general motion without the need for standardised movements. However, given the relatively small amount of useful data that was extracted, it would still be necessary to use traditional methods in order to fill in any gaps that emerge in the CODA data, so that any benefit in a the shorter duration is
effectively lost. It also requires several hours to extract the relevant co-ordinates from the data files in order to construct a diagram of the reach range for each participant.

Potential disadvantages

- **Difficulty with affixing markers to skin of older and disabled participants.** This was not an issue in this pilot as no participants were suffering from any skin disorder, or on any medication that resulted in fragile, thinning skin. All could therefore have markers attached to the skin if necessary. As a precaution, all participants were asked to wear long-sleeved tops in order to reduce the number of markers affixed directly to the skin. Also, some cotton gloves and tubigrip bandages were available should a person have needed a barrier between the marker and their skin. However, these were not tested in the pilot. In summary there were no difficulties found with affixing markers to the skin or clothing of the participants in this pilot study.

- **The number of CODAs needed in order to achieve accuracy and to prevent markers from being lost from view.** With two CODAs many markers were still out of view for a significant amount of time, reducing the usefulness of the data collected. It may be that three CODAs would reduce ‘lost’ markers, but this would have huge cost implications.

- **The fact that markers can be ‘lost’ if they go out of the line of sight of the CODA, resulting in gaps in the data.** This did cause many problems, as did reflection of the marker signals causing spurious marker readings, and possible interference from other equipment within the building.

- **The level of accuracy of marker placement that is needed may result in a long time being needed for placement of markers, and inaccurate placement will affect accuracy of the data obtained.** It was certainly difficult to be sure that a marker was placed correctly, and more importantly, that it would stay there when the person moved. This was an issue, as it is difficult to position markers accurately, and if they are attached to clothing then they may move in a slightly different way to the person within the clothing. The type of clothing may also have an effect; wearing a loose jumper or thick trousers may make marker positioning less accurate, and more prone to moving, than wearing tight-fitting clothing. Also, the positioning of markers may need to be a compromise between accurate limb and joint centre locations, and positions where the markers will be most visible to the CODAs. In some cases a marker positioned accurately is obscured by other body parts, rendering the accurate placement irrelevant as the marker is rarely detected. The length of time needed to set-up the
participant with markers did not prove to be a major problem, and the time reduced with practice.

One of the objectives of the pilot study was to assess the use of CODA as a suitable data collection method for a trial involving 100 older and disabled people. On a practical level the two CODA systems cost approximately £110,000, and were extremely delicate to transport. Preparation took approximately one hour, from arriving at the location, unpacking the CODAs, setting them up, and configuring them and the software ready for readings to be taken. Advice was taken from expert users of CODA as to the set up of the room, and it was advised that minimum lighting be used. This study aimed to collect data from performance of complex tasks, with movements in different planes, and it was hoped that two CODAs would be enough to capture all the necessary information. However, from the findings of this pilot study it is felt that at least three CODAs would be required to collect all the data required and reduce the number of lost marker readings. The room used for trials would need to be set up specifically for the trials, with low lighting (as recommended), no reflective surfaces (which may be difficult, given the metal surfaces of wheelchairs, crutches, and so on), and correct positioning of three CODA systems to collect all the required data. It is felt that a period of time would be needed to experiment with the room setup and the CODAs prior to any participants arriving. None of this was possible as the CODAs were not readily available for large periods of time, and there was no dedicated room available for an extended period suitable for the trials (with wheelchair access, near an accessible toilet, parking nearby, correct lighting, and so on).

The accuracy of the CODA readings compared to the using traditional methods is impossible to ascertain, due to movement of markers and loss of data, however if CODA data could be obtained, it may prove to be highly accurate. CODA has the potential of being extremely quick and useful for collecting data; the time to set up is considerably longer than with traditional methods, but if a set-up can be left for the duration of the trials then this is not a serious problem. The time for participants to be marked-up, participate, and have the markers removed is similar to the time needed for traditional methods. However, in these circumstances the time available led to the decision that CODA was not a viable option for recording task-specific behaviours.

6.15.2 Posture analysis and video recording

The method for assessing postures was tested by watching the video recordings of the trials and categorising the task-completion postures of participants, as described in Section 6.13.1. The
video analysis required considerable time to watch the tapes, and to record the required postures. However, with practice the time taken to encode the postures reduced, and manual fast-forwarding of tapes to the relevant postures further helped to reduce the time spent on the analysis. It was felt that, for a larger sample of participants, such video analysis would require a considerable amount of time for encoding, but the ease of the data capture and use of the coding system suggested that the method would be viable for a sample of 100 participants.

6.15.3 Assessment of severity of disability
The adapted OPCS severity of disability scoring system was easy to use and to score participants, using the questionnaire to assess the scales. It was felt that additional details could be collected, of kitchen, bathroom and general household tasks, tasks away from home, and measurements of grip strength, dexterity, and reported assessment of handedness and flexibility. The adapted system does not include all areas of disability, and as with any method of classification of disability is not in itself particularly meaningful, but allowed comparison of participants within the sample, in order to ensure that a spread of abilities were included. From observing the participants it was clear that the scores for severity of disability did reflect the level of impairment and disability that participants' reported.

6.15.4 Design of the kitchen rig
The kitchen rig was rudimentary in design and did not specifically resemble a kitchen environment. Participants were observed to interact with the rig in a manner at least similar to that in a real kitchen. It was felt that in order to capitalise on this and increase the realism of participants' behaviours, the rig for the main data collection study should more accurately resemble a kitchen. Kirvesöya, Väyrynen and Häikiö (2000) used such increased realism in their investigation into preferred kitchen surface heights.

6.15.5 Design of the reach rig
The data collection pilot trial also allowed the assessment of the use of the white-board for recording reach range data. This was extremely successful at gathering reach range data and both experimenters became quicker at taking measurements and finding joint centres and anthropometric markers. It was decided to further adapt the reach range white board to incorporate a horizontal board that could be pivoted to the desired angles. This would allow for the reach of both arms to be easily recorded.
6.15.6 Anthropometry

When anthropometric measurements obtained with direct internal measurement, direct external measurement, and calculated internal measurements were compared, the results suggest that for shoulder to elbow length and shoulder breadth, direct internal measurement provided accurate data (Table 14, Section 6.14.3). This suggests that, for these dimensions, it would not be necessary to collect external anthropometry and then convert via regression equations to predict internal measurements. However, for the main data collection phase it was felt that it was worth the minimal increase in time required to take measurements of both direct link length and external anthropometry for hip breadth and upper arm length. Both external and internal anthropometric measurements may be of use to designers, whilst the internal anthropometry would be more valuable in constructing the human models of participants for the computer-based design tool.

6.16 Conclusions

Decisions were made for the main data collection phase based on the results of the data collection pilot study. It was accepted that use of CODA was not a viable option particularly due to time and cost constraints. Posture analysis using video recordings was felt to be the best option for the proposed sample of 100 individuals. It was acknowledged that analysis of such a sample would require time and effort, but would be possible within the time available.

Based on the pilot study, it was decided that amendments were to be made to the existing reach range rig design to allow pivoting and height change, and to increase the realism of kitchen tasks. The task-based data collection was felt to be informative, and participants reported finding the experience interesting, and so it was decided to expand this section of the trials to include other suitable tasks if time permitted. Other decisions made for the design of the main data collection phase were to:

- expand the information gained by the questionnaire, by including adapted questions from the survey of older and disabled people and questions about postures and behaviours
- include additional basic measures of ability, such as dexterity, grip strength, and vision
Chapter 7: Main data collection phase

7.1 Introduction
In order for the computer-based design tool to be able to predict the percentage of people who could use a given design, it was essential to collect physical and behavioural data from individuals. These physical data would be used to construct ‘virtual’ models of each individual within the computer-based design tool, and to provide a database for design use. The task-based behaviour data obtained would be used by the computer-based design tool in the estimation of percentage accommodated. The data collection pilot study (Chapter 6) informed the measurements to be taken, the methods to be used, and the equipment required for the main data collection phase.

7.2 Aims of the data collection phase
The aim of the main data collection phase was to:
• Collect data on 100 individuals (predominantly older and disabled people) which would enable reliable prediction of their abilities by the computer-based design tool. The data to be collected included:
  - anthropometry
- reach ranges
- joint angles
- postural and behavioural data concerned with the completion of specific tasks

7.3 Methods

The measurements taken, methods and equipment selected for the data collection are described in this section.

7.3.1 Measuring reach envelopes

Following on from the data collection pilot study the white-board was adapted by being fixed horizontally on to a rig allowing it to be pivoted and raised and lowered (see Figure 22). It was then possible to position each participant so that their body and arm were in a standard position, and to then pivot the board to -60°, -30°, 0°, 30°, 60°, and 90° from the horizontal. This standard position involved the participant placing the armpit of their dominant arm against a nodule on the board. The lower section of the board could be reversed to accommodate left and right handed participants. The final arcs drawn at each angle were then recorded by photographing the complete board.

Figure 22: Reach range rig in the horizontal (90°) position
7.3.2 Posture analysis and task-specific data

Following on from the findings of the data collection pilot study it was decided to continue to investigate kitchen activities, namely putting items onto different heights of shelves. In order to be as realistic as possible, actual kitchen cabinets were used for the main part of the rig, with one of the kitchen units adapted to resemble an oven and a hob (see Figure 23). It was expected that by making the rig as realistic as possible to a real kitchen, that participants would then behave in a more natural way, as they would in their own kitchen at home.

![Figure 23: 'Kitchen' rig, showing central 'oven' and top shelf, work-surface and lowest shelves.](image)

It was also decided to investigate getting in and out of chairs, as the movements involved could also indicate ability to, for example, transfer in and out of a car seat, and on and off a toilet seat unaided. To reflect the different postures and abilities that may need to be adopted for different types of seating, it was decided to position the chairs in such a way as to restrict access from the front (as in a bus, train or aeroplane) and side (as in a toilet cubicle), and also to assess free access to a low chair with arms, and a normal office chair without arms.

Posture analysis was needed in order to assess and encode the postures that each individual participant could get into whilst carrying out the 'kitchen' tasks (see Section 6.13.1 for further details) and getting in and out of the chairs. A 5-point scale for assessing ease of getting into and
out of the chairs was devised, with reference to work by Chan, Laporte and Sveistrup (1999), who reported that when rising from sitting, those people with weak hip and pelvis muscles will use their arms to assist them, as long as their arm muscles are strong enough to cope. As such, the scale reflects the ease of rising in terms of whether a person needs to use their arms to assist them, and whether this is sufficient for them to rise from sitting:

1. no problems rising from sitting
2. slight problems, need to use one hand to push/pull self up
3. considerable problems, need to use both hands to push/pull self up
4. severe problems, need to use both hands and/or take several attempts to stand and/or change position
5. impossible to rise from sitting without assistance.

7.3.3 Anthropometric measurements

The same standard anthropometric measurements as in the pilot study were taken in order for the exact dimensions of each individual participant to be reconstructed in the computer-based design tool (Section 6.12.2).

7.3.4 Other methods and investigations

As described previously, in order to collect as much data about the participants as possible within the available time (and therefore make these data available to designers via the computer-based design tool) the questionnaire used in the data collection pilot study was expanded. This information, in addition to the adapted OPCS severity of disability scales in the pilot study questionnaire, would provide designers with a richer picture of real people and real issues, and aid the prediction of people's physical capabilities. The additional questions on flexibility and postural capability that participants were asked to respond to were:

- Are you right- or left-handed?
- How 'handed' are you? Could you use the other hand if you had to?
- How far can you reach bending down (in a classic touch-your-toes exercise)?
- Can you twist your upper body to left and right?
- Can you get up from lying down without assistance?
- Can you reach to tie your shoelaces?
Some direct measures of capability were also assessed, again to provide more information for designers, and were to be included (when appropriate) in the prediction of the percentage of people who could use a design:

- A self-devised peg test: a timed exercise to remove and replace wooden pegs in a board, designed to assess dexterity within the sample group. 20 pegs had to be removed in order from a board and placed into receptacles. Once all the pegs were removed, they all had to be replaced in order again. This had to be completed using only the dominant hand, and as fast as was possible. Participants were timed on how long it took them to complete the task. The results of this test cannot be compared to the results of other peg tests by other researchers, because the results were purely for comparisons of dexterity within the sample group.

- A self-devised vision test: 6 lines of text corresponding to readily available font sizes on Microsoft Word were read, in order to give an idea of any visual problems a participant may have had. This test was designed to give a simple indication of visual ability within the sample group.

- Grip strength: the dominant hand was assessed with a Baseline grip dynamometer, to provide data on grip strength for designers, for use in relevant designs where appropriate. Participants were asked to squeeze the dynamometer as hard as they could, but not to cause themselves pain whilst doing so. For those participants who reported having asymmetric grip strength due to their impairments, the grip strength of both hands were assessed.

### 7.4 Ethical considerations

The ethical approval obtained for the pilot study (Section 6.11) also covered the work conducted in the main data collection phase (Appendix 3).

### 7.5 Participants and sampling

There were 100 participants selected for the main data collection phase. Within the time frame of the project, this would allow a spread of ability, providing data to test the computer-based design tool. The sample was not intended to be representative, either of the UK population or the UK physically-disabled population, but sampling was aimed at providing as broad a range of ability as possible, from able-bodied through to severely disabled, in order to test the predictive capacity of the computer-based design tool.

The sample was biased towards older and disabled participants in order to reflect the ‘design for all’ and EQUAL initiatives of the project, so the intended sample was:
- 20 able-bodied aged between 18 and 62 years
- 20 able-bodied older people aged 63 years and over
- 20 ambulant disabled people aged 18-62 years
- 20 ambulant disabled people aged 63 years and over
- 20 people in wheelchairs.

Within each group the aim was to have 10 men and 10 women. ‘Ambulant disabled’ refers to people with a physical disability of any kind but who are able to walk, either with or without assistance from stick(s) or a frame. ‘Wheelchair’ participants were those people who were dependent on a wheelchair for most or all of their time for mobility around the home and outside. Those in the ‘able-bodied older people aged 63 years and over’ group were those who may have been experiencing minor problems due to old age.

Participants were recruited from a range of sources, and included some of those who had taken part in the survey of older and disabled people. Recruitment also occurred through the university internet notice-board, by posters placed in Disabled Living Centres in Nottingham and Leicester, and from the Charnwood Day Centre held at a local school.

Due to problems recruiting people, particularly ambulant disabled people, it was necessary to recruit participants in other sample groups (with the focus being able-bodied older and disabled participants) in order to reach the target of 100. Participants were paid £10 per hour for giving up their time, and taxis were provided where necessary.

### 7.6 Equipment

- Harpenden anthropometer: for the anthropometric measurements, in conjunction with a standard cloth tape measure and a 30 cm plastic ruler.
- Stadiometer and sitting height table: for relevant anthropometric measurements.
- Baseline goniometer: for measurement of joint angles.
- Peg-test board (20 wooden dowels in 20 holes, with 20 plastic containers adjacent): used to assess fine motor dexterity.
- Baseline grip-dynamometer: used to measure grip strength.
- The kitchen rig, comprising three B&Q kitchen units (with the central unit and work-surface painted to resemble an oven and hob, see Figure 23, Section 7.3.2). The central unit also had a shelf affixed at 140 cm above the floor level, by means of wooden batons behind the unit.
The other shelves that were used were fixed at 14.5 cm, 35 cm and 90 cm above floor level (these were the given positions within the units of the bottom shelf, the middle shelf, and the work-surface).

- A plastic beaker, plastic bag, and baking tray: used to contain the weights used for the lifting and placing tasks, and these were weighted using bags of rice. The items available for the lifting tasks were: a beaker (to be lifted by one hand) with possible weights of 48 g, 200 g, 300 g, 400 g and 566 g; a bag (to be lifted by one or two hands) weighing 100 g, 188 g, 293 g, 300 g, and 1000 g; and a tray (to be lifted by two hands) weighing 214 g through to 2000 g. The chosen comfortable maximum weights for each item (one beaker, one bag, and one tray) were to be lifted on to the different shelves.

- Reach-range rig: could be rotated to the appropriate angle, and moved up and down so as to fit in the armpit, and was marked using coloured white-board pens (see Figure 22, Section 7.3.1).

- Two digital video recorders and a digital camera: used for recording task behaviours and postures, and somatotype.

- Two chairs: a low (39 cm) chair with arms, and a conference chair (47 cm) without arms.

### 7.7 Procedure

1. Participants were greeted and a brief explanation of the trial was given (the sheet of information given to participants is in Appendix 5).

2. Consent forms were then discussed and signed (Appendix 4). It was reiterated that if at any time they wished to stop, have a rest, or miss any part of the trial, they could do so.

3. The questionnaire to determine personal details, base-line abilities and severity of disability was then administered, and measurements of grip strength were taken. Participants also completed the peg-test task. Photographs were then taken from front and side of participant.

4. Anthropometric measurements were taken, followed by joint angle measurements (Section 6.12.2).

5. For the kitchen tasks, participants were asked to place first the beaker, then the tray, then the bag, onto the top shelf, the work-surface, the low shelf, and into the oven. Participants were also asked to do some additional tasks: to place the beaker on the work-surface as if it was a drink they were going to stir, and to simulate that the tray in the oven was a turkey, and to do whatever they would do to baste it (an oven glove and tea-towel were provided for this). Video was taken from the side and behind the participant to record postures and task behaviours.
At all times participants were reminded to only attempt to lift a maximum *comfortable* weight to each shelf, and only to those shelves they could comfortably reach. Those who could not lift with both hands did not lift the two-handed tray. Participants were asked not to over-reach or to strain themselves in attempting to reach or lift during any of the tasks, and to only do what they would normally do at home. The height and weight capabilities of each participant were recorded.

6. Participants were then asked to sit and rise from the chairs:
- One low chair, with arms, approached from any angle.
- Conference chair without arms, approached from any angle.
- Conference chair positioned facing a wall (Figure 24), with a gap of 67 cm between the rear of the seat and the wall, to simulate restricted front access (similar to on a train, bus or aeroplane, measured from a national railway operator’s train).
- Conference chair positioned within an 80 cm gap between two walls/chairs (Figure 24), to simulate side-restricted access (BS 6465-1: 1994, recommended toilet cubicle width).

![Figure 24: Chair with restricted front access (left) and chair with restricted side access (right)](image)

Participants were shown each chair and arrangement first, and asked if they were happy to attempt the task. This prevented problems of people becoming ‘stuck’ in chairs, and also allowed feedback from those who could tell from experience whether they could use the chairs or not, without them actually having to physically try them if they did not want to. This may lead to some inaccuracies, but there was no discernible reason for people to mislead the experimenter about their abilities. The situations were also those that people were likely to
have encountered on a frequent basis, so it was thought to be likely that their responses would be accurate. Video was taken from the side as people got into and out of the chairs.

7. The measurement of reach range took time to move and set up the board for each angle and each participant, but little effort on the part of the participant. Participants’ arm-pit height on the side of the dominant arm was taken, and the board positioned so that this height was achieved. Due to limitations of the board design, some angles (60° and 90°) required that taller participants be seated. In these cases the trials progressed identically to those with standing participants in all other regards. The board was positioned at 0° (horizontal), +30°, +60° and +90° (vertical), and at -30° and -60°. Participants were asked to stand (or sit) with their dominant arm on the board and the ‘notch’ resting comfortably in their armpit. They were given a marker pen, and asked to hold it in a fist grip with the nib of the pen pointing out of the bottom of the hand. They were then asked to draw an arc, starting with their hand as far back on the board as comfortable, keeping their arm straight for as long as possible, and keeping their body facing forwards at all times (twisting of the body resulted in the arc representing body and arm movements, not just the reach capacity of the arm). This was also demonstrated to participants on the first attempt, to help clarify the procedure.

If participants were unable to complete any of the reach range angles, then those were merely omitted. Video was taken of the person drawing on the board, in order to provide a visual record of arm movement (to show, for example, the point at which the elbow bent). At the end of the reach range collection, the board was placed vertically and a digital camera photograph taken for records.

8. Finally, participants were asked if they had any questions about the trial, then they were paid and thanked for their time.

7.8 Data Analysis

7.8.1 Reach range

The data for reach range were analysed by first calculating the distance from arm-pit to minimum, maximum, median and mean distances reached for each of the angles attempted (-60°, -30°, 0°, 30°, 60°, 90°), by each participant. These were then explored using SPSS statistical software to test for correlations with relevant anthropometric, joint angle, and severity of disability score data.
T-tests were conducted to compare the reach range of the different groups (men versus women, able versus disabled, and older versus younger).

7.8.2 Anthropometry
The anthropometric measurements taken were to be used in the software design tool in order to recreate each individual participant as a virtual human-model. The different groups (men versus women, able versus disabled, older versus younger) were compared using t-tests to see if there were any significant differences between the groups. The older versus younger comparison does not include the 20 participants in wheelchairs, as these were not divided according to age. The other groups were divided into those aged 18-62 years of age, and those 63 years old and over. It was noted that comparison of, for example, the anthropometry of men and women would be compounded with the influence of age and disability, and vice versa for the different comparisons. However, it was felt that the comparisons were still valid and interesting in their own right as a description of the data obtained, and an investigation into whether the data reflected any of the patterns expected from general knowledge of anthropometry.

In order to investigate the breadth and range of the sample, it was also of interest to compare the data collected with existing anthropometry databases. In order to reflect the current data available to, and used by designers, comparison was made between the collected study data and Adultdata (1998), Olderadultdata (2000), and Pheasant (1988). All three texts were mentioned by designers in the survey of design professionals (Chapter 3) as references that they used to obtain anthropometric data.

In order to reflect the nature of the project and assess the impact and importance of multivariate analysis, it was decided to use the data to assess an existing design. This would allow the author to identify who, according to the data, would be able to use the design, and who would have problems (and so be effectively ‘designed out’). The recommendations used were for bus dimensions, taken from The Public Service Vehicles Accessibility Regulations Guidance (2000). The minimum dimensions quoted as guidance for designers were compared to the relevant anthropometric data, for example minimum headroom clearance of 1900 mm. It must be noted that the dimensions quoted were given as minimum dimensions. It is felt that the comparison is still a valid one, in that whilst some designers may choose to provide dimensions in excess of the minimum recommended, it is not unreasonable to imagine that others will use the recommended
dimensions as the basis for their design. Three dimensions were considered; headroom (stature), aisle width (hip breadth) and seat-to-seat distance (buttock-knee length).

7.8.3 Joint constraints
Comfortable angles of movement for the joints of the dominant arm were collected in order to constrain the joints of the human-model of the individual within the computer-based design tool. The different groups (men versus women, able versus disabled, older versus younger) were compared using t-tests to see if there were any significant differences between the groups.

7.8.4 Physical capabilities: questionnaire and assessment
Counts were taken of participants' responses to questions on handedness, whether they were able to get up from lying down, whether they were able to reach to tie their shoelaces, and whether they were able to twist their upper body to the left and right. T-test comparisons were made between men versus women, able versus disabled, and older versus younger participants for peg test times and grip strength measures. A non-statistical comparison of vision scores was made.

Unfortunately, the equipment that was required for assessing grip strength and the dexterity peg test were not available for the whole period of the trials. Also, the question regarding how far participants were able to twist their upper body was only added partway through the trials period, after discussion with the project team. For these reasons, data given for these measures are not for all 100 participants.

7.8.5 Task-specific data
Video analysis of the postures attained and the ease of getting in and out of the chairs was conducted. Counts were taken of the scores for ease of getting in and out of the chairs, the number of participants achieving different postures during the kitchen tasks, and the weights lifted by the different participant groups on to the shelves. Analysis and description of the postures recorded is possible, but does not provide useful information. For example, it is possible to say that 30% of participants could flex their backs beyond 45°, but this does not tell anything about those who could not, or why they could not, or take into account those who completed tasks by alternative methods, for example by bending their knees. Data were deliberately collected and maintained as 'individual' data, to provide a full picture of the postural and behavioural abilities of that 'individual'. In contrast to existing data sets, the data collected were deliberately kept as 'individuals', rather than divided into summary tables and figures. The task-specific data are
fundamental to the predictive capability of the computer-based design tool, as the postures that a person can achieve will be applied to other design scenarios, in order to explore and predict how that person would interact. The task-specific data were not intended, in this study, to provide population data as such, as the sample was not designed to be representative of the population as a whole.

In order to illustrate further the benefit of presenting data as individual data sets, six participants were compared. These were two older women of the same stature, two older men with nearly identical stature, and two men of the same age in wheelchairs. The older women and older men were chosen in order to illustrate the differences between anthropometry and abilities, despite having the same stature. The two men in wheelchairs were chosen in order to identify differences in anthropometry and abilities that were not age-related.

7.9 Results

7.9.1 Participants

Trials took place between April and September 2001. The sample involved in the main data collection study is detailed in Table 16.

<table>
<thead>
<tr>
<th></th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Able-bodied (18-62 years of age)</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Able-bodied (63 years of age +)</td>
<td>14</td>
<td>15</td>
</tr>
<tr>
<td>Ambulant disabled (18-62 years of age)</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Ambulant disabled (63 years of age +)</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Wheelchair users (18 years of age +)</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>45</strong></td>
<td><strong>55</strong></td>
</tr>
</tbody>
</table>

Table 16: Gender and sample distribution

Although the sample was not intended to be representative, it was interesting to compare the proportions within the sample to the UK population, in order to provide a context for the research. The results of this comparison are given in Table 17. It can be seen (as expected) that the main data collection sample contained a higher percentage of people over the age of 63 than found in the general population, and a smaller percentage of people under the age of 63.
<table>
<thead>
<tr>
<th></th>
<th>Percentage of Population</th>
<th>Percentage of main data collection sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total aged 18-62</td>
<td>78.3</td>
<td>54</td>
</tr>
<tr>
<td>Total over 63 years</td>
<td>21.7</td>
<td>46</td>
</tr>
<tr>
<td>Men aged 18-62</td>
<td>39.6</td>
<td>28</td>
</tr>
<tr>
<td>Men over 63 year</td>
<td>9.1</td>
<td>17</td>
</tr>
<tr>
<td>Women aged 18-62</td>
<td>38.7</td>
<td>26</td>
</tr>
<tr>
<td>Women over 63 years</td>
<td>12.6</td>
<td>29</td>
</tr>
</tbody>
</table>

Table 17: Age and gender distributions of the 100 participants compared with age and gender distributions for the UK population. (* Population at mid-2000: Great Britain: Estimated resident population by single year of age and gender, dataset pp00+2, Office for National Statistics and General Register Office for Scotland)

There was a spread of severity of disability (Figure 25), with a severity score of 10 being the most severe, and 0 indicating no measurable disability. 46% of participants had a severity score of 0, but this includes those older people who may have been experiencing problems of old age, but not to a severe enough degree to register on the scoring system. Examples of such difficulties include stiffness and aches and pains, which may be indicative of the early stages of arthritis. It was not possible to compare the spread of severity of disability with the findings of previous work that had used the OPCS scoring system, as the scoring used in this research did not involve the full scoring system as devised by Martin, Meltzer and Elliot (1994), but an adapted version.

![Figure 25](image-url)  

Figure 25: Percentage of participants with each severity of disability score (n=100).
7.9.2 Reach range data

It was necessary to investigate whether it was possible to predict reach range from other measures, such as anthropometry, joint angle movements, and severity of disability score. Tables 18 to 21 show the significant correlations for participants when reach range distance was compared to other measures. The tables are arranged for ease of reading, with correlations with the reach range board angles below the horizontal (-60° and -30°) for men in Table 18, and women in Table 19. Correlations with reach range board angles of horizontal and above (0°, 30°, 60°, and 90°) for men are given in Table 20, and for women in Table 21. Any angles given are the angle of the reach range board at which the reach range distance (in mm) was measured. A positive correlation indicates that as one of the two variables (reach range distance and anthropometric measurement, joint movement, or severity score) increases, so does the other. For example, in Table 18 a positive correlation is shown for the maximum reach range distance and stature when the board was at the -60° position. This means that as stature increases, so does the maximum reach range distance for male participants with the board in this position: taller participants were reaching further. In contrast a negative correlation indicates that as one of the variables increases, the other decreases.

For male participants positive correlations were found between stature and reach range distance at -60° and -30°, with negative correlations between stature and reach range at 0°, 30°, 60°, and 90°. This indicates that, for men, as stature increased so did reach range distance for the board angles below the horizontal, whilst, surprisingly, as stature increased reach range distance decreased for board angles at the horizontal and above. Similarly, for women it was found that positive correlations between reach range distance and arm length with the board at all angles measured, indicating, unsurprisingly, that as arm length increases, so does reach range. There were fewer correlations found for both men and women when reach range was measured at the 90° angle. This may be due to the fact that shoulder extension and flexion come in to play as participants reached upwards.
<table>
<thead>
<tr>
<th></th>
<th>Stature</th>
<th>Arm Length</th>
<th>Upper arm length</th>
<th>Arm adduction</th>
<th>Arm abduction</th>
<th>Medial rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum −60</td>
<td>.433</td>
<td>.545</td>
<td>.349</td>
<td>.448</td>
<td>.444</td>
<td></td>
</tr>
<tr>
<td>Maximum −60</td>
<td>.011</td>
<td>.001</td>
<td>.046</td>
<td>.008</td>
<td>.009</td>
<td></td>
</tr>
<tr>
<td>Median −60</td>
<td>.489</td>
<td>.598</td>
<td>.412</td>
<td>.340</td>
<td>.340</td>
<td>.049</td>
</tr>
<tr>
<td>Mean −60</td>
<td>.003</td>
<td>.000</td>
<td>.017</td>
<td>.001</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>Minimum −30</td>
<td>.473</td>
<td>.550</td>
<td>.373</td>
<td>.379</td>
<td>.379</td>
<td></td>
</tr>
<tr>
<td>Maximum −30</td>
<td>.005</td>
<td>.001</td>
<td>.033</td>
<td>.027</td>
<td>.027</td>
<td></td>
</tr>
<tr>
<td>Median −30</td>
<td>.435</td>
<td>.529</td>
<td>.334</td>
<td>.334</td>
<td>.334</td>
<td></td>
</tr>
<tr>
<td>Mean −30</td>
<td>.010</td>
<td>.001</td>
<td>.050</td>
<td>.050</td>
<td>.050</td>
<td></td>
</tr>
</tbody>
</table>

Table 18: Correlation coefficients (Pearson’s r) and level of significance for male participants for reach range distances at −30° and −60° against anthropometry and joint movements (* = significant at the 0.05 level, ** = significant at the 0.02 level).

<table>
<thead>
<tr>
<th></th>
<th>Stature</th>
<th>Arm Length</th>
<th>Upper arm length</th>
<th>Arm flexion</th>
<th>Arm extension</th>
<th>Lateral rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum −60</td>
<td>.511</td>
<td>.410</td>
<td>.337</td>
<td>.358</td>
<td>.358</td>
<td>.313</td>
</tr>
<tr>
<td>Maximum −60</td>
<td>.000</td>
<td>.005</td>
<td>.022</td>
<td>.016</td>
<td>.016</td>
<td>.034</td>
</tr>
<tr>
<td>Median −60</td>
<td>.538</td>
<td>.650</td>
<td>.314</td>
<td>.430</td>
<td>.430</td>
<td></td>
</tr>
<tr>
<td>Mean −60</td>
<td>.000</td>
<td>.005</td>
<td>.034</td>
<td>.003</td>
<td>.003</td>
<td>.034</td>
</tr>
<tr>
<td>Minimum −30</td>
<td>.670</td>
<td>.638</td>
<td>.541</td>
<td>.562</td>
<td>.562</td>
<td></td>
</tr>
<tr>
<td>Maximum −30</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
<td>.034</td>
</tr>
<tr>
<td>Median −30</td>
<td>.576</td>
<td>.501</td>
<td>.501</td>
<td>.536</td>
<td>.536</td>
<td></td>
</tr>
<tr>
<td>Mean −30</td>
<td>.000</td>
<td>.000</td>
<td>.020</td>
<td>.015</td>
<td>.015</td>
<td>.045</td>
</tr>
</tbody>
</table>

Table 19: Correlation coefficients (Pearson’s r) and level of significance for female participants for reach range distances at −30° and −60° against relevant anthropometry and joint movements (* = significant at the 0.05 level, ** = significant at the 0.02 level).
<table>
<thead>
<tr>
<th>Severity score</th>
<th>Arm length</th>
<th>Elbow flexion</th>
<th>Elbow extension</th>
<th>Medial rotation</th>
<th>Lateral rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median 0</td>
<td>-.411 .005 **</td>
<td>.411 .005 **</td>
<td>.388 .009 **</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean 0</td>
<td>-.344 .021 *</td>
<td>.383 .009 **</td>
<td>.337 .024 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.304 .043 *</td>
</tr>
<tr>
<td>Maximum 30</td>
<td></td>
<td>.333 .025 *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median 30</td>
<td>-.485 .001 **</td>
<td>.479 .001 **</td>
<td>.295 .049 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean 30</td>
<td></td>
<td>.439 .003 **</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum 60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median 60</td>
<td>-.485 .001 **</td>
<td>.474 .001 **</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean 60</td>
<td>-.388 .010 *</td>
<td>.411 .006 **</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum 90</td>
<td></td>
<td></td>
<td>-.325 .040 *</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum 90</td>
<td>-.404 .008 **</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median 90</td>
<td>-.379 .013 *</td>
<td>.383 .012 *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean 90</td>
<td>-.347 .024 *</td>
<td>.359 .020 *</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 20: Correlation coefficients (Pearson’s r) and level of significance for male participants for reach range distances at 0°, 30°, 60° and 90° against relevant anthropometry and joint movements (*= significant at the 0.05 level, ** = significant at the 0.02 level).*
Table 21: Correlation coefficients (Pearson’s r) and level of significance for female participants for reach range distances at 0°, 30°, 60° and 90° against relevant anthropometry and joint movements (* = significant at the 0.05 level, ** = significant at the 0.02 level).

Table 22 shows the significant differences found when comparison is made between reach range distances of the different sample groups. For men compared with women it can be seen that significant differences in maximum, minimum and median reach range distances at the p=0.02...
level were found at the -60° board angle, and for the median reach range distances at the -30° and 0° board angles. This indicates that at these board angles, men were reaching significantly further than women. This finding is unsurprising given the expected differences in factors such as arm length in the anthropometry of men and women, which in turn affects the distance that they are able to reach. For older and younger, and able-bodied and disabled participants, only four significant differences in reach range distance were found out of the possible 24 comparisons made, and the board angles at which differences occurred varied. It may be that the variability of anthropometry with age and disability, and the affects of any impairments, impacted on the lack of clear differences between the groups.

<table>
<thead>
<tr>
<th>Angle of board</th>
<th>Reach range (mm)</th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Older</td>
<td>Younger</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>Maximum -60°</td>
<td>35</td>
<td>582.5</td>
</tr>
<tr>
<td>Median -60°</td>
<td>33</td>
<td>633.6</td>
</tr>
<tr>
<td>Mean -60°</td>
<td>33</td>
<td>565.1</td>
</tr>
<tr>
<td>Median -30°</td>
<td>35</td>
<td>603.6</td>
</tr>
<tr>
<td>Mean -30°</td>
<td>35</td>
<td>592.7</td>
</tr>
<tr>
<td>Median 0°</td>
<td>44</td>
<td>610.5</td>
</tr>
<tr>
<td>Median 30°</td>
<td>42</td>
<td>638.4</td>
</tr>
</tbody>
</table>

|                | Men     | Women    |                | |
|                | N     | Mean    | SD   | N     | Mean    | SD   | |
| Maximum -60°   | 33    | 633.6   | 39.3 | 33    | 569.9   | 61.3 | **  |
| Median -60°    | 33    | 565.1   | 49.6 | 33    | 507.5   | 52.1 | **  |
| Mean -60°      | 33    | 565.1   | 49.6 | 33    | 506.4   | 54.5 | **  |
| Median -30°    | 35    | 603.6   | 45.6 | 35    | 549.7   | 66.6 | **  |
| Mean -30°      | 35    | 592.7   | 44.3 | 35    | 552.3   | 81.8 | *   |
| Median 0°      | 44    | 610.5   | 57.0 | 44    | 574.1   | 63.8 | **  |
| Median 30°     | 42    | 638.4   | 82.3 |        | 597.9   | 59.5 | *   |

|                | Disabled | Able    |                | |
|                | N     | Mean    | SD   | N     | Mean    | SD   | |
| Median -60°    | 32    | 524.0   | 65.9 | 32    | 553.9   | 53.4 | *   |
| Mean -60°      | 32    | 522.3   | 67.5 | 32    | 548.0   | 49.8 | *   |
| Mean 0°        | 41    | 572.2   | 67.3 | 41    | 600.6   | 59.3 | *   |
| Maximum 90°    | 35    | 703.2   | 65.8 |        | 703.2   | 68.5 | *   |

**Table 22:** Results of t-tests to compare reach range distances for the different sample groups (* = significant at the 0.05 level, ** = significant at the 0.02 level)

7.9.3 Anthropometry

The mean and standard deviations for each anthropometric measurement, for men and women separately, is given in Table 23, for able and disabled participants in Table 24, and for older and younger participants in Table 25. In Tables 23 and 24, N varies as not all participants could be measured for a particular dimension. Stature, abdominal depth (standing) and thigh depth (standing) were not possible for all wheelchair participants (as not all participants were able to
stand), and ankle height, knee height and foot length were affected by whether participants were
able and willing to remove their shoes.

<table>
<thead>
<tr>
<th>Anthropometry</th>
<th>Men</th>
<th>Women</th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>43</td>
<td>81.9</td>
<td>14.2</td>
</tr>
<tr>
<td>Stature</td>
<td>35</td>
<td>1766</td>
<td>83.9</td>
</tr>
<tr>
<td>Arm length</td>
<td>45</td>
<td>768.9</td>
<td>50.5</td>
</tr>
<tr>
<td>Upper arm length</td>
<td>44</td>
<td>349.3</td>
<td>26.0</td>
</tr>
<tr>
<td>Elbow-shoulder length</td>
<td>45</td>
<td>301.4</td>
<td>45.4</td>
</tr>
<tr>
<td>Wrist-elbow length</td>
<td>45</td>
<td>251.3</td>
<td>19.7</td>
</tr>
<tr>
<td>Abdominal depth (standing)</td>
<td>34</td>
<td>265.8</td>
<td>43.0</td>
</tr>
<tr>
<td>Thigh depth (standing)</td>
<td>34</td>
<td>170.7</td>
<td>18.5</td>
</tr>
<tr>
<td>Knee-hip length</td>
<td>45</td>
<td>433.1</td>
<td>38.9</td>
</tr>
<tr>
<td>Ankle-knee length</td>
<td>45</td>
<td>418.5</td>
<td>34.4</td>
</tr>
<tr>
<td>Ankle height</td>
<td>39</td>
<td>74.9</td>
<td>15.0</td>
</tr>
<tr>
<td>Foot length</td>
<td>38</td>
<td>268.2</td>
<td>19.2</td>
</tr>
<tr>
<td>Sitting height</td>
<td>45</td>
<td>894.0</td>
<td>81.7</td>
</tr>
<tr>
<td>Sitting shoulder height</td>
<td>45</td>
<td>584.5</td>
<td>68.3</td>
</tr>
<tr>
<td>Hip-shoulder length</td>
<td>45</td>
<td>417.1</td>
<td>43.6</td>
</tr>
<tr>
<td>Chest height</td>
<td>45</td>
<td>420.3</td>
<td>63.1</td>
</tr>
<tr>
<td>Chest depth</td>
<td>45</td>
<td>266.1</td>
<td>45.6</td>
</tr>
<tr>
<td>Head height</td>
<td>45</td>
<td>204.4</td>
<td>24.2</td>
</tr>
<tr>
<td>Eye-to-top-of-head</td>
<td>44</td>
<td>99.8</td>
<td>15.1</td>
</tr>
<tr>
<td>Buttock-knee length</td>
<td>45</td>
<td>601.2</td>
<td>54.2</td>
</tr>
<tr>
<td>Abdominal depth (sitting)</td>
<td>45</td>
<td>280.6</td>
<td>65.4</td>
</tr>
<tr>
<td>Thigh depth (sitting)</td>
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<td>142.2</td>
<td>18.7</td>
</tr>
<tr>
<td>Knee height</td>
<td>41</td>
<td>508.8</td>
<td>84.3</td>
</tr>
<tr>
<td>Shoulder breadth</td>
<td>45</td>
<td>385.7</td>
<td>42.9</td>
</tr>
<tr>
<td>Hip breadth (external)</td>
<td>45</td>
<td>348.8</td>
<td>40.7</td>
</tr>
<tr>
<td>Hip breadth (link)</td>
<td>45</td>
<td>289.9</td>
<td>36.6</td>
</tr>
<tr>
<td>Hand length</td>
<td>45</td>
<td>198.7</td>
<td>11.7</td>
</tr>
<tr>
<td>Grip Length</td>
<td>45</td>
<td>73.9</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Table 23: Anthropometry results for men and women: mean and standard deviation for each measure taken, with significant differences, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).

In Table 23 it can be seen that, not surprisingly, significant differences between the anthropometry of men and women were found for 16 of the 28 dimensions. The 16 dimensions were: stature, arm length, upperarm length, elbow-shoulder length, wrist-elbow length, ankle-knee length, ankle height, foot length, sitting height, hip-shoulder length, chest height, head height, buttock-knee
length, shoulder breadth, hand length, and grip length. All these dimensions were significantly different at the p=0.02 level, apart from head height (p=0.05), indicating that the anthropometry of men and women in the sample varied on the majority of the dimensions considered.

Unsurprisingly, men had larger measurements for all the dimensions apart from weight, chest depth, abdominal depth, and hip breadth (external).

<table>
<thead>
<tr>
<th>Anthropometry</th>
<th>Disabled</th>
<th>Able-bodied</th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>50</td>
<td>75.5</td>
<td>18.3</td>
</tr>
<tr>
<td>Stature</td>
<td>38</td>
<td>1633</td>
<td>149.7</td>
</tr>
<tr>
<td>Arm length</td>
<td>55</td>
<td>715.4</td>
<td>72.9</td>
</tr>
<tr>
<td>Upper arm length</td>
<td>55</td>
<td>329.3</td>
<td>30.0</td>
</tr>
<tr>
<td>Elbow-shoulder length</td>
<td>55</td>
<td>281.0</td>
<td>32.2</td>
</tr>
<tr>
<td>Wrist-elbow length</td>
<td>55</td>
<td>236.6</td>
<td>24.5</td>
</tr>
<tr>
<td>Abdominal depth (standing)</td>
<td>35</td>
<td>277.9</td>
<td>48.6</td>
</tr>
<tr>
<td>Thigh depth (standing)</td>
<td>35</td>
<td>171.8</td>
<td>15.6</td>
</tr>
<tr>
<td>Knee-hip length</td>
<td>55</td>
<td>423.8</td>
<td>42.1</td>
</tr>
<tr>
<td>Ankle-knee length</td>
<td>55</td>
<td>396.5</td>
<td>36.1</td>
</tr>
<tr>
<td>Ankle height</td>
<td>46</td>
<td>71.2</td>
<td>16.4</td>
</tr>
<tr>
<td>Foot length</td>
<td>44</td>
<td>251.8</td>
<td>39.5</td>
</tr>
<tr>
<td>Sitting height</td>
<td>55</td>
<td>828.3</td>
<td>82.7</td>
</tr>
<tr>
<td>Sitting shoulder height</td>
<td>55</td>
<td>533.5</td>
<td>70.0</td>
</tr>
<tr>
<td>Hip-shoulder length</td>
<td>55</td>
<td>389.5</td>
<td>44.9</td>
</tr>
<tr>
<td>Chest height</td>
<td>55</td>
<td>374.0</td>
<td>59.0</td>
</tr>
<tr>
<td>Chest depth</td>
<td>55</td>
<td>283.1</td>
<td>49.6</td>
</tr>
<tr>
<td>Head height</td>
<td>55</td>
<td>194.0</td>
<td>24.1</td>
</tr>
<tr>
<td>Eye-to-top-of-head</td>
<td>54</td>
<td>96.2</td>
<td>14.8</td>
</tr>
<tr>
<td>Buttock-knee length</td>
<td>55</td>
<td>564.3</td>
<td>62.6</td>
</tr>
<tr>
<td>Abdominal depth (sitting)</td>
<td>54</td>
<td>292.7</td>
<td>60.4</td>
</tr>
<tr>
<td>Thigh depth (sitting)</td>
<td>53</td>
<td>135.1</td>
<td>21.6</td>
</tr>
<tr>
<td>Knee height</td>
<td>50</td>
<td>479.9</td>
<td>76.5</td>
</tr>
<tr>
<td>Shoulder breadth</td>
<td>55</td>
<td>362.8</td>
<td>46.6</td>
</tr>
<tr>
<td>Hip breadth (external)</td>
<td>55</td>
<td>362.2</td>
<td>52.0</td>
</tr>
<tr>
<td>Hip breadth (link)</td>
<td>55</td>
<td>293.9</td>
<td>46.8</td>
</tr>
<tr>
<td>Hand length</td>
<td>55</td>
<td>184.4</td>
<td>19.8</td>
</tr>
<tr>
<td>Grip Length</td>
<td>55</td>
<td>69.7</td>
<td>14.5</td>
</tr>
</tbody>
</table>

Table 24: Anthropometry results for able and disabled participants: mean and standard deviation for each measure taken, with significant differences, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).
In Table 24 it can be seen that, quite surprisingly, significant differences between the anthropometry of disabled and able-bodied participants were found for only four dimensions. These four dimensions were stature, sitting height, sitting shoulder height and chest height. All these dimensions were significantly different at the p=0.02 level. This indicates that the anthropometry of able-bodied and disabled participants in the sample did not vary on the majority of the dimensions considered, and that any impairments they had did not have an consistent influence on limb dimensions.

Part of this might be explained by the fact that stature could not be measured for 18 of the wheelchair participants. There may also have been inaccuracies with measuring sitting height and sitting shoulder height for the 20 wheelchair participants, as they were measured in their chairs using an anthropometer, whereas the other participants were measured using a sitting height table.

In Table 25 it can be seen that significant differences between the anthropometry of older (63 years and over) and younger (18-62 years) participants were found for 12 of the 28 dimensions. The 12 dimensions were: stature, upperarm length, elbow-shoulder length, wrist-elbow length, abdominal depth standing, thigh depth standing, knee-hip length, ankle-knee length, chest depth, chest height, abdominal depth sitting, and thigh depth sitting. Abdominal depth (standing), chest depth, and thigh depth (sitting) were significant at the p=0.05 level, whilst all the other dimensions were significantly different at the p=0.02 level. Younger participants, as expected, had larger measurements for all the dimensions with significant differences, except for abdominal depth (standing and sitting), thigh depth (standing) and chest depth, where older participants had larger measurements.
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<tr>
<td>(standing)</td>
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Table 25: Anthropometry results for older and younger participants: mean and standard deviation for each measure taken, with significant differences, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).

7.9.4 Comparison of anthropometry data with existing sources

In order to determine the breadth and range of the data collected, it was compared with data obtained from Pheasant (1988), Adultdata (1998) and Olderadultdata (2000). It is necessary to provide some information about where the data in these texts originated. The data for 19-65 year olds given in Pheasant (1988) were estimates for the British population, with stature being taken from a 1981 survey by the Office of Population Censuses and Surveys, and other dimensions being calculated from “a variety of US military surveys” (no further details given). The Pheasant
(1988) data for those over the age of 65 was based on stature data that was estimated on the assumption that any decline in stature after 65 years of age would be similar in British adults to that of USA adults. The data taken from Adultdata (1998) and Olderadultdata (2000) were obtained from PeopleSize (1998 & 1999, respectively). The data in Pheasant (1988), Adultdata (1998) and Olderadultdata (2000) are presented in these texts in the form of 5th, 50th and 95th percentile values and standard deviation for each dimension. This is replicated in Table 26, which contains anthropometric data collected in the main data collection phase, and data for the same anthropometric dimensions taken from other sources (Pheasant, 1988; Adultdata, 1998; Olderadultdata, 2000).

In order to further evaluate the data sets, comparison was made between them and design recommendations for buses (The Public Service Vehicles Accessibility Regulations Guidance, 2000). The recommended minimum distances that were considered were:

- 450 mm aisle between seats (hip breadth will provide an indication of who could walk without having to turn their body)
- 1900 mm headroom (stature will indicate who could walk without having to bend or stoop)
- 650 mm from back of one seat to back of the one in front (buttock-knee length will indicate who could sit with knees straight in front of them)

All these recommended distances concern clearance, and as such should include the largest of the population wishing to use the bus. In an ideal situation a designer would calculate at least the 99th percentile measurement for each clearance issue, but it is assumed that, in reality, many designers use the readily available 95th percentile value. By comparing the data in Table 26 with the recommended dimensions, it is possible to have an idea of who would be able to use the bus easily, and who would have to change their behaviour and/or posture to fit in. Table 26 has text in **bold** to highlight measurements that are in excess of the recommendations being compared to.

Examination of the data in Table 26 taken from Pheasant (1988) suggests that the recommended minimum dimensions of 450 mm aisle width, 1900 mm headroom, and 650 mm buttock-knee length would allow adequate clearance for all people, up to and including those who are 95th percentile on any of the given dimensions. The data from Adultdata (1998) and Olderadultdata (2000) indicate that problems with the recommended dimensions would be experienced by those women aged 18-64 years of 95th percentile hip breadth, with the 95th percentile value being given as 480 mm as opposed to the 450 mm recommended. It is also indicated that 18-64 year old
women of 95th percentile buttock-knee length would experience slight difficulties, with a length of 656 mm and over, compared to the recommended distance of 650 mm.

The new data collected for the main data collection phase suggests that men aged 45-65 years with 95th percentile hip breadth would have slight problems walking between the seats without turning sideways, due to their hip breadth being 5 mm greater than the recommended distance of 450 mm. It is also expected that all men with 95th percentile buttock-knee length, and women aged 19-45 years with 95th percentile buttock-knee length, would experience problems sitting with their knees straight in front of them. These difficulties would arise because of their buttock-knee lengths being greater than the 650 mm recommended (696 mm, 691 mm, 667 mm, and 667 mm respectively).

It was also interesting to further investigate these data to provide measurements for those at the extremes of the sample, namely those in the population/sample who are 1st and 99th percentile for each of the given measurements. Table 27 shows the 1st and 99th percentile values calculated for each of the dimensions given in Table 26, for each of the anthropometric data sources. Text in Table 27 in bold indicate that the new data (collected for the main data collection phase) have a greater range than both the data from Pheasant (1988) and Adultdata (1998)/Olderadultdata (2000). Text in italics indicate that the new data have a greater range than just one of the other data sets for the given dimension (that is, either Pheasant, 1988; or Adultdata, 1998/Olderadultdata, 2000).

It can be seen that, for 24 of the possible 36 measurements, the data collected in the main data collection phase provided a wider range of variation than both of the other data sources. The main study data also provided a wider range of variation greater than just one of the other sources for seven further dimensions. For example, it can be seen that all 1st percentile hip breadth measurements for women were less than those given in both the other sources, with 99th percentile hip breadth measurements being greater than just one of the sources (Adultdata, 1998/Olderadultdata, 2000).
Table 26: Anthropometry data from other sources, and from this study, for hip breadth, stature and buttock-knee length (all measurements in mm; N/A indicates data was unavailable, text in bold indicates measurements in excess of the recommendations being compared to)

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<td>667</td>
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Table 27: Calculated 1st and 99th percentile anthropometry data from other sources and from this study, for hip breadth, stature and buttock-knee length (all measurements in mm; N/A indicates data was unavailable, text in **bold** indicates data with a greater range than both other data sets, text in *italics* indicates data with a greater range than just one of the other data sets)

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<td><strong>Women</strong></td>
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</table>
7.9.5 Joint movements

The mean and standard deviation joint angles, along with any significant t-test results, are given in Table 28 (men and women), Table 29 (disabled and able-bodied participants), and Table 30 (older and younger participants). It can be seen that the comfortable ranges of joint movements for men and women were not significantly different, other than for wrist adduction, where \( p=0.05 \).

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</table>

*Table 28: Joint movement results for men and women: mean angle (in degrees) and standard deviation for each measure taken, with significant differences, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).*

In contrast, Table 29 shows nine significant differences between able-bodied and disabled participants: shoulder flexion, arm extension, flexion and abduction, elbow extension and supination, and wrist extension, flexion and adduction. The degree of comfortable joint movement was greater for able-bodied participants than disabled participants for all these measures. It is feasible to suggest that these differences may be due to the effect of the specific impairments that the disabled participants experienced. It should also be noted that arm extension was only recorded for 83 participants, as some participants in wheelchairs experienced problems due to the back of the chair being restrictive to this movement. This in itself suggests that the situation could be even worse, with these participants being restricted in their movements because of the wheelchair.
Joint movement | Disabled | Able-bodied | T-test significance level
--- | --- | --- | ---
| N | Mean | SD | N | Mean | SD | **
Shoulder extension | 55 | 20.5 | 7.4 | 45 | 24.1 | 6.9 |
Shoulder flexion | 55 | 5.2 | 3.8 | 45 | 7.7 | 4.0 |
Shoulder abduction | 55 | 9.2 | 5.5 | 45 | 12.4 | 6.4 |
Shoulder adduction | 55 | 16.0 | 5.1 | 45 | 17.6 | 6.9 |
Arm extension | 38 | 47.2 | 15.1 | 45 | 57.3 | 19.7 |
Arm flexion | 55 | 143.8 | 22.5 | 45 | 159.2 | 22.2 |
Arm abduction | 55 | 118.0 | 41.1 | 45 | 159.2 | 24.9 |
Arm adduction | 55 | 44.1 | 28.1 | 45 | 48.0 | 20.4 |
Arm medial rotation | 55 | 73.7 | 17.7 | 45 | 74.9 | 13.8 |
Arm lateral rotation | 55 | 54.5 | 21.2 | 45 | 62.3 | 14.9 |
Elbow extension | 53 | 1.8 | 2.0 | 45 | 2.8 | 2.7 |
Elbow flexion | 55 | 145.2 | 14.9 | 45 | 149.8 | 13.4 |
Elbow pronation | 55 | 82.0 | 16.6 | 45 | 81.8 | 12.1 |
Elbow supination | 55 | 81.7 | 13.3 | 45 | 91.6 | 8.5 |
Wrist extension | 55 | 52.6 | 18.1 | 45 | 63.1 | 12.4 |
Wrist flexion | 55 | 49.1 | 16.2 | 45 | 57.3 | 15.9 |
Wrist abduction | 55 | 14.9 | 9.6 | 45 | 18.5 | 9.1 |
Wrist adduction | 55 | 34.2 | 14.0 | 45 | 40.8 | 11.7 |

Table 29: Joint movement results for disabled and able-bodied participants: mean angle (in degrees) and standard deviation for each measure taken, with significant differences, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).

Table 30 shows the comparison of joint angle movements for older and younger participants. It can be seen that the comfortable ranges of joint movements were not significantly different, other than, once again, for wrist adduction, where p=0.05, with younger participants having the greater range of motion. Suprisingly, whilst no further significant differences were found, it can be seen that of the 18 joint movements measured, older participants had a greater range of motion than younger participants for arm flexion, elbow flexion, elbow pronation, wrist extension and wrist abduction.
<table>
<thead>
<tr>
<th>Joint movement</th>
<th>Older</th>
<th>Younger</th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Shoulder extension</td>
<td>36</td>
<td>22.3</td>
<td>6.9</td>
</tr>
<tr>
<td>Shoulder flexion</td>
<td>36</td>
<td>6.1</td>
<td>3.6</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>36</td>
<td>11.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Shoulder adduction</td>
<td>36</td>
<td>16.7</td>
<td>6.6</td>
</tr>
<tr>
<td>Arm extension</td>
<td>36</td>
<td>50.0</td>
<td>12.5</td>
</tr>
<tr>
<td>Arm flexion</td>
<td>36</td>
<td>154.9</td>
<td>14.8</td>
</tr>
<tr>
<td>Arm abduction</td>
<td>36</td>
<td>141.6</td>
<td>33.1</td>
</tr>
<tr>
<td>Arm adduction</td>
<td>36</td>
<td>39.9</td>
<td>21.0</td>
</tr>
<tr>
<td>Arm medial rotation</td>
<td>36</td>
<td>72.8</td>
<td>16.5</td>
</tr>
<tr>
<td>Arm lateral rotation</td>
<td>36</td>
<td>57.0</td>
<td>21.1</td>
</tr>
<tr>
<td>Elbow extension</td>
<td>36</td>
<td>2.2</td>
<td>2.4</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>36</td>
<td>149.4</td>
<td>15.4</td>
</tr>
<tr>
<td>Elbow pronation</td>
<td>36</td>
<td>82.9</td>
<td>12.7</td>
</tr>
<tr>
<td>Elbow supination</td>
<td>36</td>
<td>87.4</td>
<td>10.3</td>
</tr>
<tr>
<td>Wrist extension</td>
<td>36</td>
<td>59.3</td>
<td>14.3</td>
</tr>
<tr>
<td>Wrist flexion</td>
<td>36</td>
<td>48.2</td>
<td>13.5</td>
</tr>
<tr>
<td>Wrist abduction</td>
<td>36</td>
<td>18.5</td>
<td>10.3</td>
</tr>
<tr>
<td>Wrist adduction</td>
<td>36</td>
<td>32.5</td>
<td>9.7</td>
</tr>
</tbody>
</table>

Table 30: Joint movement results for older and younger participants: mean angle (in degrees) and standard deviation for each measure taken, with significant differences, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).

7.9.6 Coefficient of Variation

The coefficient of variation is the standard deviation of the main data collection phase sample as a percentage of the mean value. A high coefficient of variation is indicative of a skewed distribution of the sample. That is, the sample is not a normal distribution (with the same number of points above and below the mean), but skewed (with more data points on one side of the mean than the other). The coefficient of variation for the data from the main data collection phase for the different body measures is compared to that of Pheasant (1999) in Table 31. The data in Pheasant (1999) are quoted as being obtained from a number of sources, and as such are not indicative of a population, but provide a guide to the approximate level of variation expected.

Able and disabled participants were considered separately as it is generally acknowledged that disabled populations will have a greater variance for anthropometric data than able-bodied populations. Table 31 shows that the coefficient of variation for the main data collection phase samples was greater than would be expected, and therefore not normally distributed, but skewed. This is not altogether surprising, given that the whole main data collection phase sample was...
biased towards older and disabled participants, and no attempt was made to select a sample that was representative, either of the population as a whole or of the older or disabled population. However, it can be said that the ranking of the coefficient of variation values for both the able-bodied and disabled groups is roughly equivalent to that of Pheasant (1999), in that there is less variation for stature, and a greater variation for weight.

<table>
<thead>
<tr>
<th></th>
<th>Pheasant (n unknown)</th>
<th>Able (n=54)</th>
<th>Disabled (n=46)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stature</td>
<td>3-4</td>
<td>6.2</td>
<td>9.2</td>
</tr>
<tr>
<td>Body heights</td>
<td>3-5</td>
<td>5.9-9.2</td>
<td>10-13.1</td>
</tr>
<tr>
<td>Parts of limbs</td>
<td>4-5</td>
<td>7.1-16.5</td>
<td>9.1-15.7</td>
</tr>
<tr>
<td>Body breadths</td>
<td>5-9</td>
<td>7.9-10.3</td>
<td>12.8-15.9</td>
</tr>
<tr>
<td>Body depths</td>
<td>6-9</td>
<td>12.6-18.4</td>
<td>9.1-17.5</td>
</tr>
<tr>
<td>Weight</td>
<td>10-21</td>
<td>17.6</td>
<td>24.3</td>
</tr>
</tbody>
</table>

*Table 31: Comparison of coefficient of variation obtained for the able and disabled participants with Pheasant (1999)*

### 7.9.7 Physical capabilities

With regard to physical characteristics, 7% of the participants were left-handed, 90% were right-handed, and 3% were ambidextrous. When asked ‘how handed’ they were, and whether they could use their other hand if they had to, 46% of all participants (23 able-bodied and 20 disabled people) replied that they could use their other hand “if they had to”. However, this was a subjective measure as it was not specified exactly what a person ‘could do if they had to’ with their non-dominant hand, and all indicated that the dominant hand would still be their preferred hand. 31% responded that they were ‘very’ handed and so would have problems if they had to rely on their other hand. One participant was unable to use one hand, and interestingly, seven participants had swapped handedness as a result of their impairments.

In order to assess aspects of flexibility and the postures that people could achieve, participants were asked a number of questions about their physical capabilities. They were asked how far they could reach if they were to bend forward in a classic ‘touch your toes’ manner (keeping the knees straight), whether they could reach to tie their shoelaces, and whether they could get up unaided from lying down. Figure 26 shows reported capabilities in reaching their toes. Surprisingly, 42% of the sample reported that they could touch either their toes or the floor (23 able-bodied and 19 disabled participants). In response to being asked if they could get up from a lying-down position unaided, ten participants reported that they could not, although three of those who said that they could, said that they could “only just manage” it.
When asked if they could reach to tie their shoelaces from a sitting position, only five disabled participants reported that they were unable to do this, with one of the participants who could reach responding that they could only just manage it. It should be noted that participants were only asked if they could reach to tie their shoelaces, not whether they could actually tie them (as this concerns fine manual dexterity, which it is beyond the abilities of the computer-based design tool to model).

Participants were also asked if they could twist their upper body (keeping the hips still) to the left and right. Figure 27 shows the reported responses to this question. 90% of participants could twist their upper body fully in both directions, indicating a good degree of upper body flexibility. Only two participants could not twist in either direction, having very restricted flexibility, and two participants could only twist a small amount to both sides. It was found that very few participants experienced asymmetrical twisting ability, with only one participant reporting being able to twist fully to the left but only partly to the right, and one reporting the opposite.
Participants were asked which of 6 lines of text (with letters 30 cm high, 19 cm high, 12 cm high, 9 cm high, 7 cm high, and 5 cm high) they could read from a distance of approximately 1 metre (the test card was placed on the wall behind the oven rig). Participants were allowed to wear the glasses that they would normally be using, and were scored according to how many lines of text they could read. For example, if all six lines were read, that scored a 6, if only three lines were read, the score was 3. Ninety-one participants took this test (the rest were erroneously omitted). 94% of these participants were able to read all six lines of text. There was no indication that older participants were limited in distant vision when wearing corrective glasses.

Table 32 shows the results for the peg test and the grip strength test, for the different groups. Of the 83 participants who attempted the peg test, only 3 failed to complete it. It can be seen in Table 32 that there was little difference between peg-test times for men and women, but disabled people took longer than able-bodied (mean 89.8 s, SD 41.1, as opposed to mean 52.7 s, SD 7.1), and older participants took longer than younger participants (mean 62.8 s, SD 10.2, compared to mean 41.1 s, SD 11.6). Such differences would be predicted for those disabled and older participants with problems affecting their hands and fine dexterity.
Maximum comfortable grip strength was assessed in 88 participants, with 2 kg being the minimum recorded strength, and 70 kg the maximum. Table 32 shows that disabled participants had weaker grip strength than able-bodied participants (mean 23.9 kg, SD 12.2, compared to mean 37.6 kg, SD 14.2), and men were found to have stronger grip strength than women (mean 38.1 kg, SD 14.6, compared to 21.2 kg, SD 10.0). Again, this would be expected given that the disabled participant may have been suffering from impairments in the muscles of the hand and arm, and also it is generally known that men are, on the whole, physically stronger than women.

<table>
<thead>
<tr>
<th></th>
<th>Older</th>
<th></th>
<th>Younger</th>
<th></th>
<th></th>
<th></th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>28</td>
<td>26.7</td>
<td>11.0</td>
<td>28</td>
<td>33.3</td>
<td>18.7</td>
<td>**</td>
</tr>
<tr>
<td>Peg test</td>
<td>24</td>
<td>62.8</td>
<td>10.2</td>
<td>24</td>
<td>54.1</td>
<td>11.6</td>
<td></td>
</tr>
<tr>
<td>Disabled</td>
<td></td>
<td></td>
<td></td>
<td>Able-bodied</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>33</td>
<td>23.9</td>
<td>12.2</td>
<td>33</td>
<td>37.6</td>
<td>14.2</td>
<td>**</td>
</tr>
<tr>
<td>Peg test</td>
<td>28</td>
<td>89.8</td>
<td>41.1</td>
<td>28</td>
<td>52.7</td>
<td>7.1</td>
<td>**</td>
</tr>
<tr>
<td>Men</td>
<td></td>
<td></td>
<td></td>
<td>Women</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>34</td>
<td>38.1</td>
<td>14.6</td>
<td>34</td>
<td>21.2</td>
<td>10.0</td>
<td>**</td>
</tr>
<tr>
<td>Peg test</td>
<td>27</td>
<td>67.5</td>
<td>23.9</td>
<td>27</td>
<td>68.8</td>
<td>31.3</td>
<td></td>
</tr>
</tbody>
</table>

Table 32: Mean, standard deviation and t-test significance level for the peg test task (in seconds) and the grip strength task (in kg), where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level)

7.9.8 Task-specific data and capabilities

Participants were assessed getting in and out of chairs to simulate seated scenarios (for example getting on and off a toilet or in and out of a bus seat). The effort that participants required to get out of the chairs was assessed by video analysis, using a 5-point scale (see Section 7.3.2). Some participants were erroneously omitted from the seating tasks. Details of how participants succeeded with getting in and out of the chairs is given in Table 33. Those participants who found getting in and out of the chairs ‘impossible without the aid of another person’ were all in wheelchairs, and unable to self-transfer. It can be seen that the low chair caused most problems, with only 19% of participants having ‘no problems’ getting in and out of the chair, and 10% finding it ‘impossible without the aid of another person’. Several participants reported anecdotally that the chair would be too low for them, although the arms on the chair did assist many participants.
<table>
<thead>
<tr>
<th></th>
<th>Low chair – free access</th>
<th>Conference chair – free access</th>
<th>Conference chair – front-restricted</th>
<th>Conference chair – side-restricted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – no problems</td>
<td>19</td>
<td>68</td>
<td>53</td>
<td>62</td>
</tr>
<tr>
<td>2 – slight problems, need use one hand to lift/push self up</td>
<td>2</td>
<td>4</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>3 – considerable problems, need use two hands to lift/push self up</td>
<td>59</td>
<td>10</td>
<td>19</td>
<td>14</td>
</tr>
<tr>
<td>4 – severe problems, need use both hands &amp;/or take several attempts &amp;/or change position to attempt stand</td>
<td>10</td>
<td>9</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>5 – impossible without the aid of another person</td>
<td>10</td>
<td>8</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>N</td>
<td>93</td>
<td>97</td>
<td>94</td>
<td>95</td>
</tr>
</tbody>
</table>

Table 33: Percentage of participants experiencing different degrees of difficulty getting out of different chairs.

Participants were assessed putting objects of different weights onto a range of heights of shelves in a ‘kitchen’ set-up, and were coded as to the postures they obtained during the ‘kitchen’ tasks (see Section 7.3.2). Table 34 shows the results of t-tests to compare the weights lifted (in grammes) on to the kitchen shelves, by the different participant groups. Nine disabled participants were unable to lift the two-handed tray (4 women, 5 men). It can be seen that the bag weight lifted varied very little between any of the groups (with a mean weight of between 950 g and 1000 g), whereas the two-handed tray weight varied greatly (with a mean weight of between 1291.4 g and 1810.7 g), with able-bodied participants lifting significantly more (p=0.02) than disabled participants. Interestingly, the only other significant difference found was that older participants lifted more in the one-handed beaker than younger participants did. The younger participants included some of the more seriously disabled participants, which may have affected their ability to lift the same weights.
<table>
<thead>
<tr>
<th></th>
<th>Older</th>
<th></th>
<th>Younger</th>
<th></th>
<th>T-test significance level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td>One-handed beaker</td>
<td>30</td>
<td>535.0</td>
<td>72.4</td>
<td>30</td>
<td>475.1</td>
</tr>
<tr>
<td>Two-handed tray</td>
<td>28</td>
<td>1592.9</td>
<td>493.6</td>
<td>28</td>
<td>1660.0</td>
</tr>
<tr>
<td>Bag (one or two hands)</td>
<td>28</td>
<td>1000.0</td>
<td>0.0</td>
<td>28</td>
<td>950.0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Disabled</td>
<td></td>
<td>Able-bodied</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-handed beaker</td>
<td>37</td>
<td>517.5</td>
<td>89.9</td>
<td>37</td>
<td>533.7</td>
</tr>
<tr>
<td>Two-handed tray</td>
<td>27</td>
<td>1291.4</td>
<td>421.2</td>
<td>27</td>
<td>1810.7</td>
</tr>
<tr>
<td>Bag (one or two hands)</td>
<td>32</td>
<td>978.1</td>
<td>123.7</td>
<td>32</td>
<td>1000.0</td>
</tr>
<tr>
<td></td>
<td>N</td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td>Men</td>
<td></td>
<td>Women</td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-handed beaker</td>
<td>36</td>
<td>532.8</td>
<td>77.8</td>
<td>36</td>
<td>528.2</td>
</tr>
<tr>
<td>Two-handed tray</td>
<td>27</td>
<td>1751.2</td>
<td>404.9</td>
<td>27</td>
<td>1651.0</td>
</tr>
<tr>
<td>Bag (one or two hands)</td>
<td>30</td>
<td>976.7</td>
<td>127.8</td>
<td>30</td>
<td>1000.0</td>
</tr>
</tbody>
</table>

**Table 34:** Mean, standard deviation and significant differences for weights (in grams) of items lifted during the kitchen tasks, where N is the number of participants measured (* = significant at 0.05 level, ** = significant at 0.02 level).

In order to illustrate some of the different postures that participants adopted during the task-based activities, three images taken from the video footage recorded are included (Figures 28, 29 and 30). It can be seen that participants were able to adopt any posture that they were happy to do so, in order to place an item on the lowest shelf of the kitchen rig. The different postures reflect the capabilities of the participants with regard to the task. Such variation in behaviours would be impossible to predict from tables of percentiles alone, and requires data about individuals to be kept as complete data sets.
Before details of the postures attained by all participants in the sample are discussed, the postures of the individuals in Figures 28, 29 and 30 are presented in Table 35, in order to illustrate and explain some of the postures adopted, and how these were coded.
<table>
<thead>
<tr>
<th>Posture</th>
<th>Figure 28</th>
<th>Figure 29</th>
<th>Figure 30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leg position</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs straight (180° - 170°)</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>Legs bent between 171° and 120°</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Legs bent between 119° and 40°</td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs bent between 39° and 0°</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kneeling on the left knee</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kneeling on the right knee</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Sitting</td>
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<td>*</td>
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<tr>
<td><strong>Back position</strong></td>
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</tr>
<tr>
<td>No back twist</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Left back twist</td>
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<tr>
<td>Right back twist</td>
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<td></td>
</tr>
<tr>
<td>Upright back (0° to 10°)</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Back lean (11° - 45°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back bend (46° +)</td>
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<td></td>
<td>*</td>
</tr>
<tr>
<td><strong>Use of aids</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No aids needed</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Chair used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-handed support used</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaning for support</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 35: Part of the posture analysis coding for the participants in Figures 28, 29 and 30 (* indicates the posture observed and recorded).

Table 36 compares the different postures for placing items on the highest shelf, to those for the lowest shelf. It can be seen that, generally, the postures adopted for placing items on the highest shelf involved less leg and back bend, whilst placing items on the lowest shelf resulted in a greater frequency of leg and back bending, and also use of one-handed support to help participants’ balance as they bent over.

Some of the aspects of the postures adopted varied greatly, with back twist being an example of this. When placing the cup, tray and bag on the lowest shelf of the kitchen rig, 31%, 58% and 38% of participants respectively showed no back twist, with the remainder twisting either to the left or right. When placing the same items on the top shelf, 73%, 79% and 69% respectively did not twist their backs. As a further example, 80% of participants kept their legs straight when placing a cup or bag on to the highest shelf, with 78% keeping their legs straight when placing the tray on the top shelf. In comparison, only 2% kept their legs straight when placing the tray on the lowest shelf, with 3% and 4% keeping their legs straight when placing the cup and bag on the
lowest shelf respectively. Instead, when placing a tray on the lowest shelf, 27% of participants bent their legs to between 39° and 0°, and 4% of participants chose to kneel.

<table>
<thead>
<tr>
<th>Posture</th>
<th>Lowest shelf (4 cm)</th>
<th>Highest shelf (140 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cup</td>
<td>Tray</td>
</tr>
<tr>
<td><strong>Leg position</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Legs straight (180°-170°)</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Legs bent between 171° and 120°</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
<td>Legs bent between 119° and 40°</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Legs bent between 39° and 0°</td>
<td>22</td>
<td>27</td>
</tr>
<tr>
<td>Kneeling on the left knee</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Kneeling on the right knee</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sitting</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td><strong>Back position</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No back twist</td>
<td>31</td>
<td>58</td>
</tr>
<tr>
<td>Left back twist</td>
<td>41</td>
<td>15</td>
</tr>
<tr>
<td>Right back twist</td>
<td>24</td>
<td>13</td>
</tr>
<tr>
<td>Upright back (0° to 10°)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Back lean (11°-45°)</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>Back bend (46°+)</td>
<td>59</td>
<td>54</td>
</tr>
<tr>
<td><strong>Use of aids</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No aids needed</td>
<td>54</td>
<td>65</td>
</tr>
<tr>
<td>Chair used</td>
<td>17</td>
<td>9</td>
</tr>
<tr>
<td>1-handed support used</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>Leaning for support</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 36: Comparison of percentage of participants demonstrating different postural capabilities when placing a cup, tray, and bag separately on to each of two shelves: 4 cm and 140 cm from ground level.

7.9.9 Comparison of data from six participants

In order to further highlight the advantages of presenting data as individual data sets, the anthropometric, joint constraint and severity of disability data for six participants were compared. Figure 31 illustrates the individuals selected for this comparison.

Table 37 shows a comparison of joint movements and general postural abilities for the six individuals. It can be seen that, although these older women have the same stature, participant B has greater range of joint movements for most of the movements assessed, except for wrist adduction, elbow supination, elbow flexion, arm medial rotation, and arm adduction. The greatest difference in joint movement between participants B and A is a 57° difference in arm flexion.
For the older men with nearly the same stature, less difference was found in range of joint movement between the two, with identical measurements for wrist extension, and the other measures which had the greater range of movement being split between the two men. The largest difference in range of movement was 33° for arm flexion. The wheelchair participants of the same age and gender had identical joint range movements for elbow extension and shoulder abduction. The largest difference in joint movements was 81° for arm abduction. These comparisons highlight the variability of joint movements between people.

Figure 31: Participants chosen for comparison
<table>
<thead>
<tr>
<th>Participant number</th>
<th>Older women (same stature)</th>
<th>Older men (nearly same stature)</th>
<th>Wheelchair users (same gender and age)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>Shoulder extension</td>
<td>36</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Shoulder flexion</td>
<td>10</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>11</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Shoulder adduction</td>
<td>15</td>
<td>5</td>
<td>24</td>
</tr>
<tr>
<td>Arm extension</td>
<td>46</td>
<td>33</td>
<td>34</td>
</tr>
<tr>
<td>Arm flexion</td>
<td>152</td>
<td>95</td>
<td>135</td>
</tr>
<tr>
<td>Arm abduction</td>
<td>90</td>
<td>79</td>
<td>138</td>
</tr>
<tr>
<td>Arm adduction</td>
<td>24</td>
<td>37</td>
<td>22</td>
</tr>
<tr>
<td>Arm rotation</td>
<td>29</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Arm lateral rotation</td>
<td>46</td>
<td>24</td>
<td>60</td>
</tr>
<tr>
<td>Elbow extension</td>
<td>10</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>135</td>
<td>143</td>
<td>152</td>
</tr>
<tr>
<td>Elbow pronation</td>
<td>87</td>
<td>60</td>
<td>95</td>
</tr>
<tr>
<td>Elbow supination</td>
<td>90</td>
<td>101</td>
<td>85</td>
</tr>
<tr>
<td>Wrist extension</td>
<td>71</td>
<td>37</td>
<td>53</td>
</tr>
<tr>
<td>Wrist flexion</td>
<td>30</td>
<td>60</td>
<td>53</td>
</tr>
<tr>
<td>Wrist abduction</td>
<td>20</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Wrist adduction</td>
<td>20</td>
<td>47</td>
<td>40</td>
</tr>
</tbody>
</table>

Table 37: Comparison of joint constraints (given in °) for six participants, matched in terms of stature or age (* indicates data was not collected (was omitted), N/A indicates that it the measure was not applicable for that participant, due to restrictions of movement due to wheelchairs, or inability to stand)

General details and anthropometry for these individuals are given in Table 38. For the older women with the same stature, there were no other physical dimensions taken on which they had the same measurement. However, estimates of anthropometry are often made using formulae that calculate measurements such as arm length and so on from stature. If this were the case, both these women would be predicted to have the same measurements for all the dimensions. A similar pattern is found in the older men with nearly the same stature: they are identical on only one other dimension (eye-to-top-of-head), for the other dimensions participant D is larger for ten and participant B is larger for the other 16.
Table 38: Comparison of general information and anthropometry for six participants, matched in terms of stature or age (* indicates data was not collected (was omitted), N/A indicates that it the measure was not applicable for that participant, due to restrictions of movement due to wheelchairs, or inability to stand)

<table>
<thead>
<tr>
<th>Participant number</th>
<th>Older women (same stature)</th>
<th>Older men (nearly same stature)</th>
<th>Wheelchair users (same gender and age)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>A</td>
<td>D</td>
</tr>
<tr>
<td>Age</td>
<td>72</td>
<td>82</td>
<td>64</td>
</tr>
<tr>
<td>Severity of disability</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>96.7</td>
<td>64.5</td>
<td>73.2</td>
</tr>
<tr>
<td>Stature</td>
<td>1579</td>
<td>1579</td>
<td>1742</td>
</tr>
<tr>
<td>Arm length</td>
<td>705</td>
<td>708</td>
<td>744</td>
</tr>
<tr>
<td>Upper arm length</td>
<td>327</td>
<td>342</td>
<td>328</td>
</tr>
<tr>
<td>Elbow-shoulder length</td>
<td>267</td>
<td>314</td>
<td>228</td>
</tr>
<tr>
<td>Wrist-elbow length</td>
<td>203</td>
<td>230</td>
<td>229</td>
</tr>
<tr>
<td>Abdominal depth (standing)</td>
<td>340</td>
<td>288</td>
<td>250</td>
</tr>
<tr>
<td>Thigh depth (standing)</td>
<td>200</td>
<td>147</td>
<td>169</td>
</tr>
<tr>
<td>Knee-hip length</td>
<td>454</td>
<td>457</td>
<td>423</td>
</tr>
<tr>
<td>Ankle-knee length</td>
<td>365</td>
<td>412</td>
<td>385</td>
</tr>
<tr>
<td>Ankle height</td>
<td>96</td>
<td>65</td>
<td>73</td>
</tr>
<tr>
<td>Foot length</td>
<td>246</td>
<td>260</td>
<td>255</td>
</tr>
<tr>
<td>Sitting height</td>
<td>842</td>
<td>847</td>
<td>932</td>
</tr>
<tr>
<td>Sitting shoulder height</td>
<td>566</td>
<td>514</td>
<td>551</td>
</tr>
<tr>
<td>Hip-shoulder</td>
<td>392</td>
<td>405</td>
<td>450</td>
</tr>
<tr>
<td>Chest height</td>
<td>362</td>
<td>346</td>
<td>456</td>
</tr>
<tr>
<td>Chest depth</td>
<td>384</td>
<td>275</td>
<td>245</td>
</tr>
<tr>
<td>Head height</td>
<td>215</td>
<td>181</td>
<td>236</td>
</tr>
<tr>
<td>Eye-to-top-of-head</td>
<td>104</td>
<td>91</td>
<td>119</td>
</tr>
<tr>
<td>Buttock-knee length</td>
<td>603</td>
<td>598</td>
<td>496</td>
</tr>
<tr>
<td>Abdominal depth (sitting)</td>
<td>371</td>
<td>290</td>
<td>280</td>
</tr>
<tr>
<td>Thigh depth (sitting)</td>
<td>163</td>
<td>112</td>
<td>145</td>
</tr>
<tr>
<td>Knee height</td>
<td>499</td>
<td>534</td>
<td>415</td>
</tr>
<tr>
<td>Shoulder breadth</td>
<td>364</td>
<td>351</td>
<td>397</td>
</tr>
<tr>
<td>Hip breadth (external)</td>
<td>473</td>
<td>360</td>
<td>368</td>
</tr>
<tr>
<td>Hip breadth (link)</td>
<td>353</td>
<td>294</td>
<td>297</td>
</tr>
<tr>
<td>Hand length</td>
<td>180</td>
<td>190</td>
<td>186</td>
</tr>
<tr>
<td>Grip Length</td>
<td>71</td>
<td>53</td>
<td>66</td>
</tr>
</tbody>
</table>
Comparison of the data in Tables 37 and 38 further highlights the need for a multivariate approach. A designer considering any of these anthropometric dimensions and joint constraints needs to be aware of the variability both within and between people. It is not possible to predict this variability without reference to individual people. Even if a participant is larger overall than another, it still does not necessarily follow that they will be larger on all dimensions being considered, and vice versa for smaller participants.

7.10 Discussion

The results of the main data collection phase are discussed in this section, along with an examination of the validity and reliability of the data collected. Utilisation of these data within the computer-based design tool is presented in Chapter 8.

7.10.1 Anthropometry

It appears from comparisons of older versus younger participants that the anthropometry of older participants is significantly different from that of younger participants for a number of anthropometric measures. Significant differences at the p=0.05 level and above were found for 12 of the 28 dimensions measured. Such findings were expected due to factors such as secular growth resulting in the older generation being generally physically smaller than the younger generation (Pheasant, 1999). This also reflects the physiological changes in the body due to increased age, such as reduced muscle mass (Lindle et al, 1997).

As expected there were fewer differences between the anthropometry of disabled and able-bodied people, with significant differences only being found for stature, sitting height, sitting shoulder height, and chest height. As an example for stature the results were mean 1633 mm, SD 149.7 for disabled participants, with mean 1691 mm, SD 105.1 for able-bodied participants (significant at the p=0.02 level). This is likely to be explained by the fact that stature could not be measured for 18 of the wheelchair participants. It is also highly likely that there may have been inaccuracies with measuring sitting height and sitting shoulder height for the 20 wheelchair participants, as they were measured in their chairs using an anthropometer, whereas the other participants were measured using a sitting height table. This suggests that alternative methods for collecting these specific dimensions may need to be considered for future data collection, in order to increase accuracy.
A high coefficient of variation indicates skew of the normal distribution. It is generally acknowledged that disabled populations have greater anthropometric variance than able-bodied populations. The results for coefficient of variation for stature, body heights, parts of limbs, body breadths, body depths, and weight of the sample varied widely from the range given in Pheasant (1996). This may be due to the fact that the study sample was not selected to be truly representative of the population in terms of anthropometry, or to differences between whoever was in the ‘population’ in Pheasant (no details of which are given) and the sample in the data collection phase. However, a similar ranking of variance was reflected by the findings of this study, with stature yielding smaller variances than weight, which is the expected pattern as reported by Pheasant (1996), suggesting that the data obtained are still valid when compared to population data.

Comparison of three of the anthropometric dimensions collected during the study was made with the same dimensions from anthropometric data sources mentioned in the survey of design professionals (Chapter 3). These sources were Pheasant (1988), Adultdata (1998) and Olderadultdata (2000). The comparison made in Section 7.9.4 provides evidence that these sources do not cover the variation in body dimensions that are found in older and disabled populations. It was found that, when calculations of 1st-99th percentile were compared, the new data collected provided a wider range of measurements than both the other data sources for 24 of the possible 36 dimensions. This suggests that designers using the new data to set, for example, clearance limits will include a larger proportion of the population than if they used the other data sources. This in turn implies that the computer-based design tool will consider a wider range of participants’ dimensions when estimating percentage accommodated. These findings indicate that designers will inevitably continue to ‘design out’ more people in the general population if they design using existing data sources. It must also be remembered that participants ‘designed out’ or excluded due to having measurements above 95th percentile on one dimension, may not be the same people who are designed out due to having measurements above 95th percentile on a different dimension. Therefore the number of people being excluded from consideration in the design process increases, potentially increasing the number of people who may encounter problems with a design.

In order for designers to consider the needs of older and disabled people when designing it is therefore essential that up-to-date and accurate data is made available. With the best will in the world, without the correct, relevant data being available a designer cannot adequately consider the
wide variety of sizes, shapes and capabilities of humans. The comparison of the study data with existing data also allows some validation of the data, as it is comparable to existing databases. Highlighting the variability within people, in terms of anthropometry and joint constraints, shows that inclusion of individual data sets is a good way of conveying such rich, multivariate information. The comparison of the postures and measurements of six participants (Section 7.9.9) also highlights the need for multivariate data, showing that, for example, although the two older women had the same stature, no other anthropometric dimension measured was the same.

The data presented in this chapter are mostly presented in tables, exactly demonstrating to the reader the problem that designers have accessing such information. Tables such as those in Section 7.9.3 are not immediately accessible; they require reading and interpretation, although the origins of the data in them are fully documented and available. These tables only show the mean and standard deviation, requiring designers to either calculate further percentile values themselves, or else use the 50th percentile mean as given, with all the inherent problems that this would cause. This text-based thesis and study are in contrast to the graphics of the computer-based design tool and the visual images that can be generated using the anthropometric data collected. Data sources such as the diagrams presented by Dreyfuss (1978), begin to address the need for data to be in a visual format, but convey the concept of the ‘average man’, with the idea that people come in small, medium and large. Other data sources have tried to move beyond this, with more detailed and variable anthropometry available, such as PeopleSize (1998) with its database of anthropometry and manikins. The SAMMIE computer-aided design tool, with its human-modelling capabilities allows designers to vary anthropometry and move human models to test design scenarios, but is not a database within its own right, and requires training and ergonomics knowledge. Within the computer-based design tool being constructed as part of this research, the anthropometric data collected would be available to design professionals as a database, and would also be used by the tool to construct the individuals to be assessed in the estimation of percentage accommodated by a given design.

7.10.2 Joint angles
When comparing joint ranges between the sample groups it would be expected that differences would be found between the abilities of able-bodied and disabled participants, due to the limiting nature of certain impairments. The results supported these expectations, with significant differences at the p=0.05 level and above being found for 9 of the 18 movements measured. It was not certain that such a difference would be found between older and younger participants, as
such movements may be less dependent on age and more dependent on ability. It was expected that some difference would exist, however, as flexibility of joints may decrease to some degree in old age, irrespective of direct impairment. However, a significant difference between older and younger participants was only found for wrist adduction, at the p=0.05 level. Such findings do not match the work of Bassey et al (1989), who found a decrease in shoulder abduction in older participants. However, this is not that surprising given the level of disability within the sample in the main data collection phase sample. Overall, despite the lack of statistically significant differences, the results do reflect the fact that joint flexibility decreases with age, with younger participants having a greater mean range of movement than older participants for 13 of the 18 measurements taken. It was not possible to compare the findings of this research with other researchers such as Vandervoort et al (1992), due to differences in the measures taken.

All participants were asked to only move to their comfortable maximum, rather than to attempt their maximum joint angle movement. This was done in order to minimise the risk of injury, and also to reflect the fact that in most activities of daily life, most people would move only within their personal comfort limits. However, some participants may have interpreted this differently, and been prepared to move further to the limits of their comfort than others. This is not seen as an error as such, as it is likely that in an every day situation, people are likely to adjust and limit their movements accordingly. For instance, people who are hesitant about over-exerting themselves in the laboratory setting, could probably be expected to react in a similar way when at home. It must also be remembered that goniometry can result in inaccuracies of reading of joint angles, although efforts were made by the experimenters to avoid this.

7.10.3 Reach ranges

When reach ranges between groupings were compared, it was expected that differences would be found between older and younger participants, due to anthropometry differences, and between disabled and able-bodied participants, due to the impairments of the disabled participants. However, it may be that the sample did not contain a large enough spread of difference in ability and anthropometry that affected reach range. Also, it could be that the combination of anthropometry and joint movements which resulted in reach range capabilities is harder to detect for age group alone.

It appears from the results that prediction of reach range from other data may be possible. Correlation between reach range distance and anthropometry, severity of disability and joint
angles generally followed the expected pattern. Those individuals who were taller (namely men, or younger participants) generally had longer arms, and therefore reached further than smaller individuals (women, or older participants). It is interesting to note that men had fewer significant correlation coefficients than women did when reach range and anthropometry, severity of disability and joint angles were compared. It is not clear why this difference was found. It may be that variation was due to errors arising from inaccurate board location, or due to changes in degree of shoulder extension during reaches.

'Strong correlations' were given to be those where three or more of the four measures (minimum, maximum, mean, mode for each board position) correlated to the same anthropometry, joint angle or severity of disability score measure. Strong significant positive correlations were found for men between reach range and stature, arm length and upper arm length when the board was positioned at -60° and -30°, indicating that, not surprisingly, as stature, arm length and upper arm length increased, so did reach range distance. A strong negative correlation for men was found between reach range and severity score with the reach board at the 90° position. For women, there was strong positive correlation between reach range and arm length, upper arm length, and arm extension with the board at -60°, and between reach range and arm length, upper arm length, arm extension and stature at -30° and 0°. With the board at 30° strong positive correlation was found for reach range and stature, arm length, arm extension, and shoulder medial rotation. From these results it is suggested that prediction of reach range distance should be possible, at least for reach distances with the board in the horizontal position or angles above the horizontal, using stature and arm length data. Further investigation would be needed to determine if prediction were an accurate, and efficient method of obtaining reach range data.

Comparison of the reach range data and that found by previous research was difficult, given the variability in how the range was measured. For example, the data of Molenbroek (1999) included stature as part of vertical reach, and the Centre for Accessible Environments (1999) include the width of the body and wheelchair within their measurements of reach of wheelchair users. Wright, Major Kumar and Mittal (1994) measured horizontal reach range of 133 people aged between 65 and 89 years of age. Visual comparison of their findings with those of this study suggests that similar results were obtained for horizontal (board at 0°) reach ranges, although the difference in data collection methods prevents further detailed comparison.
Kirvesöya, Väyrynen and Häikiö (2000) investigated preferences for seat height and kitchen work-surface heights. Their work differs from this study in that participants in the main data collection phase were not asked for their preferences, merely observed interacting with the different seat heights. However, comparison can be made between some of the findings of the two sets of research. Kirvesöya, Väyrynen and Häikiö (2000) found that a 35 cm-high chair was not liked, with a 45 cm-high chair being the preferred height. This reflects the findings of this study, where 72% of participants were able to get up from the 47 cm-high chair with 'no problems' or 'slight problems', as opposed to only 21% who found the 39 cm-high chair similarly easy to rise from.

With regard to kitchen work surface heights, Kirvesöya, Väyrynen and Häikiö (2000) found a preference for surface heights or shelves between 30 cm and 85 cm. The results of this study again support the new findings, with the percentage of participants being unable to reach below this height (to the shelf at 14.5 cm from the ground) varying between 4% and 14% for the different items lifted. When asked to reach above 85 cm (to the shelf 140 cm from the ground), the percentage of participants unable to do so increased to between 14% and 20% for the items lifted. These results illustrating participants unable to reach above and below certain heights clearly reflect the preferences of the participants in the Kirvesöya, Väyrynen and Häikiö (2000) study.

Clark, Czaja and Weber (1990) also investigated the postures adopted during activities of daily life, in a study of 60 people aged between 55 and 95 years of age (see Section 4.5.3 for further discussion of this research). It is relevant to reiterate the fact that they concluded that there are certain movements that are common to many ADL, namely ability to lift/lower, push/pull, use a precision grip, stand for more than a few seconds, and to reach. They found that, of the tasks they observed, 95% involved using the hands and/or arms, with 60% of all actions involving lift/lower or push/pull, with leaning and reaching accounting for 21% of postures, and bending accounting for 14%. It is not possible to make a direct comparison between these data and the findings of the main data collection phase, due to differences in data collection methods. However, it can be seen that the overall pattern of results supports the main decision for this study, namely to include tasks involving use of the upper body, which reflects the focus on reach, lift, and bend.
7.11 Critique of the methodology

As discussed after the two surveys (Section 3.13 and Section 5.12) the sample of participants was not intended to be representative of the population as a whole, but to encompass a wide range of abilities in order to develop and test the proposed computer-based design tool. To ensure a wide range of individuals, sampling attempted to fulfill a specified quota for men and women, older and younger participants, and a spread across ability (as determined by the adapted OPCS scoring system, discussed in Section 6.8).

The task-based approach was novel and innovative, but the tasks that could be considered were constrained by the need to collect data without causing undue fatigue to participants, and by the modelling capabilities of the proposed computer-based design tool. The tool was unable to model fine motor dexterity, so gross movements were considered, yet to increase the usefulness of the tool the tasks needed to be those that contained generic elements. The inclusion of generic task elements allows the comparison of data to other task scenarios. As an example, getting in and out of the bath was a task that was highlighted by the survey of older and disabled people as being an activity that caused many problems. However, the postures and movements required to get in and out of the bath are not those that are employed in many other situations: getting in and out of bed being the only general comparison. On the other hand, cooking, and tasks associated in the kitchen, were also found to be very important to older and disabled people, and contain elements of lift, reach and bend that are applicable in many other situations, such as supermarket shopping, getting items out of cupboards, and so on. The importance of cooking tasks to older and disabled people was not an expected result of the survey of older and disabled people, but with hindsight it is not surprising that cooking has an impact on independence.

The posture analysis system devised for coding the postures attained during the task-based data collection was a simple concept that was very successful. The system was based loosely on the ideas of RULA (McAtamney & Corlett, 1993) and OWAS (Finnish Institute of Health, 1992). However, these two systems are specific to the workplace tasks for which they were devised, and therefore not applicable to the situation of older and disabled people performing ADL. Whilst encoding postures by use of video analysis was somewhat time-consuming, coding times did reduce with practice, and the use of video removed the need for participants to repeat tasks or maintain postures.
During the data collection phase there was a fine line between collecting as much data as possible, and keeping the trial length short to reduce the risk of tiring participants. It was necessary to prioritise which data were essential and required in detail, and what was of interest but acceptable to collect in a 'quick and dirty' manner. It was not considered feasible to ask participants to return for successive trials, so selectivity in terms of data required and collected was vital. Data such as grip strength, peg test times, reported ability to reach to toes/reach to tie shoelaces/get up from lying down/twist the upper body were not used in the computer-based design tool (Chapter 8) so may not be seen to be immediately useful to design professionals using the tool. However, it was felt that it was better to collect these data as there was the potential for use by design professionals as part of the database within the tool. In addition, collection of such data within one session also served to save the time and money involved in recalling participants for successive sessions.

Further work is needed into ways to present these data in order to maximise the potential, and investigate the collection of qualitative data (such as preferences, likes and dislikes, life aspirations, and so on) to increase the usefulness of the tool further.

### 7.12 Conclusions

In conclusion, the expected pattern of results, given the effects of age and disability, were found for anthropometry, joint constraints and reach range distances when the different sample groups were compared. Surprising findings were a lack of significant differences between the comfortable maximum joint angles of able-bodied and disabled participants, or between older and younger participants. Also, it appears that the prediction of reach range distance from anthropometry, joint movement angles and severity of disability is possible, at least for reach range with the arm held horizontal or at angles below the horizontal. This is potentially useful for prediction of reach range distances and volumes for populations where sure data is not currently available.

In addition, the sample data contained a wider range of anthropometry measurements than existing sources, which is what was required for the computer-based design tool. By showing that individuals vary greatly with regard to anthropometry also highlighted the need for a multivariate approach to designing. Finally, the task-based data collection highlighted the problems with bending to low shelves and reaching to high shelves, and the difficulties with sitting and rising from low chairs or those in restricted positions.
Chapter 8: The computer-based design tool

8.1 Introduction
The overall aim of the project was to develop a computer-based design tool to allow designers to predict the percentage of people accommodated by a design. The main data collection phase (Chapter 7) served to provide rich data on 100 individuals for this purpose. The tool itself was developed by another researcher in parallel with the research presented in this thesis. Brief details of the software behind the development, and the development of the tool itself, are given in this chapter. The interested reader is directed towards Marshall et al (2001), Marshall et al (2002), and Case et al (2001) which concern the computer-based design tool in more detail. This chapter also details feedback obtained from design professionals with respect to the tool, and case studies conducted in order to test and validate the predictive capabilities of the tool.

8.2 Aims
The main aims of the computer-based design tool were:
- to provide a database for design usage of anthropometry, joint constraints, reach range, and other physiological data
- to estimate percentage accommodated by a design
8.3 Development of the computer-based design tool

8.3.1 SAMMIE
SAMMIE (System for Aiding Man-Machine Interaction Evaluation) is a 3-dimensional human-modelling computer-aided design system. It is possible to vary the anthropometry of the human models, and also to define comfortable and maximum joint angle constraints. A workplace modeller is included in the package, to allow the interaction between the human models and the workplace models (such as cars, aeroplane cockpits, and so on) to be investigated (Porter et al, 1998). Further information concerning SAMMIE can be found in Case, Porter and Bonney (1990).

8.3.2 The computer-based design tool: HADRIAN
HADRIAN (Human Anthropometric Design Requirements Investigation and ANalysis) is the name given to the computer-based design tool that was developed as part of the EPSRC project. HADRIAN has two main aims: to provide a data base of information about individuals for designers to use when designing; and to allow designers to investigate which of these individuals could use a concept design and which could not and therefore effectively be designed-out. One of the objectives of the main data collection phase (Chapter 7) was to collect reliable and relevant data for HADRIAN to use during such predictions and to form a reliable and relevant database available to designers through the tool. Details of how these data are utilised within HADRIAN are given in this section.

Anthropometric data are essential in order to construct the individual participants within HADRIAN, as are joint constraint data. These were encoded into the tool in order to restrict the arm movements of the individual human-models to replicate the movements of the actual participants. These joint restrictions would therefore constrain the movements during the estimation of percentage accommodated. These joint constraint data would also be available to designers within the tool in the visual database.

The posture and behavioural analysis of the participants during the ‘kitchen’ tasks was also incorporated into HADRIAN. This information, along with the ‘virtual’ humans created from
anthropometry and joint constraint data, was used to predict the postures and behaviours the
individual human-models would adopt in similar situations. Images such as those in Section 7.9.8
were also made available in the tool for all participants, and included video clips of them
performing the kitchen and chair tasks recorded. These images may not be involved in the
prediction of percentage accommodated (who could use a design), but it was hoped that they
would provide an invaluable visual database and source of information for designers to see, and
empathise with, the problems people have performing tasks, and their methods for coping with
difficulties.

The reach range data obtained in this study were used to construct reach volumes within
HADRIAN, and an example of a resultant image is given in Figure 32. These reach range
volumes were then made available, along with the raw data co-ordinates, to designers in the tool,
and the volumes themselves were used in the estimation of percentage accommodated. Again, this
graphical representation of a reach range volume is in stark contrast to the tables in Section 7.9.2.
Pictorial representations of reach range volumes and reach range data are instantly understandable,
whereas tables of co-ordinates and reach distances require much work to produce volumes and
dimensions for design use.

Figure 32: HADRIAN image of the reach range volume for one
participant, constructed from data obtained using the reach range rig

Details regarding participants’ handedness was made available to designers in the database, and
were also used in the process of estimating percentage accommodated. Details of participants’
responses to questions concerning postures that they could attain, and the results of the grip
strength and peg test tasks, and their comfortable maximum weights lifted were also made available to designers within the database. It is expected that in future versions of HADRIAN these data could also be used in the prediction of percentage accommodated.

8.4 Feedback and discussion of HADRIAN

HADRIAN was demonstrated to some of the project collaborators and other design professionals in order to get feedback for future development. These meetings took place between August and October 2002. HADRIAN was demonstrated to:

- Ideo (a human factors specialist, an engineer, a prototyper, and two industrial designers)
- Nottingham Rehab Supplies (two product designers and a marketing manager)
- The Helen Hamlyn Institute (two inclusive design specialists).

The system and its mode of operation were described to the design professionals by means of an example, in this case the assessment of the design of an automated teller machine (ATM). In the first instance the designer inputs a computer-aided design image of the ATM for assessment. They then decide if they wish to assess the accommodation of the whole data sample within the tool, or selected members of the sample. The designers then inputs the tasks that the individuals in the sample need to be able to do in order to successfully complete the task, in this case accessing the ATM. So, for this example, the task elements required would be to look at the card slot, to reach to the card slot, and reach to keyboard to input personal identification number. If a person fails to complete any of these tasks, they will be unable to access the ATM, and so will not be accommodated by the design. HADRIAN then runs through the designated sample of individuals, testing each one with their unique combination of anthropometry, joint constraints, and postural abilities, and reports back with details of the percentage of the sample that could not use the design. The designer can then view those who were not accommodated, and see where the design failed, for example if the card slot was too high.

The feedback presented here concerns the presentation of the system as it was made to the collaborators and design professionals. Screen shots are included to illustrate and highlight some of the comments made, allowing the reader to see the current design of the interface. The feedback and comments made are presented around the relevant screen shots of the system. Firstly, there was praise for the inclusion of video footage of participants performing tasks (Figure 33), and the reach range volume diagrams (Figure 32), as two of the three groups felt that these would provide useful methods of 'sparking' ideas and increasing empathy. One group suggested that more details of why a person failed a task and the degree of failure would increase the
usefulness of the system, as they felt it would enable designers to assess methods of reducing failure.

All the groups that HADRIAN was shown to believed that consideration of older and disabled people is commercially driven, and that if a client does not pay for consideration then it is not possible. This view reflects the findings of the survey of design professionals (Chapter 3). As such, all wanted the system to be highly time-efficient in order to minimise additional time requirements, and how they would be able to use it to convince clients of the benefits of considering older and disabled people. All felt that the system would be useful early in the design process, allowing human factors consideration before the need for expensive mock-ups. All also wanted HADRIAN to be able to interact with existing CAD software packages to order to increase ease of use and fit in with existing work patterns (this is also consistent with the findings of the survey of design professionals, Chapter 3).

In considering the appearance of HADRIAN, it was felt that screens such as that shown in Figure 34 were ‘heavy reading’ and the general feeling was that the interface as it currently stands would be more suited to an ergonomics expert. The project team was aware of these issues with the HADRIAN system, with the focus of the project having been on getting an operational system with the relevant data in it. Recommendations for a simpler interface for designers are needed, and design professionals would need to be actively involved with the design of the final interface. This would enable the final design to meet the needs of the design professionals as expressed in Chapter 3, and to ensure the final tool fits with current design practises.
Figure 33. Screen shot from HADRIAN, showing the anthropometry (top), joint movements (middle) and capability (bottom) for one participant.
Figure 34: Screen shot from HADRIAN, showing the task definition page for an automated teller machine (ATM)
Figure 35: Screen shot from HADRIAN, showing the final estimation of percentage accommodated by a given design, and detailed results for a participant who failed the task (was not accommodated)
Issues arose concerning how much trust design professionals could place on data within HADRIAN. How large would the database of individuals need to be, and how many different tasks would need to be assessed for it to be truly generic? Would designers over-estimate the validity of, for example, using grip reach data to predict fingertip reach? It was made clear to all the groups that the current sample was not intended to be representative of the population as a whole, but to provide data to develop and test the methodology of HADRIAN. All groups felt that, whilst not being wholly representative, the data available in HADRIAN was still an improvement on the current lack of available relevant data on older and disabled participants. All groups conceded that HADRIAN would allow assessment of products with a much larger end-user group than currently involved during the design process, and with a much wider range of abilities, and that any such consideration had to be an improvement.

All three groups also agreed that it would never be possible to design for 100% of people; there will always be some people who require specialist equipment or consideration. However, all also conceded that anything that would assist them, and encourage clients to allow them, to consider ‘design for all’ would be an improvement on the current situation. It was also suggested by specialists at the Helen Hamlyn Institute that changing the results page (as shown in Figure 35) to ‘percentage excluded’ as opposed to ‘included’, may serve as a better way of highlighting to designers and clients that they are losing potential customers if people are unable to use the existing design. It would then be possible for designers to explore details of who had been excluded, and why. Finally, all three groups felt strongly that HADRIAN would make designers more aware of possible issues and the variation in sizes and abilities in the general population, and therefore encourage them to do further research as an important part of the design process.

Ideo staff requested details of ethnicity and clothing as being additional information that would be ‘useful to designers’. They also suggested being able to set automatic inclusions / exclusions for the individuals to be assessed, for example only including participants over 17 years of age if designing a driving environment. It was also mentioned by all three groups of design professionals that all design is context-based, and as such information about emotions, likes, dislikes, cognitive and other abstract aspects of end-users are all useful. These aspects are currently missing from HADRIAN. Information about, and the ability to investigate, the interaction of participants and carers was highlighted by the design professionals from Nottingham Rehab Supplies.
8.5 The validation case studies
In order to demonstrate the usefulness of HADRIAN it was necessary to validate the tool and the data collected, and the method by which estimates of the percentage accommodated were calculated. As such, HADRIAN needs to be able to predict how individuals will behave given information about their abilities and behaviours from data collected. In order to test whether HADRIAN could perform this task, new data were collected on how individuals performed a completely different set of tasks. HADRIAN would then predict how the individuals in the case studies would perform, allowing comparison of the findings of the actual task performance and the computer prediction.

8.6 Aims of the validation case studies
The aims of the validation case studies were to:

- collect additional task-based data from 10 individuals (from the original data set)
- compare the actual capabilities of case study participants completing different tasks with predictions of their capabilities performing these tasks made by HADRIAN
- assess the validity of the tool for predicting percentage of people who could use a given design

8.7 Rationale for the validation case studies
In order to test the predictive capabilities of HADRIAN, data were collected on participants completing tasks that had not already been recorded in the main data collection phase. However, it was important that the tasks selected contained similar elements of reach, bend, and lift, to the kitchen activity tasks in order that it could be realistically expected that the tool could extrapolate existing posture and behavioural data to the new tasks.

The tasks chosen for the validation case studies were: reaching into a supermarket chest freezer, reaching to shelves above a supermarket chest freezer, removing socks from a washing machine, and getting in and out of the passenger seat of a car. These tasks were chosen as they contained postural demands similar to those investigated by the kitchen rig in the main data collection phase, and were also all activities that a person might reasonably expect to want to do as part of everyday life.

It was expected that data used by HADRIAN, namely the reach range volume co-ordinates, anthropometry and joint constraints obtained in the main data collection phase, would provide enough information to predict the postures and coping strategies that these individuals would
adopt. In order to assess validity the actual postures and behaviours adopted by participants in the case study trials would be compared to those predicted by HADRIAN, as well as comparison of predicted and actual task-completion.

8.8 Participants
Ten participants from the main data collection phase data set were selected to represent the variation in size and ability of participants. These were: a man and a woman in wheelchairs, an able-bodied man and a woman over the age of 63 years, an ambulant disabled man and woman over the age of 63, an able-bodied man and woman between 18 and 62 years of age, and an ambulant disabled man and woman between the ages of 18 and 62 years.

8.9 Equipment
A freezer rig (see Figure 36) was constructed to represent the actual dimensions from several high street supermarkets. The chest freezer was not identical to any one design, but incorporated the main elements of those that people may come into contact with. The rig included shelves above the freezer level. The highest shelf was 149 cm from ground level, and the lowest internal level of the freezer was 30.5 cm. The front wall of the freezer rig was 80 cm in height. The weights and sizes of the objects used reflected those used in main data collection phase, with a two-handed weight of 1000 g, a one-handed weight of 170 g, and a one- or two-handed bag weighing 500 g.

The washing machine tasks were conducted using a functioning washing machine (see Figure 37), although only the door-opening mechanism had to be operated by participants. The machine was 83 cm in height and 62 cm wide. The door opening was 27 cm from the base of the machine, and 25 cm in diameter. A Vauxhall Nova (see Figure 38) was used for the car trials, with the passenger front seat placed in a central position within its range of adjustability, and kept in the same position for all the trials. The car was parked on flat ground and easily accessible to the passenger side, and the passenger side door could be opened fully.
Figure 36: Chest freezer and shelving rig

Figure 37: Washing machine

Figure 38: Car used, with door open to reveal seat position.
8.10 Ethical considerations
Ethical considerations were largely the same as those detailed in Section 6.11. However, additional attention was paid to ensuring that participants were not fatigued. The trials lasted a maximum of one hour to reduce this risk. Those who were unable to self-transfer were not asked to attempt the car exercise.

8.11 Procedure
1. Greeting and signing of consent forms
2. Washing machine tasks: participants were asked to open the washing machine door and attempt to reach and retrieve three socks (one at the back of the barrel, one in the middle, and one at the front). Video was taken of postures throughout, and a tick-list of achieve/fail recorded. Participants were also asked if they could read the washing machine controls. A note was made of success/failure of this, and also if the participant was able to open and close the washing machine door, as well as any other comments made.
3. Supermarket freezer tasks: the half of the freezer rig with no shelves in was stacked to capacity with items weighing 170 g, 500 g, and 1000 g (see Figure 39). Participants were given one of each item to hold prior to the trials, in order to decide if they would normally lift that weight or not. The items were positioned initially at the front of the rig, and then at the back of the rig. Participants were asked to reach to and remove all of the items that they could comfortably reach and lift, both from the front and from the back of the freezer rig. They were then asked to reach to and remove those items on the shelves on the left-hand side of the freezer rig, again only reaching to and lifting those that they could comfortably achieve. A note was made of which level for each item a participant could reach to, so that the upper and lower limits, and any weight differences in limits, could be ascertained. If a participant was unable or unwilling to lift a weight, this was noted and the next weight attempted. Video was taken throughout, and a tick-list of which weights were placed on which shelves completed.
4. Participants were paid and signed the payment form.
5. Car tasks: participants were asked to get in and out of the passenger seat of a Vauxhall Nova. Those participants who were unable to self-transfer were not required to attempt this task. Video was taken throughout.
8.12 Data Analysis

The postures that participants adopted during the tasks were coded from the video recordings, using the same method as detailed in Section 6.13.1. It was found that the posture analysis method was not adequate to allow coding of the postures adopted by participants as they got into and out of the cars. In addition, HADRIAN did not contain enough postural data to enable the prediction of access to and from a car. As such, the results for the car task are not included in the results section. Further discussion is made of the difficulties experienced and the implications this has for HADRIAN in Section 8.14.

The postures adopted by participants during the freezer and washing machine tasks were compared with the postures predicted by the computer-based design tool. A Sign test was used to compare the postural classifications for individuals for the case studies and predicted postures, in order to assess the accuracy of the predictive capabilities of the software.

8.13 Results

8.13.1 Data obtained during validation case studies

Trials were conducted in December 2001. Details of the participants selected for the case studies are given in Table 39.

Figure 39: 1000 g and 170 g items stacked at the rear of the freezer, and 500 g items stacked at the front of the freezer
<table>
<thead>
<tr>
<th>Classification of ability and age</th>
<th>Gender</th>
<th>Age</th>
<th>Severity of disability score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheelchair user</td>
<td>Male</td>
<td>36</td>
<td>7</td>
</tr>
<tr>
<td>Wheelchair user</td>
<td>Female</td>
<td>56</td>
<td>10</td>
</tr>
<tr>
<td>Younger ambulant disabled</td>
<td>Male</td>
<td>61</td>
<td>5</td>
</tr>
<tr>
<td>Younger ambulant disabled</td>
<td>Female</td>
<td>56</td>
<td>8</td>
</tr>
<tr>
<td>Older ambulant disabled</td>
<td>Male</td>
<td>73</td>
<td>2</td>
</tr>
<tr>
<td>Older ambulant disabled</td>
<td>Female</td>
<td>73</td>
<td>2</td>
</tr>
<tr>
<td>Younger able-bodied</td>
<td>Male</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>Younger able-bodied</td>
<td>Female</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>Older able-bodied</td>
<td>Male</td>
<td>73</td>
<td>0</td>
</tr>
<tr>
<td>Older able-bodied</td>
<td>Female</td>
<td>72</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 39: Age, gender and abilities of participants (n=10)

All ten participants were able to reach into the washing machine and retrieve all three socks from their positions. All participants were able to open and close the washing machine door, and able to see the controls, although three participants did remark that they could not clearly see the labelling of the controls. When reaching to retrieve items from the front and rear of the chest freezer, a count was taken of the number of each item (170 g, 500 g and 1000 g) the participants’ could reach to and retrieve. Figures 40 and 41 show the number of items that participants were able and unable to reach to, detailing the number of items left (irretrievable). It can be seen that fewer participants left items when placed at the front of the freezer (Figure 40) than the rear of the chest freezer (Figure 41), indicating, not surprisingly, that participants were able to reach and retrieve more items from the front than the rear of the freezer.
When reaching to items on the three shelves of the freezer rig, eight participants were able to reach to and retrieve all the items from all the shelves. The other two participants (both in wheelchairs) were able to reach to and retrieve only the 500 g bag and 170 g weight from the front
of the bottom shelf, and the 170 g weight from the front of the middle shelf. Examples of the postures adopted by participants when asked to reach to items in the chest freezer rig are given in Figures 42. The participants shown in Figure 42 were able-bodied younger, able-bodied older, and a wheelchair user. It can be seen that the freezer itself severely restricts access for wheelchair users (who were unable to reach all items), and also has an effect on the reach capabilities of those standing participants of shorter stature. These images also serve to once again illustrate the effect of visual images for highlighting the variation in postures and behaviours exhibited.

Figure 42: Four of the validation case study participants reaching into the chest freezer

8.13.2 Predictions by HADRIAN

HADRIAN correctly predicted that the two participants in wheelchairs would be unable to reach any items on the top shelf. However, HADRIAN will always be conservative when predicting postures, and so incorrectly predicted that one participant would be unable to reach the top shelf, when in fact they could reach. The reach, though, was only achieved with considerable effort and by standing on tiptoes. The current state of detail within the tool does not permit separate assessment of one- and two-handed items, so succeed/fail is given for each participant for each shelf in total (top, middle and bottom).
Comparison of postures predicted by HADRIAN yielded more confusing results, as the postures predicted were not always identical to those observed in real life. When a Sign test compared the posture analysis coding system recorded for participants reaching to the highest shelf they could, and the computer prediction of the posture analysis code for the same participants attempting the same task, a significant difference of $p=0.07$ was found. This indicates that the postures that were predicted by the computer-based tool and those observed were not identical in terms of the posture analysis code used. Figure 43 illustrates the comparison between the actual postures adopted by three of the participants when reaching to the shelves above the freezer, and the predicted postures for the same three ‘virtual’ participants, reaching to the same shelves, from HADRIAN. It can be seen that the predicted postures of the older lady and wheelchair user are almost identical to those attained in the case study trials. However, the top image of the younger lady serves to highlight one of the current limitations of the tool, in that the posture predicted includes the person’s knees being bent through the front wall of the freezer. Obviously such a posture is not possible in real life. This occurs because the tool currently is not aware of solid objects, but work is being done to rectify this problem.
Figure 43: Comparison of real images of postures attained by three participants, and virtual images of the predicted postures for the same participants reaching to the same items.

8.14 Discussion

8.14.1 Comparison of actual and predicted postural data and task completion

One of the main aims of the computer-based design tool was to enable the estimation of percentage accommodated. It has been shown that, as it currently operates, HADRIAN is able to do this for reaches to items with free access. HADRIAN did not, though, necessarily predict
identical postures to those observed in real life during the case study trials. The data used by HADRIAN to predict the postures was that which had been previously obtained for each individual. This means that the postures predicted were ones that the individuals concerned had got into (in the main data collection phase), even if they were not the same as those observed in the case study trials. Such 'errors' in the prediction of postures by the computer-based tool arise due to the fact that individuals may chose different methods of achieving tasks, with there being no 'right' or 'wrong' posture for those participants able to achieve a task in a number of ways. To help address this a 'tolerance level' was included within HADRIAN, which designers can adjust if they wish. This tolerance level can be used to determine whether a person has to totally achieve a posture in order to be recorded as completing a task, or whether a 'near miss' will be deemed a success by the system.

Data about coping behaviours, such as standing on tiptoes, or using an item to pull another item towards the participant, was not encoded into the system. It is likely to be a limitation of the tool that it cannot predict these novel coping behaviours, although the addition of further posture and behaviour data during different activities may reduce the risk of these errors.

8.14.2 HADRIAN as a computer-aided design tool

Designers who participated in the survey of design professionals and those who gave feedback on the prototype HADRIAN system (Section 8.4), expressed the wish that the tool work in conjunction with existing computer-aided design tools. The tool currently operates in conjunction with SAMMIE, a human-modelling system, and allows concept design images to be imported in a number of other CAD software formats (for example, 'obj' files from Alias, and 'dxf' files from AutoCAD). There is also the possibility that, with future work, HADRIAN could be reconfigured to allow it to operate directly in conjunction with CAD software other than SAMMIE. Such interaction with existing computer-aided design tools is essential, given the growing trend in design work being conducted in such systems (Sumner, 1995; Erbug, 1999).

There are other computer-based tools available currently to design professionals, but from the findings of the literature review and survey they are not widely used. This may be due to lack of knowledge about them or due to them not meeting the needs of designers (Section 3.12.7). HADRIAN allows consideration of the needs of older and disabled people, and assessment of 'design for all' issues, early in the design process. The design professionals who gave feedback on the tool (Section 8.4) saw this as being of value. It is expected that such early consideration of
the issues and end-users will reduce the need for expensive, in terms of time and money, redesign being required when consideration occurs later in the design process (Porter & Porter, 1999; Bruder, 2000). HADRIAN serves to highlight the need for multivariate consideration, and the impact of 'designing out' and excluding people. Such information is important to design professionals (Section 8.4), and may also prove useful to convincing commissioning clients of the need for 'design for all' and consideration of older and disabled people (Section 3.12.5).

8.14.3 HADRIAN as a database

The database within HADRIAN currently contains anthropometry, joint constraints, reach range volumes and volume co-ordinates, details of participants' grip strength and postural abilities (being able to bend to touch their toes, and twisting of the upper body). These data were used by HADRIAN to predict the percentage accommodated by a design, and were also data requested in the survey of design professionals (Section 3.11.3). These data are presented in a visual format (Figure 32, Section 8.4) in the design tool. Such visual presentation reflects the findings of the survey of design professionals, and previous research into designers' preferred format for design information (Section 2.5). Perry and Sanderson (1998), Kuffner and Ullman (1991), and Toames, Oates and Armstrong (1998) all discussed designers' preference for information presented in a visual format, as opposed to tables and text. Video footage of participants completing the main data collection study tasks were also included, to increase empathy and provide the opportunity for insight into the problems experienced and how real people interact with products and environments. Feeney and Bobjer (2000) advocated such an approach, stating that use of real life video footage allows designers to see how people really behave with products.

The design professionals who gave feedback on HADRIAN (Section 8.4) requested details of end-users wants, needs, desires, likes and dislikes. In addition some of the design professionals contacted during the survey requested information on minority groups and buying habits. Inclusion of such information, on participants' emotions and thoughts, was not collected in this project, but is a possibility for inclusion in any future work. Also of importance in the future development of HADRIAN is consideration of other data requested in the survey of design professionals, for instance details of standards, legislation and guidelines, spine curvature, and sight lines.
8.14.4 Problems with HADRIAN

At the current time HADRIAN cannot differentiate between accessible areas and solid surfaces in a virtual model. Whilst a real person knows that, for example, a washing machine can only be reached into through the hole in the front, and so will move themselves to get into a posture suitable for accessing that area, HADRIAN does not have that intelligence (Figure 44). Instead, as it currently operates, the tool ‘sees’ the virtual reach target (in this example, an item in the washing machine) and the virtual person who will be assessed reaching to it, and attempts to connect the two in virtual space in the easiest way possible. If that includes, for this example, the virtual person putting their hand through the top surface of the virtual washing machine, then the tool will not recognise that this is not a viable option in reality.

There is currently research being conducted into the use of a constraint modeller to assist with this problem, along with further development of HADRIAN and its ‘knowledge’ of solid objects and the way it deals with these. It is hoped that a combination of the two methodologies will solve this issue. At the present time HADRIAN is able to accurately predict posture and task completion for reach and bend activities where free access is available to the object being reached. Whilst this may be of limited benefit alone, it is still an improvement on the current data available, from which it is impossible even to predict movements such as these.

The current screen format of HADRIAN needs development, and the direct input from designers. Design professionals are limited in time, and time constraints have featured as concerns both from the survey of design professionals (Section 3.12.1 specifically) and those giving feedback on HADRIAN (Section 8.4). In order to refine and develop the HADRIAN interface to maximise efficiency, and minimise ‘wasted’ time when learning and using the system, it is necessary to work closely with designers. Lack of involvement of designers in the development of HADRIAN could be a criticism of the project, although great efforts were made to involve designers through the survey of design professionals and in the feedback on HADRIAN. It has been acknowledged that interface development will require direct end-user involvement, and this will be crucial to future work on the system.

8.15 Conclusions

It is recognised that further work is needed to increase the scope of the tool and its validity in predicting postures and capabilities. The tool does however provide instant access to 100 unique individuals, with task behaviours, images, anthropometry and joint constraints, which can be used
in human modelling and CAD systems for assessing the fit of designs, even if not used for prediction of abilities and postures. Such a database is of huge value to designers using such systems, who at the current time are required to construct virtual people, looking up data to use for body dimensions and ‘inventing’ the combination of dimensions that they use in any assessment.

The HADRIAN interface has been developed so that a working prototype was available that would meet the wishes and needs of design professionals, as determined by the survey in Chapter 3, within the time constraints of the project. HADRIAN is a design tool, and also an educational resource, allowing and encouraging multivariate consideration, and increasing empathy. The system and interface now need to be refined, with design professionals involved.
Chapter 9: Summary and future work

9.1 Introduction
The work presented in this thesis, and as part of a larger project (Section 1.1 and 1.4), has detailed data collection methods and issues for supporting designers in ‘design for all’. The research has informed the development of a computer-based design tool (HADRIAN) to estimate percentage accommodated by a given design. This chapter contains an overview of this research, discussing whether the initial objectives of the project were met, a critique of the methodology used in the research, new knowledge gained, and areas of possible future work.

9.2 Meeting of objectives
The objectives of the research within this thesis are detailed in Section 1.5. These are introduced in this section with brief details of how they have been met.

- What is the current understanding and practice of ‘design for all’ by design professionals (product designers, architects, transport designers)? What are the obstacles and opportunities? A review of the current literature (Chapter 2) and survey of design professionals (Chapter 3) allowed (amongst other findings) it to be seen that the majority of design professionals are aware...
of 'design for all' as a concept, but that few are readily embracing the philosophy. Reasons given for not considering such an approach were lack of time, lack of money, and lack of support from clients commissioning the design.

- What specific information do design teams require in order to encourage them to consider older and disabled people during designing? What format should such data be presented in, and in what media?

The design professionals consulted (Chapter 3) felt that relevant, accurate, up-to-date information on older and disabled people was vitally important. Such data should include anthropometry and other physical measurements, as well as details of what people are able to do and would like to do. The overwhelming view of design professionals, both from findings in the literature and of the survey, is that data should be presented in a clear, concise, visual format.

- What do older and physically disabled users think of current everyday products, systems and services, and what problems do they experience? How could designers most effectively improve their quality of life?

A literature review (Chapter 4) and survey of older and disabled people (Chapter 5), highlighted the fact that the majority of older and disabled people experience difficulties with activities of daily life that rest of the able-bodied population take for granted. Being able to cook for oneself, wash oneself, and get out and about, were all found to be vitally important to the independence and quality of life of older and disabled people, and were areas where good design is still lacking.

- What data are needed to support the development of the computer-based design tool, and what methods could be used to collect such data from older and disabled people?

Chapter 6 details the pilot study for the main data collection phase, given in Chapter 7. Methods were developed for assessing severity of disability, reach range, and task-based behaviours and postures. Anthropometry, joint constraints, reach range, and task-based posture analysis data were collected from 100 individuals (Figure 44), along with a rich variety of information on general postural abilities. These data were preserved as individual data sets within the computer-based design tool, to ensure consideration of multivariate issues, and to increase empathy for design professionals with the older and disabled people and the problems they face.
Are the data collected, and the computer-based design tool developed, valid for estimating percentage accommodated?
The creation of HADRIAN was proposed to support and encourage adoption of the ‘design for all’ approach, to provide a multivariate estimation of percentage accommodated in a particular design. The development and operation of HADRIAN has progressed towards these objectives. As the tool currently exists it is able to support designers in considering ‘design for all’ and is able to estimate the percentage accommodated by designs that involve reaching to items within open areas. Further work is needed to expand the capabilities of HADRIAN to include more complex reach and bend tasks.

Figure 44: A selection of the 100 participants

9.3 Critique of the methodology
It is important to reflect on the methods employed during the entire research project. The survey of design professionals and of older and disabled people, and the main data collection phase are discussed in more depth earlier in the thesis (Section 3.13, Section 5.12, and Section 7.11 respectively). Overall, the main issues were of sampling and the confidence in how appropriate it would be to generalise from the findings. The fact is that in both surveys it was possible to see, even given the small sample sizes, a consensus of opinions on the issues being discussed. This
indicates that the concerns, problems and wishes being raised are likely to reflect those of the wider population of design professionals, and older and disabled people, respectively.

With the surveys and the data collection phases, the primary aim was to gain information and data that would inform the design and development of HADRIAN, from as broad a range of viewpoints and abilities as possible. As such, it was never the aim to achieve statistically rigorous sampling methods, but to collect data from as many individuals as possible within the time and financial constraints of the project, sufficient to the development of the tool. The sample of 100 individuals was adequate to allow development of the tool, and to provide a much-needed resource of data from older and disabled people.

End-user involvement was highlighted from the literature review and survey of design professionals as being fundamental to reducing problems with the design of products, systems and services, yet as being an element of the design process that often causes problems or seems difficult to achieve. This pattern is reflected in the development of the computer-based design tool. Design professionals are the intended end-users of the tool, and had input via the survey, but then were not involved in the development process until demonstrations of the tool were made and feedback sought. The focus of the development of HADRIAN was to build and test the methodology within the tool. As such, the interface of HADRIAN now needs to be designed and developed with direct input from design professionals.

One of the most novel and fundamental approaches of this research was the focus on task-based activities and postural capabilities. This proved to be a suitable and useful approach for collecting postural data from which to predict who could complete a task (and therefore successfully interact with a product, system or service). Participants could instantly relate to the tasks that they were asked to perform, and were not required to maintain static postures due to the use of video analysis. The posture analysis method devised drew on existing, workplace-based, methods of assigning coding to postures, and was specific to the data required for HADRIAN yet could be applicable to other situations in which the postural capabilities of older and disabled people needs to be assessed. Once data were obtained and encoded within HADRIAN, the design professionals who provided feedback on the tool were very positive about the inclusion of such data. Task-based data gave designers instant empathy for how people actually perform tasks in real life, and also provided them with data not currently available, and more appropriate to the design of products, services and systems than, for example, tables of percentiles.
9.4 New knowledge gained

This thesis has contributed a number of items of new knowledge to ‘design for all’ and ergonomics generally. These include:

- Highlighting the fact that many older and disabled people still experience considerable problems with activities of daily life and interacting with everyday products and environments.

- Designers and design professionals are generally aware of the ageing population and the fact that they will need to consider the needs of such people at some point, but there is an overall reluctance to do so until clients request it. It is expected that this will occur when the ageing population demands it, and when market forces necessitate it.

- It is impossible to predict a person’s abilities from tables of percentile data. Keeping data sets complete for individuals increases designers’ empathy and makes them instantly aware of the myriad variations in size, posture and ability that all of us have. Such recognition is fundamental to ‘design for all’ and the inclusion of older and disabled people in the design of mass-market products. Also, design professionals appear to like the presentation of data as ‘individuals’, regarding it as providing instant empathy and a clearer identification of the needs of individuals.

- A new method for assessing task-based activities, to include coping strategies, behaviour and posture, has been developed. This novel approach concerns the collection of data on specific tasks, but allows generic abilities to be assessed, such as bending, reaching and lifting, in a less artificial setting than standardised tests. Such a method allows the variety of postures and behaviours to be exploited to the designer’s advantage, enabling them to investigate possible alternatives that may not be considered by existing standardised movements and postures.

Dissemination of the project activities and findings has occurred through journal papers (Marshall et al, 2002a; Case et al, 2001), conference papers (Porter et al, 2003; Porter et al, 2002; Oliver et al, 2002; Marshall et al, 2002b; Marshall et al, 2001; Gyi et al, 2001; Oliver et al, 2001; Gyi, Porter & Case, 2000), and workshops with design professionals (Section 8.4). Dissemination is also ongoing, with additional journal and conference papers being written, and the existing WebPages being further developed.
9.5 Future work

- Additional development of HADRIAN, with the possible addition of a constraint modeller, will enable the prediction of the percentage accommodated by designs involving bend, reach and lift in constrained areas.

- The continuing development of the HADRIAN tool will enable the interface to be developed with the involvement of design professionals, to ensure the final version is easy to operate and is the most efficient use of designers' time, as requested by design professionals in Chapter 3.

- It is hoped that in the future funding will be available for the database in HADRIAN to be expanded from the 100 individuals it currently contains. Expanding the database will:
  - enable the sample to be more representative of the population as a whole. This will serve to increase the accuracy of the data when applied to the wider population, and increasing the validity of the prediction of percentage accommodated.
  - allow inclusion of a wider variety of tasks and postures to allow prediction of different types of activity and product. Including other tasks, such as getting in and out of a car, will help to solve existing limitations with HADRIAN (as discussed in 8.12 and 8.14).
  - allow inclusion of cognitive and emotional aspects of participants, such as end-users likes, dislikes, wants, needs, and desires with regard to existing products and their lifestyles. Design professionals requested this information, and it is felt that all additional data will increase the benefit of HADRIAN to design professionals by increasing empathy.
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Appendix 1
Design Professionals’ Survey Questionnaire

Any details of information sources used, web addresses of sites, in-house checklists and guidelines, company product information – ask to be sent copies for validation purposes.

Section 1: Personal and company details

1. Can you give some examples of specific projects that you have undertaken that include the needs of older and disabled people?

2. What do you understand by the terms Design for All or Universal Design?

Section 2: Current Practice

3. What information needs are the most important in the development of a product/building/vehicle?

4. Do you currently use any of the available sources of anthropometric data about users? Yes No

5. What sources do you currently use? (data tables, computer packages, SPECIFY WHICH ONES)

6. How do you find it using this data?

7. What would be your preferred format for such data? (video, paper-based, CD-Rom, CAD tool)

8. Some people feel that the best time to consider the user is at the beginning of the design process - Do you feel that this is possible? Yes No

9. Why/why not?

10. What sort of information about users is of most use to you? (body sizes, reach, vision, grip, etc.)

11. Did you involve end-users during the design process? Yes No

12. How do you involve them? (user trials, fitting trials, focus groups, etc.)

13. How many people are involved, and at what stage in the design process (concept stage, prototype stage, all through the design process)?

14. Did you personally test/use the finished products/designs? Yes No

15. Few people currently take special care to consider the needs of older and/or disabled people in designs (for mass-market products). Do you have any ideas why this may be so?
3. Computers
16. Have you used any computer-aided design packages? Yes No
17. Which one(s)?
18. What sort of computer(s) do you use?
19. Have you used any software relating to anthropometric data? Yes No

20. How do you/they find using this?

21. If a computer modelling system that included data from older and disabled people as well as able-bodied people, for use as a design tool were available, would you be interested in using it? Yes No

22. Do you think you would have time to learn to use such a system? Yes No

23. What do you think you would want to be able to do using such a system? (vision, grip, strength, sizes, reach, etc.)

24. I am now going to list some alternatives for the type of information that such a system could present to you. Please answer yes or no as to whether you would want each type of information.
(detailed statistical information, simple measurements, graphical snapshots of problems, suggestions for improvements, details about the % population who could use the design, ergonomic guideline/rules)

Any others?

25. Would you wish to tailor the system to the person who would be using it? – for example, a trained ergonomist could interact with detailed data, whilst an untrained designer could view simpler guidelines with out complex detail Yes No

4. The Future
We are hoping to encourage designers to consider the needs of older and disabled people more in designs. How do you think we could encourage people?

I have another list of possible information sources which could be of use to designers if they were to consider older and disabled people more. Please answer yes or no as to whether you would consider each to be a useful tool in encouraging design for all.

26. formal training in design for all practices and techniques (for example, workshops or lectures)? Yes No

27. anthropometric data and other information about users presented in a preferred way? Yes No

28. legislation to spell out the expectations for designs? Yes No

29. computer-aided design and man-modelling systems which include data from older and disabled people? Yes No

30. checklists of constraints and issues? Yes No

31. procedures for evaluating current designs and concepts? Yes No

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Sample letter to design professionals

Name of addressee,
Address

Contact details for author

date

Dear *name*

Re: Investigation into design methods and the needs of older and disabled people

With respect to our recent telephone conversation, I am hereby sending you further information about the above research project that we hope you are able to help us with (see enclosed project outline). Your opinions and experiences of product design are very important, as they will ensure that the design tool that will result from this project is actually designed with your needs in mind. Consideration of older and disabled people within design will become more essential as the number of people over 65 years of age increases (by a predicted 50% between 1998 and 2040), and legislation increasingly forces designers to consider the needs of the disabled.

Also enclosed is a consent form which must be signed by whoever is to take part in the study. The consent form concerns the fact that the telephone interviews are to be tape-recorded. This is simply as a memory aid for the interviewer. The tapes will be erased once the project is complete, ensuring your anonymity and the confidentiality of all answers.

In order to arrange the date and time for the telephone interviews (to last no longer than thirty minutes) please complete the relevant section of the consent form. Please return the completed form to me as soon as possible, either by fax or by post if preferred.

We value your contribution to this important project, and would like to involve as many practising designers as possible. If you are unable to participate please let me know as soon as possible, using any of the contact methods above.

Thank you for your time, please do not hesitate to contact me if you have any other questions about the project and your involvement in it.

Yours faithfully,

Ruth Oliver (Miss)
Design professionals' survey consent form

Loughborough University

Department of Design and Technology

EPSRC 'Design for All' Project

Interview date and time preference:

Interviews will take place until 30/04/00. Please indicate your preferred date and time (please allow at least 30 minutes). Date _________________ Time ________________

Consent Form:

I agree to the interview being tape-recorded. I understand that what I say may be used for research or to compile a report.

I understand that every effort will be made to respect my confidentiality and anonymity. The tape recording will be used as a memory aid only, and will be erased on completion of the project. No details about specific products or company details will be released.

I understand that I am free to stop the interview at any time, without giving any reason for doing so.

Name (please print)

Signed

Date

Please return this completed form to me as soon as possible by fax, or by post if preferred. Thank you

Ruth Oliver

Contact details for author
PARTICIPANTS WANTED

Are you interested in helping improve the way that all every day products are designed?

We are looking for people over the age of 18, with a physical disability, to take part in a study.

The trials will take place at Loughborough University, and last either one or two hours. The trials will involve having various body measurements taken (such as arm length, stature, and so on), measurements of how far you can comfortably reach, and joint mobility of the arms. We will also be looking at completion of simple tasks, for example placing trays of varying weights on different height shelves, and getting in and out of chairs. You will receive £10 per hour for giving up your time to help us.

If you would like to take part or would like more information, please contact:

Ruth Oliver on contact details
Information letter for survey of older and disabled participants

Investigation into design methods and the needs of older and disabled people

This research project is funded by the Government, and is to result in the production of a computer-aided design tool. The project team consists of Professor J. Mark Porter, Professor Keith Case, Dr. Diane Gyi, Dr. Russell Marshall, and Miss Ruth Oliver.

The design tool will be in the form of a computer-based 3D human-modelling system, which will help the design team to consider the needs of older and disabled people in designing. The tool will provide information about users, and predict the percentage of the population who will be able to use the product if it is manufactured to the specifications of the on-screen design. In order for the tool to be as useful as possible, we are investigating what information designers need to have about users during design, and what problems older and physically disabled people currently have with the way that everyday products and environments are designed.

We are aiming to talk to people with a wide range of physical disabilities, aged from 18 years upwards. Questions will concern aspects of home life, getting out and about, leisure activities, and working, as applicable. The study will involve interviews with a total of 50 older and disabled individuals, hopefully reflecting the wide range of problems experienced.

If you have any questions about the project or your involvement, please do not hesitate to contact me.

Ruth Oliver (Miss)
Details for author
Older and disabled participants’ survey consent form

Loughborough University

Department of Design and Technology

EPSRC ‘Design for All’ Project

Consent Form:

I agree to the take part in this interview. I understand that what I say may be used for research or to compile a report.

I understand that every effort will be made to respect my confidentiality and anonymity. My responses will be identified by a number, so my name will not be used in the report.

I understand that I am free to stop the interview at any time, without giving any reason for doing so.

Name (please print)

Signed

Date
Questionnaire for survey of older and disabled people

This questionnaire concerns the use of products in activities of everyday living, those activities that are fundamental to everyone’s lives each day, such as cooking, cleaning, shopping, eating, toileting, washing, and so on. The questions are divided into sections that reflect the different areas of daily life, in order to provide focus and consider all issues affecting activities of daily life. These questions concern you in your own home – please mention any helpful items that you have that are relevant to the question asked, or if you need the assistance of another person in order to accomplish any of the activities mentioned.

Subject number __________

1. Gender
2. Age

Do you work?

3. Yes, full time
4. Yes, part-time
5. No, retired
6. No, unable to work
7. If applicable, what sort of work do/did you do?

Do you live in:

8. your own house?
9. your own bungalow?
10. your own flat (what floor?)?
11. a rented house?
12. a rented bungalow/
13. a rented flat (what floor?)?
(if in rented, who is the landlord? Local council places may have more access to social services support)

With regard to your mobility around the home, are you:

14. Completely independent (can walk totally unaided)?
15. Independent (but may use stick, frame, etc.)?
16. Walk with help of one person (verbal or physical)?
17. Wheelchair independent?
18. Unable to move without assistance from another person?

19. What do you see as the main problems you experience as a result of your condition? (ask about diagnoses)

With regard to your mobility outside the home, are you:

20. Completely independent (can walk totally unaided)?
21. Independent (but may use stick, frame, etc.)?
22. Walk with help of one person (verbal or physical)?
23. Wheelchair independent?
24. Unable to move without assistance form another person?

Can you manage stairs indoors?

25. Independent (up and down)
26. Need help (verbal, physical, aid)
27. Unable
How reliant are you on other people on a daily basis?
28. Not at all
29. Need some assistance in some tasks
30. Need continual assistance

Kitchen
How do you manage with the following activities? *(ask for any ideas to improve the situation for each mentioned)*

31. Lifting a small saucepan of milk onto the back hob?
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

32. Lifting a dish into the oven? (What level oven? Which shelves used?)
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

33. Picking up a small washing-up item in the bottom of the sink?
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

34. Turning the hot and cold taps on and off? (What sort of taps?)
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

35. Reaching an item on a high shelf in a kitchen cupboard?
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

36. Lifting an empty kettle? (What process used to fill the kettle?)
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

37. Loading and unloading clothes from a washing machine? (What level is the machine placed at?)
   Easily Some difficulties (no assistance) Need some assistance Need considerable assistance Impossible

38. Given your abilities, is there any one thing on a practical daily level that you would really like to be able to do in the kitchen but are unable to do so because of the way the necessary equipment or environments are designed?

39. On a scale of 1 to 5, with one being ‘no problem’ to 5 being ‘considerable difficulty’, how much of a handicap do you feel your disabilities are in kitchen activities?
   1 2 3 4 5
   no problem slight moderate considerable

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**Bathroom**
How do you manage with the following activities? (*ask for any ideas to improve the situation for each mentioned*)

40. Are you able to get in and out of the bath?
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

41. Are you able to get in and out of the shower?
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

42. Getting on/off the toilet?
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

43. Given your abilities, is there any one thing on a practical daily level that you would really like to be able to do in the bathroom but are unable to do so because of the way the necessary equipment or environments are designed?

44. On a scale of 1 to 5, with one being ‘no problem’ to 5 being ‘impossible’, how would much of a handicap do you feel your disabilities are in bathroom activities?
   - 1
   - 2
   - 3
   - 4
   - 5

**General in the house**
How do you manage with the following activities? (*ask for any ideas to improve the situation for each mentioned*)

45. Opening/closing windows? (What level windows, what type of catches?)
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

46. Opening/closing the internal doors? (What type of handles?)
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

47. Putting plugs into/out of sockets?
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

48. Given your abilities, is there any one thing on a practical daily level that you would really like to be able to do around the house but are unable to do so because of the way the necessary equipment or environments are designed?

**Away from home**
How do you manage with the following activities? (*ask for any ideas to improve the situation for each mentioned*)

49. Transferring into/out of a car as a passenger? (Own car? Taxi?)
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible
50. Can you use public buses? (type of bus)
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

51. Can you use trains? (the train the problem or the station?)
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

52. Filling up the car at petrol stations?
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

53. Getting money out of cash machines? (cognitive vs functional problems)
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

54. Buying goods in supermarkets/large shops?
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

55. Given your abilities, is there any one thing on a practical daily level that you would really like to be able to do away from home but are unable to do so because of the way the necessary equipment or environments are designed?

56. On a scale of 1 to 5, with one being ‘no problem’ to 5 being ‘impossible’, how would much of a handicap do you feel your disabilities are outside the home?

   1  2  3  4  5

Work
What sort of environment do you work in?

57. Office
58. Open-plan
59. Outside
60. Driving
61. Home

62. Do you have easy access to your place of work?
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

63. Can you reach everything that you need to use at work?
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

64. Can you move around your place of work as you would like to do?
   Easily  Some difficulties (no assistance)  Need some assistance  Need considerable assistance  Impossible

65. Is there anything in the design of your work and workplace that you would really like to change?
66. Given your abilities, is there any one thing on a practical daily level that you would really like to be able to do at work but are unable to do so because of the way the necessary equipment or environments are designed?

**Leisure**

67. What sorts of leisure activities do you like to do?

68. Is there anything that you do not do that you would like to have a go at?

69. Can you get access to leisure centres?
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

70. How do you manage in the garden?
   - Easily
   - Some difficulties (no assistance)
   - Need some assistance
   - Need considerable assistance
   - Impossible

71. Given your abilities, is there any one leisure activity that you would really like to be able to do but are unable to do so because of the way the necessary equipment or environments are designed?
The severity scales for disability (OPCS)

### Locomotion

<table>
<thead>
<tr>
<th>Description</th>
<th>Severity score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannot walk at all</td>
<td>11.5</td>
</tr>
<tr>
<td>Can only walk a few steps without stopping or severe discomfort/</td>
<td></td>
</tr>
<tr>
<td>Cannot walk up and down one step</td>
<td>9.5</td>
</tr>
<tr>
<td>Has fallen 12 or more times in the last year</td>
<td>7.5</td>
</tr>
<tr>
<td>Always needs to hold on to something to keep balance</td>
<td>7.0</td>
</tr>
<tr>
<td>Cannot walk up and down a flight of 12 stairs</td>
<td>6.5</td>
</tr>
<tr>
<td>Cannot walk 50 yards without stopping or severe discomfort</td>
<td>5.5</td>
</tr>
<tr>
<td>Cannot bend down far enough to touch knees and straighten up again</td>
<td>4.5</td>
</tr>
<tr>
<td>Cannot bend down and pick something up from the floor and straighten up again</td>
<td>4.0</td>
</tr>
<tr>
<td>Cannot walk more than 200 yards without stopping or severe discomfort/</td>
<td></td>
</tr>
<tr>
<td>Can only walk up and down a flight of 12 steps if holds on to something to keep balance/ Has fallen 3 or more times in the last year</td>
<td>3.0</td>
</tr>
<tr>
<td>Can only walk up and down a flight of 12 stairs if holds on (doesn’t need a rest)</td>
<td></td>
</tr>
<tr>
<td>Cannot bend down to sweep up something from the floor and straighten up</td>
<td>2.5</td>
</tr>
<tr>
<td>Can only walk up and down a flight of stairs if goes sideways or one step at a time</td>
<td>2.0</td>
</tr>
<tr>
<td>Cannot walk more than 400 yards without stopping or severe discomfort</td>
<td>1.5</td>
</tr>
</tbody>
</table>

### Reaching and Stretching

<table>
<thead>
<tr>
<th>Description</th>
<th>Severity score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannot hold out either arm in front to shake hands</td>
<td>9.5</td>
</tr>
<tr>
<td>Cannot put either arm up to head to put hat on</td>
<td>9.0</td>
</tr>
<tr>
<td>Cannot put either arm behind back to put jacket on or tuck shirt in</td>
<td>8.0</td>
</tr>
<tr>
<td>Cannot raise either arm above head to reach for something</td>
<td>7.0</td>
</tr>
<tr>
<td>Has difficulty holding either arm in front to shake hands with someone</td>
<td>6.5</td>
</tr>
<tr>
<td>Has difficulty putting either arm up to head to put a hat on</td>
<td>5.5</td>
</tr>
<tr>
<td>Has difficulty putting either hand behind back to put jacket on or tuck shirt in</td>
<td></td>
</tr>
<tr>
<td>Has difficulty raising either arm above head to reach for something</td>
<td>4.5</td>
</tr>
<tr>
<td>Cannot hold one arm out in front or up to head (but can with other arm)</td>
<td>3.5</td>
</tr>
<tr>
<td>Cannot put one arm behind back to put on jacket or tuck shirt in (but can with other arm)/ Has difficulty putting one arm behind back to put jacket on or tuck shirt in, or putting one arm out in front or up to head (but no difficulty with other arm)</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Dexterity

<table>
<thead>
<tr>
<th>Description</th>
<th>Severity score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cannot pick up and hold a mug of coffee with either hand</td>
<td>10.5</td>
</tr>
<tr>
<td>Cannot turn a tap or control knobs on a cooker with either hand</td>
<td>9.5</td>
</tr>
<tr>
<td>Cannot pick up and carry a pint of milk or squeeze the water from sponge with either hand</td>
<td>8.0</td>
</tr>
<tr>
<td>Cannot pick up a small object such as a safety pin with either hand</td>
<td>7.0</td>
</tr>
<tr>
<td>Has difficulty picking up and pouring from a full kettle or serving food from a pan using a spoon or ladle</td>
<td>6.5</td>
</tr>
<tr>
<td>Has difficulty unscrewing the lid of a coffee jar or using a pen or pencil</td>
<td>5.5</td>
</tr>
</tbody>
</table>
Cannot pick up and carry a 5lb bag of potatoes with either hand 4.0
Has difficulty wringing out light washing or using a pair of scissors 3.0
Can pick up and hold a mug of coffee with one hand but not the other 2.0
Can turn a tap or control knob with one hand but not with the other/Can squeeze the water from a sponge with one hand but not the other 1.5
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 or strings 0.5

**Personal Care**
Cannot feed self without help/ Cannot go to and use the toilet without help 11.0
Cannot get into and out of bed without help/ Cannot get into and out of chair without help 9.5
Cannot wash hands and face without help/ Cannot dress and undress without help 7.0
Cannot wash all over without help 4.5
Has difficulty feeding self/ Has difficulty getting to and using the toilet 2.5
Has difficulty getting in and out of bed/ Has difficulty getting in and out of a chair 1.0
Appendix 3
## RESEARCH PROPOSAL FOR HUMAN BIOLOGICAL INVESTIGATIONS

This application should be completed after reading the Code of Practice paying particular attention to the advice given in Section 6.3.

### (i) Applicants:

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Department/Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ruth Oliver</td>
<td>Research Associate</td>
<td>Department of Design and Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>01509 223045</td>
</tr>
<tr>
<td></td>
<td></td>
<td><a href="mailto:R.E.Oliver@lboro.ac.uk">R.E.Oliver@lboro.ac.uk</a></td>
</tr>
</tbody>
</table>

### (ii) Project Title:

Collection of anthropometric and behavioural data from older and physically disabled persons.

### (iii) Aims and Outline of the Project:

The project aims to collect data from individual older and disabled people that can be used to build computer human-models of the individual participants in order to assess their ability to perform tasks and interact correctly with products and environments.

### (iv) Names and status of investigators:

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Department/Institute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prof. J. Mark Porter</td>
<td>Professor of Design Ergonomics, Department of Design &amp; Technology</td>
<td></td>
</tr>
<tr>
<td>Prof. Keith Case</td>
<td>Professor of Computer Aided Engineering, Wolfson School of Mechanical and Manufacturing Engineering</td>
<td></td>
</tr>
<tr>
<td>Dr. Diane Gyi</td>
<td>Research Fellow, Department of Design &amp; Technology</td>
<td></td>
</tr>
<tr>
<td>Dr. Russ Marshall</td>
<td>Research Associate, Department of Design and Technology</td>
<td></td>
</tr>
<tr>
<td>Ruth Oliver</td>
<td>Research Associate, Department of Design and Technology</td>
<td></td>
</tr>
</tbody>
</table>
(v) Participants (see Section 6.3e):
100 older and physically disabled people, ranging in ages from 18 upwards. This sample is not intended to be representative of the population as a whole, but to cover as broad a range of ability and disability as possible. It is proposed that a screening questionnaire will be given to all interested volunteers. This questionnaire will be based on the Office of Population Censuses and Surveys (OPCS) rating scale for severity of disability, and participants will be chosen to ensure an even spread of severity ratings from 1-10. The full OPCS scaling system is not needed for our purposes, and it is proposed that we use just 4 scales - locomotion, dexterity, personal care, and reaching and stretching. These involve asking participants what they can/cannot do from a rated list of possibilities. The score of these ratings is then weighted using an equation, and this weighted score then forms their severity score, ranging from 1.55 (least severe) to 19.05 (most severe).

It is proposed that participants will be screened to result in a sample that will consist of: 50 men and 50 women, with each gender further divided into: 10 not disabled (63 yrs +), 10 disabled 63 yrs +, 10 disabled 48-62 yrs, 10 disabled 33-47 yrs, 10 disabled 18-32 yrs
Each of the age-bands of disabled people will also aim to include a range of severity of disability, as calculated using the method described above. For example, we may aim to get (within each group of 10 disabled people) 3 people with a score of between 1.55 and 7.00, 3 with a score between 7.01 and 13.00, and 3 with a score of between 13.01 and 19.05, with the last person being anywhere on the severity scale. This idea will be piloted along with the procedure.

(vi) Location (any special facilities to be used):
It is proposed that the equipment to be used will be transportable. Locations will be near a disabled toilet, and participants will be shown the toilet facilities before participating, and will be reminded of the location at intervals throughout the session. The room will need to have full wheelchair access, with sufficient power points for the equipment, and have blinds/curtains on all windows for privacy. It is currently proposed that possible sites on university campus could include Studio 1 in the Bridgeman Centre, or the Engineering laboratory in Wavy Top. Estates have been contacted to determine if they know of any suitable locations.

(vii) Duration (including demand on participant's time):
This is still under investigation, but it is proposed that the MAXIMUM that people could be expected to participate for is 2 hours 30 minutes, and this may have to be divided into two sessions to reduce the risk of fatigue or undue exertion.

(viii) Reasons for undertaking the study (eg contract, student research):
The study forms part of a 3 year project funded by the EPSRC, under the EQUAL initiative. The project aims to encourage 'Design for All' within the design community, by providing data in a computer software package on the abilities of older and disabled people, for consideration during the design process. This will enable designers to better consider the needs and abilities of such people during the design process.
Methodology (a brief outline of research design):

- Initial screening of volunteers to determine suitability for participation, using questionnaire based on OPCS survey (appendix 3).
- Discussion of procedures with participants on arrival (still to be designed)
- Signing of consent form, including gaining permission to take photographs and video-tape, and detailing how faces/identifying features will be obscured if photographs are used in the report, and informing participants that they may stop participation at any time, without having to give any reason for doing so (appendix 4).
- Discussion of payment details and signing of payment receipt.
- In-depth questionnaire about physical abilities in order to build a series of postures that the participant can attain (still to be designed).
- Anthropometric measurements – external, clothed, as near to standard postures as possible, but not if unnatural for the participant.
- Measures of joint movements and postures.
- Measures of strength capability (non-maximal).
- Measures of reach capability.
- Measures of behaviours and postures (throughout all procedures).
- Debriefing of participants.

Procedures and measurements (for experimental and control participants):

This is still a working document and the procedures and measures taken may change as the details are finalised. All participants will be subject to the same procedure. The procedures given below are too numerous to all be undertaken during the trials – we are in the process of prioritising and refining them.

Anthropometric measurements – using Harpenden anthropometer, stadiometer, and sitting-height table. Measurements of wheel-chair users will be taken without removing them from the chair, and the height, seat height, width and seat depth of the wheel-chair will also be measured.

- list of measures to be taken: Stature, Eye to top of head, Sitting height, Head height, Sitting shoulder height, Shoulder breadth, Hip breadth, Hip to knee, Ankle to knee, Floor to ankle, Foot length, Elbow to shoulder, Wrist to elbow L/R, Hand length L/R, Hand grip length L/R

Joints movements and postures – captured using 3 linked CODA machines, involving fixing markers onto participants’ limbs by means of markers on Velcro straps.

- list of measures to be taken: Shoulder – extension / flexion, abduction / adduction, positive and negative rotation, Upper arm – extension / flexion, abduction / adduction, positive and negative rotation, Elbow – flexion, positive and negative rotation, Wrist – extension / flexion, abduction / adduction, Spine – extension / flexion, abduction / adduction, positive and negative rotation, Neck / head – extension / flexion, abduction / adduction, positive and negative rotation, Hip – extension / flexion, abduction / adduction, positive and negative rotation, Knee – flexion, positive and negative rotation, Ankle – extension / flexion, abduction / adduction, positive and negative rotation

Strength and reach capabilities – using purpose-built rig designed to assess push-pull (minimal force requirement) reach capabilities, and reach whilst holding (1- and 2-handed) objects of various weights.

- list of measures to be taken: Left arm & Right arm - Arm reach strength envelope: push (minimal) i.e. close door, Arm reach strength envelope – pull (minimal) i.e. open door, Arm reach strength envelope – twist (minimal) i.e. door handle. Also Standard task / postures – kneeling, tying shoe laces, crouching etc.

Postures and behaviours – recorded throughout using video camera and digital stills camera, for analysis and coding afterwards.
(xi) Possible risks, discomforts and/or distress (see Section 6.3k):

Fatigue, risk of exacerbating any existing conditions, risk of falling in some cases if loss of balance occurs during behaviour tasks. Participants will be reminded before each activity that they do not have to attempt anything that they feel may cause them pain, injury or fear (of fall, for example). Participants will not be forced to attempt any activity that they have verbally stated that they are unable to do.

Access to the building must be easy for those in wheelchairs (whether manual or electric) and the ambulant disabled. The toilets must also be accessible, and it be ensured that the location of these is known to the participants and that they are made to feel at ease about asking to stop participation to use the facilities should the need arise. It is proposed that participants be asked at stages throughout the session if they are all right and if they would like a break, and to use the toilet if they would like to. Any persons needing assistance with using the toilet will be requested to bring an assistant to help them.

(xii) Procedures for taking measurements and for chaperoning and supervision of participants during investigations:

Two experimenters will be present at all times with all participants. Participants will perform activities in a room without other people being present, to preserve confidentiality and dignity. Participants will not be asked to perform any activities that they would not normally attempt, and will be closely monitored by the investigators who will stop the participant if it is deemed that they are putting themselves at risk. Curtains/blinds are needed to reduce light levels for the use of the CODA equipment, and will also ensure the privacy of participants. Participants will be accompanied to the toilet to ensure they get to and from the cubicle safely, but if they need assistance in actually going to the toilet this will have to be provided by their own carer or assistant, not by the experimenters.

(xiii) Names of investigators and personal experience of proposed procedures and/or methodologies:

Miss Ruth Oliver - MSc Ergonomics, which included training in anthropometric measurement techniques, and has since been involved in the anthropometric measurement of undergraduate students as part of their courses.

Dr. Russell Marshall – has been trained in the collection of anthropometric measurements, and been involved in the anthropometric measurement of undergraduate students as part of their courses. Both investigators have been involved at all stages of the rig construction and methodological design.

There is also the possibility of hiring additional support staff for this phase, to assist the investigators named above. Full training will be given in all procedures to all additional staff, and they will work under supervision until sufficiently experienced.

(xiv) Details of any payments to be made to the participants:

Participants will be paid £10 per hour to cover any expenses and their time given to participate. Travel expenses will be met where appropriate.

(xv) Do any investigators stand to gain from a particular conclusion of the research project:

N/A
(xvi) Whether the University's Insurers have indicated that they are content for the University's Public Liability Policy to apply to the proposed Investigation (Committee use only):

N/A

(xvii) Whether insurance cover additional to (xv) has been arranged by the Investigator (see Section 6.30):

N/A

(xviii) In the case of studies involving new drugs or radioisotopes, written approval for the study must be obtained from the appropriate national body and submitted with the protocol. State if applicable:

N/A

(xix) Declaration

I have read the University's Code of Practice on Investigations on Human Participants and completed this application.

Signature of applicant:

Signature of Head of Department:

Date
Information for data collection pilot trial participants

Thank you for helping us with these trials

The purpose of this trial is to look at ways of collecting information to help designers. One of the main things we will be looking at is how useful the equipment in this room is, for example, to track movements, accuracy of measurements, and so on. The experimenters will explain the details of the trial.

The order of the activities is as follows:

1. Collection of details about mobility and other physical activities
2. Measurement of body size – height, limb lengths etc
3. Measurement of how far you can comfortably move your arm joints
4. Measurement of how far you can reach in various directions
   - - - - - BREAK - - - -
5. Collection of all of the above using different equipment
6. Assessment of capability in kitchen tasks using different equipment and methods
7. Photographs taken.

Before we begin you will be asked to read and sign a consent form. You will see that, with your permission we will be videoing most of the things that you will be doing and also taking some photographs.

You are free to stop the trial at any time, and do not have to give a reason for doing so. We want this trial to be a pleasant and interesting experience for you. If we are asking you to do something that you are not happy about, or that is causing you any discomfort than please tell us. You are not obliged to do all parts of the trial, and if there is anything that you would rather not do then please tell us and we will move onto something different. If you wish to have a break at any time, or to use the toilet, please do not hesitate to tell us.

The trial will take a last for a maximum of 2 hours. We will ask for your bank details and National Insurance number so that the £20 you receive for giving up your time can be paid directly into your bank account.

Thank you again for helping us today. If you have any questions at all, whether now, during the trial or afterwards, please feel free to ask.

Ruth Oliver contact details
Subject Consent Form

Subject Number

I consent to taking part in these tasks to collect data to help designers consider all people during the design of products.

An explanation of the nature and purpose of the assessments has been given to me by the researcher and I understand that I may withdraw from the study at any time, and that I am not under obligation to give reasons.

I understand that measurements will be taken.

I understand that photographs and video recordings may be taken as methods of data collection to be used by the research team only, and I consent to their use for this purpose.

I understand that these and all information about myself will be treated as strictly confidential by the research team.

Signed

Date

Signature of researcher
I consent to allowing photographs or video footage of myself to be used during presentations or lectures. This will include university teaching, conferences, and the inaugural lecture to be given by Professor J. M. Porter.

I understand that all measures will be taken to preserve my anonymity when photographs or video footage is being used, and that I will not be referred to by name.

Signed

Date

Signature of researcher
Data collection phases questionnaire

Name
Age
Gender
Nationality
Handedness
Weight
Occupation
History of disability

Assessment of locomotion:
1. Can you walk at all? Yes / No
   If NO, move to Q7
2. If yes, approximately how far can you walk before needing a rest? Few steps
   50 yards 200 yards 400 yards
3. Can you walk up and down stairs? Yes / No
   If yes, do you need to use a rail and have a break? Yes / No
4. How far can you bend down? Above knees Knees
5. Can you lie on the floor and get back up again? Yes / No
6. Can you reach to tie your shoelaces? Yes / No
7. Have you fallen over in the last year? (ask number of times) Yes / No
   3-11 times 12+ times

Assessment of reaching and stretching:
8. Can you reach out with either hand (shake hands)? Yes / Neither / Only one
9. Can you raise either arm above your head? Yes / Neither / Only one
10. Can you reach to turn bath/sink taps on with either hand? Yes / Neither / Only one
11. Can you reach backwards with either hand? Yes / Neither / Only one

Assessment of dexterity:
12. Which of these objects can you pick up and hold using either hand?
    Mug of coffee Yes / No (If no, go to Q11) / Only one
    Pint of milk Yes / No / Only one
    5lb bag of potatoes Yes / No / Only one
13. Which of these things can you do with either hand?
    Turn cooker control knobs Yes / No (If no, miss next 2) / Only one
    Unscrew a jar Yes / No
    Turn the taps on and off Yes / No / Only one
    Pick up a small object (safety pin) Yes / No / Only one
    Use a pair of scissors Yes / No
14. Can you squeeze the water out of a sponge or cloth with either hand? Yes / No / Only one

Assessment of personal care:
15. Can you use the toilet without help? Yes / Difficulty / No
16. Can you get in and out of bed without help? Yes / Difficulty / No
17. Can you wash and dress without help? Yes / Difficulty / No
Do you live in:
72. your own house?
73. your own bungalow?
74. your own flat (what floor?)?
75. a rented house?
76. a rented bungalow/
77. a rented flat (what floor?)?
(if in rented, who is the landlord? Local council places may have more access to social services support)

With regard to your mobility around the home, are you:
78. Completely independent (can walk totally unaided)?
79. Independent (but may use stick, frame, etc.)?
80. Walk with help of one person (verbal or physical)?
81. Wheelchair independent?
82. Unable to move without assistance from another person?

With regard to your mobility outside the home, are you:
83. Completely independent (can walk totally unaided)?
84. Independent (but may use stick, frame, etc.)?
85. Walk with help of one person (verbal or physical)?
86. Wheelchair independent?
87. Unable to move without assistance from another person?

How reliant are you on other people on a daily basis?
88. Not at all
89. Need some assistance in some tasks
90. Need continual assistance

91. Are you able to get in and out of the bath?
92. Are you able to get in and out of the shower?
93. Opening/closing windows? (What level windows, what type of catches?)
94. Opening/closing the internal doors? (What type of handles?)
95. Putting plugs into/out of sockets?
96. Transferring into/out of a car as a passenger? (Own car? Taxi?)
97. Can you use public buses? (type of bus)
98. Can you use trains? (the train the problem or the station?)
99. Filling up the car at petrol stations?
100. Getting money out of cash machines?
101. Buying goods in supermarkets/large shops?

Work
What sort of environment do you work in?
102. Office
103. Open-plan
104. Outside
105. Driving
106. Home

270
107. Do you have easy access to your place of work?

108. Can you reach everything that you need to use at work?

109. Can you move around your place of work as you would like to do?

110. Is there anything in the design of your work and workplace that you would really like to change?

111. Given your abilities, is there any one thing on a practical daily level that you would really like to be able to do at work but are unable to do so because of the way the necessary equipment or environments are designed?
Posture classification system

The end postures of the recorded activities are classified – the point at which the task has been achieved.

Horizontal direction – the location of the target relative to the starting posture of the participant in the horizontal plane
1. In front (between both shoulders)
2. Left
3. Right
4. Behind

Vertical direction – the location of the target relative to the starting posture of the participant in the vertical plane
1. Above shoulder
2. Between shoulder and hip
3. Below hip

Arm used – which arm is used to reach for the target
1. Left
2. Right
3. Both

Alignment – the angular displacement of the feet (an indication of the starting posture) from the target
1. +/- 10 degrees
2. -11 to -45 degrees
3. 11 to 45 degrees
4. -46 to -90 degrees
5. 46 to 90 degrees
6. -91 degrees +
7. 91 degrees +
(positive degrees are to the right of 0, negatives to the left, with 0 being the line connecting the subject with the target)

Legs – the posture of the legs
1. Upright (180 to 170 degrees)
2. Bent 1 (171 to 120 degrees)
3. Bent 2 (119 to 40 degrees)
4. Crouch (39 to 0 degrees)
5. Left kneel
6. Right kneel
7. Full kneel
8. Sitting

Back twist
1. None
2. Left
3. Right
Back bend
1. Upright (0 - 10 degrees)
2. Lean (11-45 degrees)
3. Bend (46 degrees+)

Shoulder
1. Relaxed
2. Extended

Aids – specified for any support given
1. None
2. Chair
3. 1-handed support
4. 2-handed support
5. Lean

Head direction (yaw) – rotation about the neck, the direction the face is pointing in relative to the body
1. Neutral
2. Left
3. Right

Head inclination (pitch) – flexion and extension of the neck
1. Neutral
2. Forward
3. Back

Head tilt (roll) – adduction and abduction of the neck
1. Neutral
2. Left
3. Right
Appendix 5
Information given to main data collection phase participants

Thank you for helping us with these trials

The purpose of this trial is to collect information to help designers. The experimenters will explain the details of the trial.

The order of the activities is as follows:
1. Collection of details about mobility and other physical activities
2. Measurement of body size – height, limb lengths etc
3. Measurement of how far you can comfortably move your arm joints
4. Measurement of how far you can reach in various directions
   - - - BREAK - - -
5. Assessment of capability in kitchen tasks
6. Assessment of capability in seating
7. Photographs taken.

Before we begin you will be asked to read and sign a consent form. You will see that, with your permission we will be videoing most of the things that you will be doing and also taking some photographs.

You are free to stop the trial at any time, and do not have to give a reason for doing so. We want this trial to be a pleasant and interesting experience for you. If we are asking you to do something that you are not happy about, or that is causing you any discomfort than please tell us. You are not obliged to do all parts of the trial, and if there is anything that you would rather not do then please tell us and we will move onto something different. If you wish to have a break at any time, or to use the toilet, please do not hesitate to tell us.

The trial will take a last for a maximum of 2 hours. We will ask for your bank details and National Insurance number so that the £20 you receive for giving up your time can be paid directly into your bank account.

Thank you again for helping us today. If you have any questions at all, whether now, during the trial or afterwards, please feel free to ask.

Ruth Oliver contact details