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Using HADRIAN for eliciting virtual user feedback in 'design for all'

R Marshall^{1*}, K Case³, J M Porter¹, R Sims¹ and D E Gyi²

¹Department of Design and Technology, Loughborough University, Loughborough, Leicestershire, UK

²Department of Human Sciences, Loughborough University, Loughborough, Leicestershire, UK

³Mechanical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, UK

Abstract: 'Design for all' is an approach to product, environment or service design that aims to maximize the usability of a particular design. However, a key concept of this approach is not to tailor designs to the user in a bespoke fashion, but rather to provide a single solution that accommodates the needs of all users, including those who are older or are disabled.

In order to support the designer/design team in 'design for all' a computer aided design and analysis tool has been developed. The tool, known as HADRIAN, has been developed to address two critical factors. The first factor is the provision of accurate and applicable data on the target users, including a broad spectrum of size, shape, age and ability. The second factor is an efficient and effective means of utilizing the data for ergonomics evaluations during the concept stages of design. HADRIAN's database and task analysis tool work in combination with the existing human modelling system SAMMIE. The system as a whole allows assessment of a design against the population in the database, providing a means to elicit some of the feedback that might be gained by real user trials at a stage in the design process when physical mock-ups and user group selection would be prohibitively time consuming and expensive.

Keywords: design, ergonomics, CAD

1 INTRODUCTION

'Design for all' or 'inclusive design' is an approach to the design of products, services or environments that focuses upon meeting the needs of the broadest range of users. This is a distinction from meeting the broadest range of user needs, as the focus is not necessarily on providing increased functionality but rather ensuring that any functionality is accessible to anyone who wishes to use the product. The main driver behind this approach is to address the needs of older and disabled people. However, as the name suggests, the key is not to address their needs in isolation with bespoke or customized products, but instead to provide an inclusive design that accommodates the needs of both older and disabled people together with younger and more able people [1].

While there is a significant social responsibility to take this approach to design, there is also an increasing legislative and economic impetus to address the needs of the increasing numbers of older and disabled people within

the population. In Europe, 25 per cent of the population will be aged 60 or over by 2020 [2]. Estimates suggest that the world total will be more than 1 billion people aged 60 or over by the year 2025 [3]. Socially, accommodating these people will allow them to lead much more normal lives without the stigma and cost associated with specialized products. Economically, developing a product or service that is equally suited and appealing to younger able-bodied people, in addition to older and/or disabled people, hugely broadens the potential market. It has also been estimated that 36 million disabled people in the United States spend 40 billion dollars on special products and the population aged over 50 purchases 60 per cent of all domestic cars and own 50 per cent of all homes [4].

While the numbers of older and disabled people are significant it is their ability to utilize current designs that is at the heart of the 'design for all' approach. The potential exclusion faced by the older and disabled population due to poor, or just careless, design is a fundamental concern. Research carried out into the experiences of older and disabled people in undertaking 'activities of daily living' (ADL) highlighted the difficulties in achieving these fundamental tasks. Interviews were conducted with 50 older and disabled people about their own ADL. Of

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**Corresponding author: Department of Design and Technology, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK.*

these people 42 per cent had severe difficulties using the bath and around 20 per cent had severe difficulties with performing kitchen tasks such as placing pans at the back of the hob, putting things in the oven or reaching high shelves [5]. These findings support those of other similar studies [6, 7], all of which highlight older and disabled people being 'designed out'.

There is clearly a significant need to increase the awareness of these issues and to educate designers about 'design for all'. This is where initiatives such as EQUAL (extending quality life) [8] are playing a significant role. EQUAL was initiated by the UK Government's Office of Science and Technology in 1995 to draw together research activities that bear on the extension of the active period of people's lives, thereby helping individuals to achieve a better lifestyle and avoid or alleviate the effects of disability. As part of the EQUAL initiative, research councils such as the Engineering and Physical Sciences Research Council (EPSRC) have run programmes into areas such as 'design for all', of which this research is a part. However, educating designers is not sufficient on its own to achieve the necessary change in the timescales required. Thus, a key element of the research detailed here is the support of the designer/design team in a 'design for all' approach. The first element of the support concerns the provision of appropriate and applicable data on the target population. The second element then provides a mechanism for utilizing these data to gain a form of 'virtual' user feedback. Together these two elements form the software tool HADRIAN (human anthropometric data requirements and analysis). HADRIAN consists of a novel database of individuals complete with data on anthropometry, joint constraints, capabilities and behaviour stored as a complete set for each person. This database is integrated with the task-based analysis tool aimed at providing a means for obtaining rapid ergonomics feedback during the concept stages of design in a manner that minimizes the need for ergonomics expertise and expertise in the use of human modelling systems.

2 VIRTUAL FITTING TRIALS

Fitting trials are a common technique employed in ergonomics evaluations [9]. The fitting trials employ a panel of users carefully selected to be representative of the population at which the product, or environment, has been targeted. The panel are then used to evaluate the design against a set of criteria in order to determine a level of suitability of the design. While traditionally this process has taken place with real people and full-size mock-ups, increasingly aspects of this process are becoming computer based, making use of computer aided design (CAD) models and human manikins in a virtual fitting trial [10]. The trend follows that of traditional design techniques where the benefits of information

technology are being employed to support the drive for up-front loading of effort, data sharing and integration, and in general a more integrated approach to product development.

The use of these computer-based ergonomics evaluation tools in supporting the development of products that clearly promote user's requirements from the very early stages promises numerous benefits to both those who use and those who supply such products. However, while the use of these technologies can clearly play a key role in supporting design that is user-centred, there are a number of concerns in the current technology, data and infrastructure used for computer aided ergonomics evaluations in design. Such concerns include [11]:

1. Ergonomics data are difficult to access and difficult to apply, especially when considered in the human modelling context.
2. Human modelling systems have to make compromises in creating valid human models from data that were not designed for this process.
3. The use of human modelling systems not only requires the user to be a skilled user of the tool but also to have ergonomics expertise in order to use the tool appropriately.
4. Human modelling systems invariably suffer from many of the issues that surround more traditional CAD systems in that they provide focused support for downstream activity but still do not adequately address use at the concept stage when ergonomics considerations should initially be addressed.
5. The combination of statistical data and the virtual environment detaches the designer from any empathy they may have had with the real person that the human models are meant to represent.

In addition to these generic concerns, specific issues arise when products are aimed at users who may be older or disabled. Clearly, for products targeted at these sectors of the population the generic nature of the data available and the even greater lack of empathy with the very specific needs of these users often leads to compromises or incorrect assumptions being incorporated into the design [12].

3 ERGONOMICS DATA

One of the key concerns outlined earlier is the reliance of traditional ergonomics data on univariate percentiles for each limb dimension (5th, 50th, 95th, etc.) [13, 14]. While this approach attempts to simplify presentation and understanding it does not help in using the data for multivariate task-based analyses of products or environments. A further concern is the relevance of the available data. Most anthropometric and biomechanical data refer to younger able-bodied populations. Task-based data are captured for standardized postures and activities.

While this is a pragmatic approach to data collection it often causes difficulties when the situation to be assessed falls outside standardized parameters. Such situations require assumptions to be made. For these assumptions to have any real validity they often require expertise and this is not always available, especially if the process is taking place during the concept stages of design. Additionally, commonly used data can be ten, or more, years old [15, 16] and as the population to which it refers is not static over time its accuracy decreases. This deviation from the true state of the population can be accommodated by manipulating the data for secular growth. However, this is not clear to the non-expert user, and even then this is another layer of uncertainty on data that is likely to be a compromise in the first place.

The use of human modelling systems can help in removing some of these issues by automatically creating human models from the data using statistical processes such as Monte Carlo simulation or principal component analysis. Secular growth can be automatically factored in and the user can be presented with a range of human models that are meant to represent real people. However, there is still a real validity issue with all of these techniques and even though the burden of expertise is removed from the designer there is still the danger of designing a product around an invalid population [17].

If further factors are introduced into the equation, such as the data associated with subsets of the population, e.g. older or disabled people, the validity of typical data is even more questionable. Correlation between measures is even less predictable, asymmetry may be a major concern and capabilities will vary considerably from the 'norm'. In addition, this takes no account of behavioural issues such as coping strategies that are employed by these people to allow them to complete tasks that data would suggest is not possible.

As discussed, there are many issues with current anthropometric and biomechanics databases that hinder their application in design, but the key concern is that typically data are not collected with human modelling in mind. However, the ongoing developments in CAD could support a completely different approach. Storage and retrieval of large amounts of data are now trivial and the use of body scanning technologies allows many more measures to be taken with greater accuracy and repeatability in much less time. There is also the potential to combine these data with new tools to simplify their application and support the designer in evaluating their designs in a much more interactive, intuitive and valid manner.

4 SUPPORT FOR THE DESIGNER

The present approach of supporting the designer/design team in 'design for all' has resulted in the development of

a prototype CAD tool called HADRIAN. HADRIAN consists of a database of individuals including their anthropometry and functional capability, together with a mechanism for exploiting these data. HADRIAN has been developed to work with the existing human modelling system SAMMIE [18, 19] and together they provide a package aimed at addressing the concerns outlined earlier (Fig. 1).

4.1 Individuals as a data entity

The HADRIAN database takes the novel approach of maintaining the integrity of the human data sets by storing them as individuals (Fig. 2). Thus, each entry in the database is a person. In this manner data are much more accessible, removing the need for data manipulation to create a valid human from a set of statistical tables, though the individuals can still be collectively decomposed into the statistical tables if required. This format is ideal for human modelling purposes. The data belonging to the individuals can automatically be used to create a human model with correct anthropometry, joint constraints and flesh shape. In addition, the format provides the ability to append other valid data to the individual, such as capability and behaviour, directly relevant to using the human models in a virtual fitting trial.

The use of individuals as data entities, and their subsequent use in a virtual analysis of a product design, is analogous to the use of real people in a real fitting trial. Thus, it is also necessary to provide a sample of individuals to represent a suitable population from which trial candidates can be selected, in addition to mechanisms to aid in this selection. However, the initial approach taken for HADRIAN is to provide a sample set of individuals that form a core group of virtual fitting trial individuals, all of which will be used to assess a design and report on the percentage of those individuals who fail to successfully complete the trial.

The use of an individual as a data entity also provides the platform for a richer source of information including details about the individual's background, likes, dislikes, needs and desires. A resource of this kind then becomes much more than a repository for anthropometric data, allowing the designer to gain an empathy with the types of people they are designing for. This empathy then forms a key part of the 'design for all' process, where the designer is not just looking to make quantitative judgements about the people who can and cannot use their design but instead is presented with the fact that, for example, 'Janet' an older lady with arthritis or 'Tom' a younger wheelchair user cannot use their design. Taking this approach then encourages the designer to support all of the diverse needs of the population rather than merely working to the accepted percentile range.

Fig. 1 The functional layout of the HADRIAN/SAMMIE partnership

Fig. 2 An individual stored in the HADRIAN database

4.2 A database of individuals

To address the concern with the appropriateness of the data, interviews were conducted with 50 older and disabled people [5]. The interviews focused on how design could directly improve their quality of life. The clear response was that preparing meals for family and friends, and the use of local transport were all very important areas that could also be improved through design. These responses were then used to drive the data collection process.

Physical and behavioural data were collected on 100 individuals covering a broad range of ages and abilities [20]. The sample was deliberately skewed towards the older and disabled population to offset the relatively well understood younger/able-bodied population. Using traditional methods, data were collected on external anthropometry, joint constraints, background information and details regarding any disabilities and problems experienced with activities of daily living. The process also captured more novel data on link (bone) lengths and functional reach.

In addition to the range of anthropometry and joint constraint data, it was important that the process also record task-based data. Ideally, the data collection would have targeted a large range of kitchen-based activities, together with the varied activities of using public transport including: access to and use of ticketing facilities, ingress and egress of a range of public transport vehicles, access to seating, etc. However, additional concerns had to be taken into account. Firstly, a maximum time limit for data collection was set at 2 hours to minimize fatigue and reduce the risk of exacerbating any existing conditions among the older and disabled participants. Secondly, the complexity of some of the tasks was beyond the initial scope of the system and would require very complex laboratory rigs to be developed. To simplify data collection and yet still achieve a broad set of applicable data, it was decided to focus on generic activities that are derivative of the types found in the scenarios previously identified. This led to the targeting of a

simplified set of kitchen-based tasks and a variety of restricted access seating arrangements.

The task element of the data collection ultimately revolved around a number of pick-and-place type of activities using a simple kitchen rig (Fig. 3). Subjects were asked to select a variety of comfortable maximum weights and move them around to various heights and locations. In order to ensure that the data collected was as accurate and representative of ADL as possible, comfort maximums were recorded to reflect what the subjects would be likely to do in their own homes, where absolute maximums would not normally be used. In addition, tasks that represented hot loads, such as lifting items into and out of the oven, were performed using oven gloves to represent their effects on capability and behaviour.

The actual data recorded from the tasks included a success or a failure for each task element. However, a key element in the data collected related to not just whether a task was completed but rather to how it was completed. This behavioural element was captured in order for the HADRIAN system to have a better mechanism for predicting accurate postures in task situations. It could be argued that as long as the system predicts postures that the individual could adopt the results would be valid and useful. However, older and disabled people often develop mechanisms for dealing with their reduced capability, referred to as coping strategies. These coping strategies make it much less predictable what an individual might do and subsequently what they might be capable of for any given task. Thus, the authors felt that it is equally important to capture and then predict what an individual might be capable of in a virtual fitting trail in addition to how they might do it.

4.3 Virtual task analysis

In addition to providing a much more integrated, intuitive and thought-provoking database, HADRIAN was also

Fig. 3 Task-based data collection in progress

Fig. 4 A task being defined in HADRIAN

designed to support the use of the data within ergonomics evaluations. One aim of the research was to encourage the use of ergonomics evaluations at the concept stage of design. Without the benefit of computer-based systems this would be a difficult proposition, as typically designs are not sufficiently mature during concept design to warrant physical mock-up and user trials. Even if it was possible, typically it would not be practical or cost effective. However, while the tools exist to perform ergonomics evaluations in the CAD environment through the use of human modelling systems they suffer from the same data concerns discussed earlier. In addition, human modelling systems also require ergonomics expertise in order to posture the human model correctly with respect to the product to be evaluated. A final concern is the nature of the systems themselves. Recent developments have seen human modelling systems integrated into mainstream CAD systems. While this is efficacious during detail design these systems still have many difficulties to be addressed for concept design; thus, by combining the two the process almost legitimizes leaving the use of ergonomics evaluations to the detail design phases of product development.

To reflect the process by which a designer or design team might actually wish to evaluate a design, HADRIAN provides a mechanism to define a task that the individuals in the database will then try to perform. To provide structure to the definition and to break the process down into easily managed segments, the

complete task is constructed from task elements [1]. Task elements consist of a range of physical activities generally supported by human modelling systems such as reach and vision. Having selected an activity the system will also normally require a target, where targets are interactive elements of the design to be evaluated. Finally, there are a number of activity-specific parameters (view distances, grip types, etc.) that can be specified if desired or left for the system to determine (Fig. 4).

Having defined the task, the designer can then run the analysis whereby the individuals in the database are recreated as digital human models in the SAMMIE system, which are then used to perform an ergonomics analysis on the chosen design. When complete results are displayed, they include the number of individuals excluded from using the design due to failure of one or more task elements. In addition, the actual individuals who are excluded are identified so that the designer can learn what characteristics of the design and its interaction with the user cause difficulties. Finally, the process loop is closed by the designer making changes and re-running the analysis in order to see the effect of any changes on the percentage excluded.

5 INITIAL VALIDATION

Initial validation of the HADRIAN tool was carried out by comparing a laboratory-based trial against the

Fig. 5 Observed postures compared to HADRIAN-generated postures during validation trials

equivalent virtual set-up in the software tool. Ten individuals from the data collection phase were asked to take part in the validation case studies. The two case studies represented the process of retrieving goods from a supermarket chest freezer and the shelves above it, and the process of loading/unloading washing from a washing machine. Models of the laboratory rigs were created within the SAMMIE system and the ten individuals from the database were selected as the trial population in HADRIAN. Finally, a task was specified equivalent to the trial specification given to the participants.

The results of the validation case studies were assessed on a number of levels. The first and most basic was whether the percentage excluded reflected that observed in the real trials. Validation showed that the HADRIAN system was slightly conservative in its results (one extra failure when compared with reality). The main reason for this is that, while behavioural coding is being employed, the system cannot yet implement the subtleties of human movement observed in the large variety of coping strategies that may be used to achieve success. The second level was the postures predicted by the tool and those observed during the trials (Fig. 5). The difference in this area was more marked, reflecting the need to synthesize postures in the tool based on data taken from similar, but not the same, tasks. While not necessarily important for relatively simple tasks, such as those chosen for the trials, this might be an issue for more complex tasks where the actual posture adopted may be important, such as restricted access tasks and safety

critical tasks. It is important to note that while the postures may have differed to varying degrees the postures predicted by the system are ones that the real person could have used; i.e. they are valid postures, but in the particular cases observed not exactly the same postures.

6 CONCLUSIONS AND FURTHER WORK

HADRIAN has been developed to support designers/design teams in the use of ergonomics evaluations at the concept stage of the design process. To do this HADRIAN has addressed a range of issues related to the data available to the designer and to the mechanisms for using the data. The use of individuals as a data structuring method provides benefits to both the ease of understanding and the ease of use of the data for human modelling. The task analysis model provides a simplified method for employing ergonomics evaluations without ergonomics expertise. Initial validation trials have shown the acceptable accuracy of the tool in some relatively simple environments, but have also highlighted a number of areas for further development. It is fully acknowledged that HADRIAN is a prototype tool and as such will undergo continuous development and refinement. In particular, areas to be addressed include the usability of HADRIAN as a tool, the refinement of the underlying model that drives the task analysis and the definition and collection of further data to ensure a representative database.

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REFERENCES

- 1 Marshall, R., Case, K., Oliver, R. E., Gyi, D. E. and Porter, J. M. A task based 'design for all' support tool. *J. Robotics and Computer Integrated Mfg*, 2002, **18**(3–4), 297–303.
- 2 Population ageing—a public health challenge. World Health Organisation Fact Sheet 135, World Health Organisation, 2004; <http://www.who.int/inf-fs/en/fact135.html>.
- 3 *World Population: More Than Just Numbers*, 1999 (Population Reference Bureau, Washington, DC).
- 4 Steinfeld, E. The concept of universal design. In Proceedings of the 6th Ibero-American Conference on *Accessibility*, Center for Independent Living, Rio de Janeiro, Brazil, 1994.
- 5 Oliver, R., Gyi, D., Porter, J. M., Marshall, R. and Case, K. A survey of the design needs of older and disabled people. In *Contemporary Ergonomics 2001, Proceedings of the Ergonomics Society Annual Conference*, 2001, pp. 365–370 (Taylor and Francis, London).
- 6 *A Study of the Difficulties Disabled People Have When Using Everyday Consumer Products*, 2000, Department of Trade and Industry Consumer Safety Research (DTI, London).
- 7 Ashworth, J. B., Reuben, D. B. and Benton, L. A. Functional profile of healthy older persons. *Age and Aging*, 1994, **23**, 34–39.
- 8 EQUAL ageing and disability network, 2004; <http://www.fp.rdg.ac.uk/equal/>.
- 9 Porter, J. M. and Porter, C. S. Occupant accommodation: an ergonomics approach. In *An Introduction to Modern Vehicle Design* (Ed. J. Happian-Smith), 2001, pp. 233–276 (Butterworth-Heinemann, Oxford).
- 10 Case, K., Porter, M., Gyi, D., Marshall, R. and Oliver, R. Virtual fitting trials in 'design for all'. *J. Mater. Processing Technol.*, 2001, **117**, 255–261.
- 11 Marshall, R., Case, K., Porter, J. M., Gyi, D. E. and Sims, R. E. Virtual task analysis in 'design for all'. In *Virtual Engineering Applications for Design and Product Development* (Eds R. I. Campbell and N. O. Balci), Media Services, Loughborough University, European Virtual Engineering Network (EVEN) and Trinity College Dublin, Ireland, 2003, pp. 235–242.
- 12 Keates, S. and Clarkson, J. Design exclusion. In *Inclusive Design, Design for the Whole Population* (Ed. J. Clarkson et al.), 2003, pp. 88–102 (Springer-Verlag, Berlin, Germany).
- 13 Haslegrave, C. M. Characterising the anthropometric extremes of the population. *Ergonomics*, 1986, **29**(2), 281–299.
- 14 Roebuck Jr, J. A., Kroemer, K. H. E. and Thomson, W. G. *Engineering Anthropometry Methods*, 1975 (John Wiley, New York).
- 15 Pheasant, S. T. *Bodyspace: Anthropometry, Ergonomics and the Design of Work*, 1996 (Taylor and Francis, London).
- 16 *The Handbook of Adult Anthropometry and Strength Measurements—Data for Design Safety* (Eds L. Peebles and B. Norris), 1998, Adultdata (Department of Trade and Industry, London).
- 17 Hasdogen, G. The nature and limitations of user models in the household product design process. *Des. Studies*, 1995, **17**(1),