SIZING UP AUSTRALIA: HOW CONTEMPORARY IS THE ANTHROPOMETRIC DATA AUSTRALIAN DESIGNERS USE?

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Sizing Up Australia: How contemporary is the anthropometric data Australian designers use?

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- Daisy Veitch, SHARP Dummies Pty Ltd
- David Caple, David Caple and Associates Pty Ltd
- Verna Blewett, New Horizon Consulting Pty Ltd.

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Executive summary

This pilot research project, commissioned by Safe Work Australia was undertaken by Daisy Veitch (SHARP Dummies Pty Ltd), David Caple (David Caple and Associates) and Verna Blewett (New Horizon Consulting Pty Ltd). It aimed to take the first steps to investigate the suitability and use of anthropometric data by designers who design products and workplaces for Australian industry.

The reason for this research is the acknowledgement that safety and health can be ‘designed in’ to Australian workplaces and the products and equipment used in these workplaces. For designers to find design solutions that not only prevent work-related illness and injury, but also that contribute to improved health and safety at work, they must have access to reliable data about the Australian workforce. Anthropometric data are fundamental in the design process. They give designers information about the end-user and clearly show where the limits of design lie with respect to health and safety. Anthropometric data allow them to consider the end-user in CAD applications or in drawings and prototypes.

This pilot research project aimed to find the answers to two research questions:

- What anthropometric data are currently being used to help create design solutions for Australian workers?
- Do these data adequately reflect the requirements of the contemporary Australian workforce?

The answers to these questions were sought from a search of the international literature, from the examination of the ‘grey’ literature and by seeking the opinions of designers, advisers to designers and people who evaluate designs for the Australian workplace. The research team conducted a small survey of these people, interviewed key individuals and conducted two focus groups, one in Adelaide and one in Melbourne. Our sample sizes were small and unable to yield statistically significant data, however, participants tended to have a strong interest in the use of anthropometry in design and generated useful qualitative data that gives insight into the state of play with respect to the collection and use of anthropometric data in Australia.

Our research enabled us to identify the sources of anthropometric data currently used in Australia – and thus answer the first research question. The research found that some anthropometric data targeted at working populations in Australia are proprietary or commercial-in-confidence. Of the publicly available data much is out-of-date or of military origin, not civilian population-based, and thus it is of limited value when applied to civilian populations. Some Australian Standards contain anthropometric data, but this is out of date and therefore unreliable. There are international data available but they are not necessarily relevant to the

Australian population. In general, there is a paucity of good quality, reliable anthropometric data on the Australian working population that is available to designers of Australian workplaces and products used in Australian workplaces.

Australian designers currently rely heavily on readily available 1D data sources to tell them about users. These data are almost certainly misleading most of the time, so even with the best will in the world, errors are designed in from the start. In any case, when these data are used they are not always used in a reliable and statistically robust way. These difficulties are increased when data contained in standards are conflicting or inaccurate and the standards are called up into legislation, or are a design criterion in contracts. The designer is left with an uncertain level of responsibility; an uncomfortable place to be in an increasingly litigious society.

The answer to the second research question is more problematic because to be definitive about it would require an Australian sizing survey. However, the research team was able to hear the opinions of participants to this research. The short answer is that the currently available data do not reflect the Australian working population, particularly at the extremes of the population (the very small and the very large) and that designers are forced to make ‘educated guesses’, use themselves or those around them as models, or take other short cuts in their design practice. There is rarely the opportunity to conduct a sizing survey for particular designs because this is both expensive and requires specific skills that are not readily available. Products and spaces are often designed with strict timelines and budgets that do not allow the luxury of prototyping. Thus, designers are often blind to the market or population that they are designing for.

There is anecdotal evidence that the Australian population is changing over time, and existing evidence supports the trend that Australians are getting heavier but not much taller, which must be accounted for in future workplace and product design. However, without good data, the extent of the changes in the population over time will not be known.

The designers, advisers to designers and evaluators of products and spaces were vocal about their needs now, and into the future, for reliable, high quality, accessible and affordable anthropometric data that can inform their work. The recent formation and rapid growth of the Human Factors and Ergonomics Society of Australia’s (HFESA) Anthropometry Resources Australia Special Interest Group (ARASIG), reinforces this assertion. ARASIG also provides a forum for users and producers of anthropometric data in Australia that could be used to educate and inform people.

A further emerging source of anthropometric data is the international, not-for-profit group, WEAR (World Engineering Anthropometry Resource). In 2009 WEAR will release the beta version of its on-line software that connects over 150 anthropometric databases. The database will contain some Australian data and there is potential to produce further data and lodge it with WEAR for international use. The increasing accessibility of technology to collect 3D data and the access to online databases such as WEAR provides the ASCC with a range of new opportunities to access and promote anthropometric data for workplace designers.

Optimally these problems would be avoided by having the correct information to hand during the design and testing phase to enable good design solutions to be prepared in the first place. This can only happen with an up-to-date, relevant, Australian anthropometric database that includes 3D body scans. The database needs to be available at low cost because the design and testing phases are still expensive and it needs to be available so that designers can verify and fine tune their designs. These data are an investment in the future. They will enable Australian designers to produce their work using a scientifically reliable base for safer, better designed workplaces and products for all Australians.

Chapter 1 Background and rationale

This pilot research project was commissioned by the Office of the Australian Safety and Compensation Council (ASCC). Its aim was to take the first steps to investigate the suitability and use of anthropometric data by designers who design products and workplaces for Australian industry.

Anthropometric data are the measurements of the human body form used by designers to represent the human shape and size in designing products, spaces and systems.

As part of this pilot research project the research team conducted a literature review in which the research team interrogated the international published literature as well as the 'grey' literature within Australia. The project also consisted of two focus groups and an indicative survey of designers and users of anthropometric data, providing an opportunity to consult with a cross-section of stakeholders who generate, use and assess anthropometric data in a range of industry applications. The research team was able to not only identify what data are used and the way these data are used, but also how designers, at a more general level, reflect the human needs within their specifications.

The target group for this study were designers (architects, interior designers, industrial designers, engineers and so on), ergonomists and others who advise designers, those who develop briefs for designers, as well as government technical staff involved in the evaluation of safe design within Australian workplaces.

There were two research questions posed for this pilot project:

- What anthropometric data are currently being used to help create design solutions for Australian workers?
- Do these data adequately reflect the requirements of the contemporary Australian workforce?

The first question the research team was able to answer from our quantitative and qualitative data. The second question the team were are unable to answer definitively (this would require an Australia-wide sizing survey), but we are able to reflect the views of our respondents. Given they have significant experience in design, their responses to this question are valuable and significant in considering the needs of the future.

These questions have fundamental importance for occupational health and safety in Australia. Poorly designed workplaces and poorly designed equipment can lead both directly and indirectly to workplace-related illness and injury. These are illnesses and injuries that are preventable through good design based on high quality, readily available data.

Chapter 2 Literature Review

Introduction

What are anthropometric data?

Anthropometric data are static and dynamic measurements of the human body. They provide designers with the potential end user's physical, functional and relational characteristics and are therefore an important part of the process of developing a design solution. Incorrect product and workspace dimensions often result in customer dissatisfaction and may lead to discomfort, accidents and injury. The correct use of appropriate data helps make workplaces and products fit real people (rather than the other way around) so that design solutions are safe and comfortable. For example, anthropometric data can provide an architect with information about how many people can fit safely and comfortably into a given workspace so that optimal use is made of space without compromising health and safety. Thus reliable, up-to-date and appropriate anthropometric data are fundamental tools for designers of products and spaces used by humans.

Anthropometric data are usually confined to body size and shape, but when collected in various postures they include reach capabilities and, where eye position is recorded, can be linked to visual field data. Other data defining user's abilities, such as strength, running speed or psychological data are sometimes collected for specific applications and might be called anthropometric data. This is because the fields of design ergonomics and anthropometry are overlapping and inextricably linked; the one depending on the other. The nature of overlap between anthropometry and design, where the user is functioning in the environment, often makes the boundary between the two indistinct. However, for the purposes of this report the research team will limit our definition of anthropometric data to physical measurements of people.

Anthropometric data come in many forms that include 1D, 2D and 3D data. 1D data can be identified easily because there is only one number, such as *stature = 1670mm* or summary statistics. Similarly each data point in 2D data will have two dimensions, that is x and y, such as a body silhouette. Each 3D data point has three numbers, x,y and z. An example is a 3D body scan that may have 300,000 data points, each grouped in x,y and z directions, making 900,000 numbers for one single body scan. Although the data increases in complexity from 1D to 3D data, each form of the data has its uses in design.

In this review of the literature we describe the strengths and weaknesses of 1D, 2D and 3D data. The sources of anthropometric data that are currently used in Australia by designers were examined. These include ergonomists, architects, industrial designers and engineers. Where the information was available the origin of the data, including its method of sampling and collection is described, to provide some basis of its currency and validity for the proposed design applications.

Sources of inquiry

In the preparation for this literature review, and for the wider project report, the following computer-based databases were interrogated: Web of Science, Academic Search Premier, Academic OneFile, PubMed, ScienceDirect, and Google Scholar. Searches were done on the keywords: *anthropomet*, work, design, Australia,* in an attempt to locate publications that were specific to this topic. Whilst there is a wide range of literature on anthropometrics, there is a dearth of formal literature on our specific topic and only three (3) articles were sourced with this combination of keywords. The results were extended when terms were dropped one by one, but although more papers were identified, after filtering the abstracts only a further 19 articles were set aside for reference in this report.

Grey literature (unpublished reports, theses, research projects and so on) potentially are a rich source of information. While the authors knew much of the grey literature existed, but had to work diligently to track down some sources. Other relevant materials have come to our attention during the data collection stages of the project and have been included in this literature review for completeness, although they may more probably belong with the research findings. The authors have cited the grey literature where they were able to obtain permission to do so, but much of this work is commercial-in-confidence and therefore unavailable to us. Sometimes the authors have only been able to allude to its existence.

The various Standards bodies, for example, Standards Australia and the ISO, have published standards that use or prescribe aspects of anthropometry. These have been incorporated wherever possible into the report. They are significant because they are often called up into legislation, thus making compliance mandatory, even though some are of questionable validity.

Identified sources of anthropometric data used in Australia

From searching the literature, from preliminary discussions with designers and their professional bodies, and from our own knowledge and experience, the authors identified sources of anthropometric data used in aspects of design for workplaces in Australia, and these are discussed below.

The International Standards Organization (ISO) standards are sometimes adopted by Australia with little or no amendment. The ISO has an overarching standard (ISO 15535:2006) (ISO 2006a) called *General requirements for establishing anthropometric databases*.

There are also three different standards, sometimes conflicting in definitions, specifying how to take anthropometric measurements:

- ISO 3635:1981 *Size designation of clothing – Definitions and body measurement procedure* (ISO 1981),
- ISO 7250:1996 *Basic human body measurements for technological design* (ISO 1996), and
- ISO 8559:1989 *Garment construction and anthropometric surveys – Body dimensions* (ISO 1989).

The following ISO standards are likely to be relevant to this topic, but are not discussed here because the scope of this project is tightly confined to the two research questions mentioned earlier. The authors have not been able to establish their status in Australia:

- ISO 14738:2002 Safety of machinery — Anthropometric requirements for the design of workstations at machinery (ISO 2002).
- ISO 15537:2004 Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs (ISO 2004).
- ISO 13232-3:2005 Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 3: Motorcyclist anthropometric impact dummy (ISO 2005a).
- ISO 15534-3:2000 Ergonomic design for the safety of machinery — Part 3: Anthropometric data (ISO 2000).
- ISO 20685:2005. 3-D scanning methodologies for internationally compatible anthropometric databases (ISO 2005b).
- ISO 15536-1:2005 Ergonomics — Computer manikins and body templates — Part 1: General requirements (ISO 2002c).
- ISO 15536-2:2007 Ergonomics — Computer manikins and body templates — Part 2: Verification of functions and validation of dimensions for computer manikin systems (ISO 2007).
- ISO 15830-3:2005 Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy — Part 3: Electronic subsystems (ISO 2005d).
- ISO 15830-4:2005 Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side impact dummy — Part 4: User's manual (ISO 2005e).

- ISO 7250-1:2008 Basic human body measurements for technological design — Part 1: Body measurement definitions and landmarks (ISO 2008).

There are two standards referred to in Australia for women's clothing, the first an Australian Standard and the second an international standard:

- *AS1344-1997 Size coding scheme for women's clothing – Underwear, outerwear and foundation garments* (Standards Australia and Standards New Zealand 1997)
- ISO 3637:1977 *Size designation of clothes – Women's and girls' outerwear garment*s (ISO 1977).

There is an Australian standard called up into the Building Code of Australia:

- AS-1428 2, 1992: Design for access and mobility, Part 2: Enhanced and additional requirements – Buildings and facilities (Standards Australia 1992a). This document is discussed later in this report.

The Worksafe Australia Ergonomics Unit published a paper called *An Anthropometric Data Base For The Australian Workforce* (Stevenson and Phillips 1992). It outlines a method of using existing data collected in other countries that reflects the different ethnic backgrounds of Australian workers. Percentiles for at least 36 dimensions allow the designer to compare body size of people from 16 different countries or combinations of these groups. Eleven of these national surveys did not collect the required 36 dimensions, so these measures are estimated using the method described by Pheasant (1986) as cited by Stevenson and Phillips, which uses stature and ratios. These are stored in a computer database, but the authors advise that "the data content for individual ethnic groups still leaves a lot to be desired, and additional databases are being sought" (Stevenson and Phillips 1992: 29).

The summary statistics *Humanscale* (Diffrient, Tilley et al. 1983) and *Bodyspace* (Pheasant 1987; Pheasant 1988) are commonly referred to in the ergonomics literature. Neither is based on Australian data and there is no evidence that they adequately reflect the Australian working population. Both *Humanscale* and *Bodyspace* are based on United States military data from the 1970s. Both include data on women, but for present day purposes they have dubious application to the Australian workforce given their age and the lack of civilian data (that would better describe people at work).

Woodson (1992), used by some architects and interior designers in Australia, presents "carefully selected information that experience has shown to be related to the majority of design questions" (Woodson, Tillman et al. 1992: 704). Like *Humanscale* and *Bodyspace*, Woodson presents 1D data, relying on summary statistics and commonly using the 5^{th,} 50th and 95th percentile values. The authors state that these data are from US military measurements of nearly 9,000 subjects, integrated with

NASA's Man-Systems Integration Standards and suggest that, while “this is not a profile of the civilian population (male and female subjects ranged from age 18 to 51), it does provide fairly good estimates” (Tillman 2000). They claim that there was no comprehensive civilian data available at the time of publication, although they were able to herald the advent of the CAESAR (Civilian American and European Surface Anthropometry Resource) database. Thus, Woodson has the same limitations as *Humanscale* and *Bodyspace*.

The CAESAR database is a North American and European anthropometric database of men and women, aged 18-65 covering various weights, ethnic groups, gender, geographic regions, and socio-economic status. Over 12,000 3D body scans were taken of more than 4,000 participants between April 1998 and early 2000 in a joint, military-civilian project. CAESAR is a commercial product available for sale and at this stage of the project the authors have not found any Australian users of these data, except SHARP Dummies Pty Ltd (Veitch and Robinette 2006). This database will be included in the World Engineering Anthropometry Resource (WEAR) which is explained in detail later in this report.

Digital-man models include the three main commercial models, *Ramsis*, *Jack* and *Safework* and also many non-commercial ones used in research laboratories, such as *Man3D* and *Madymo*. Digital man models are static and dynamic. They are not standardised for features such as kinematic linkage, envelope, reference posture and motion and posture (Beurier and Wang 2004), all of which are relevant to design for the workplace. This lack of standardisation makes it hard to compare them to each other and to share motion data between the models (Beurier and Wang 2004). There are also differences between kinematics and external dimensions of various models and real people. These models digitally create artificially shaped humans in a CAD environment using the input of 1D anthropometric measures, which the authors discuss later. They are not sources of data in themselves. The authors will comment on their use later in this report.

Australian anthropometric data

The Australian Standard, AS1344-1997, *Size coding scheme for women’s clothing – Underwear, outerwear and foundation garments*, states:

> The first edition was prepared in 1959 as Standard L9 at the request of the Apparel manufacturers Association of NSW, with strong support from manufacturing and retail industry. It was based on a US Department of Commerce Standard (CS 215-58) and its preparation was assisted by Berlei and Dr H. O. Lancaster. The document has since undergone several revisions, the last of which was AS 1344-1975. Revisions since 1970 were accomplished with the assistance of the *Australian Women’s Weekly* in a survey which included [self-reported] information from 11,455 Australian women on bust, waist, hip and height measurements as well as age groups. In 1972 there was a conversion to metric. The size coding scheme included only bust, waist and hip

> measurements. The last edition in 1975 also included foundation garments (Standards Australia and Zealand 1997).

The document goes on to state, “This edition confirms the data in the previous edition, due to the absence of a more up-to-date survey” (Standards Australia and Zealand 1997: 2).

There are four Australian military surveys that have been conducted, three of them published (Aird, Bond et al. 1958; Army Inspection Service Headquarters 1970). The third, the Royal Australian Navy Anthropometric Reference Data measured 302 subjects, 251 male and 51 female volunteers aged late teens to late twenties, taking 30 anthropometric variables per subject using conventional tape and callipers (Department of Defence 2000). In 2004 the Australian Defence Force commissioned an anthropometric survey, known as *MIS 872, ADF Aircrew and Crewstation Anthropometry*. The measurements taken are extensive, including 3D body scans, and the data are applicable to man/machine relationships, but they focus on a fighting environment and they are limited to a select group, e.g. 250 existing ADF personnel and 1,500 young people aged 18-30 (possible recruits) with high educational standard suitable for entry as ADF aircrew (Ross et al. 2006). As yet this latest survey is not in the public domain.

All the military surveys have the same limitations with respect to their applicability to Australians at work; that is, they do not include data that represents the wider civilian population in civilian environments that make up the Australian workforce. Rather they are taken from a select group of people, mainly men, who are unlikely to be either overweight or obese, well fed and pre-selected for military service on the basis of their physique and physical condition.

In 2002 the University of Adelaide and SHARP Dummies Pty Ltd collected an anthropometric database in 6 Australian capital cities using as subjects men and women who volunteered while attending craft fairs. Fifty-four manual measurements were taken from each of 1,265 adult women and from 135 adult men ranging in age from 18—70+ years. In 2004 an extra 65 sets of women’s measurements were taken, including full laser body scans, using the method described by Henneberg and Veitch (2003). An extensive analysis of the results has been published (Veitch, Veitch and Henneberg 2007). Raw data from these surveys will be available through WEAR after June 2009.

In 2003 The University of Adelaide and Rip Curl Pty Ltd conducted a sizing survey of Rip Curls’ user population measuring 2,200 girls and women, aged 12-24 years who volunteered in Victoria, NSW and Queensland. This database is proprietary and no known work has been published.

There have been other surveys developed by individual companies to assist in their own design solutions (such as Kunelius, Darzins, Cromie and Oakman 2007). There may be more databases available, however they did not come to the attention of the authors in time to be incorporated into this report.

How anthropometric data are currently used

As discussed later in this report, our research for this project shows that Australian designers do not use anthropometric data in complex ways. Typically, 1D data would be used to define the solution to a design problem. For example, to determine the height at which a control panel should be placed on a piece of plant so that 95% of the population of users could see it and use it easily and safely, the designer would look up the 1D anthropometric tables and extract the static measurements for arm reach distance and eye height. These measurements for the 5^{th} percentile female and 95^{th} percentile male would be tested against the drawing for the control panel. The designer would then assess if the panel could be seen and reached by this portion of the adult population represented in the data. However, this population from the anthropometric data may not represent the user population of the control panel.

Moreover, the situation is even more complicated than the errors inherent in the source of 1D data used. As the authors have shown, there are many anthropometric databases currently in use but the ability to access and analyse the variety of anthropometric data depends on a range of factors. The data first must be found to exist. When found they are then often not readily accessible, especially if they are proprietary and/or commercially sensitive. Using these data can be difficult if one database is to be compared with another because the measurement-taking may vary, introducing quality assurance issues. For example, one cross-shoulder may have been measured in a different way to another cross-shoulder, which could confuse or introduce significant error for the user of the data. Finally the knowledge and skill of the user is critical in the effective use of the available data. Users have told us that, “these data are a reasonable estimate of a given population” without any demonstrated evidence that this is the case. Thus, it appears that users tend to use what is at hand, rather than what is best, on the assumption that if it’s published or available, then it is probably acceptable and useable. An assumption that may be very erroneous.

More sophisticated users, who recognise the limitations of readily available data, may engage an "expert" consultant who searches the most relevant resources available and provides a response. This is time consuming, costly, and has varying degrees of success. Even with the help of an expert, 3D image data are virtually inaccessible, though this situation will improve as use of 3D data widens. Only a handful of resources are available on-line, other data are held by isolated groups –

their existence is either not generally known or may be a closely guarded secret. If 3D raw data are available, they are typically in original scan form (very, very complex) that may only be readable with special software specific to the scanner. There are few standards and inconsistent quality control of these data.

The origin of the data

Methods of sampling and collection

Inquiry about the methods used in sampling a given population and then collecting anthropometric data on the individuals in the sample provides the basis of the currency and validity of the data for the proposed design application.

Accuracy of the data

Extrapolation between 1D and 3D data

Historically anthropometric data have been of the 1D variety and collected manually using traditional tools such as tape measures and calipers. Usually these measures took more than one hour per subject to collect; thus collecting and constructing databases was very expensive. The idea of a digital 3D body image scanned into a computer was considered to be a great improvement because it would save time and body measurements could be derived automatically using software. Any measurement not taken at the time of scanning could be analysed retrospectively by interrogating the database so users in the future could be accommodated. As a result of these ideas, the first 3D body scanners were built during the 1990's.

Currently there are many types of body scanners available on the market including, laser scanning (Cyberware, Vitronic, Hamamatsu), patterned light projection (TC2), with the very recently emerging technology of millimetre waves (www.alvanon.com and TNO) and stereophotogrammetry. Some of these are used in Australia. Our investigations revealed that Cyberware and Vitronic laser scanners and TC2 patterned white light projection scanners are in use in Australia.

However, not all of these imaging devices make a good 3D copy of a human form. Currently laser scanners have the best image acquisition capability followed by pattern light projection scanners. The lowest quality scans are currently millimetre scanners (Daanen 2008).

Body images are assembled with data processing software that stitches the various images created from different camera angles with varying degrees of success. In addition, the nature of 3D body scanning means there are always some areas of the raw scan missing due to self-occlusion of the body i.e. armpits are occluded by the arms and the crotch area cannot be scanned because the legs block the camera views.

The quality of software stitching varies considerably too (Daanen 2008). Once the 3D image of a person has been created a computer can extract specific measurements, but sometimes the accuracy is questionable. When 1D measures derived from a 3D scan and 1D measures taken manually by a skilled anthropometrist (from the same subject) are compared they show 'considerable difference', in particular for the circumferences (Hin and Krul 2005). However linear distances based on pre-palpated landmarks are comparable and reproducible (Robinette and Hudson 2006).

Trends emerging from both Australian and international data suggest that over time there is a disproportionate increase in body weight and related circumferences compared to body segments or lengths. Clearly the existence of allometry, which is the differential growth of body parts in relation to overall size, (Huxley and Tessier 1936) suggest increased body size is not a simple matter of scaling but must be measured in real people to be modeled accurately (Slice and Stitzel 2004).

This means up-to-date anthropometric surveys using body-scanning technology, which accurately capture changes in body shape and posture can be valuable as sources of data for designers. However they must be used with caution and knowledge about the veracity of their data sources. What is needed is a focus on the new, truly-3D techniques that are now available that have excellent stitching and produce accurate models, rather than a continued reliance on an inappropriate extrapolation of 1D data to 3D data. New measurement extraction software improvements are still under development and the software will continue to improve, but at the moment 1D measures derived from a 3D scan should probably be considered as a separate category from traditional, manually derived 1D measures.

Anecdotally the authors know that industries that design for the workplace, such as the apparel, manufacturing and automotive industries, remain focused on 1D measures such as waist or chest circumference. When the measurement has been acquired using a method that has been proven to be different to existing methods, such as a body scan instead of the more familiar traditional method of the tape measure, then the industry is very prone and vulnerable to making significant error that impacts on the end user – the worker.

Self-reported data

Self-reported data such as the *Women's Weekly Survey (1969)*, which was conducted for Standards Australia in order to update AS 1344-1972 and subsequently AS 1344-1997, is not high quality anthropometric data. Self-reported data have a place in other forms of scientific inquiry, such as nutrition monitoring, because they are relatively inexpensive and easy to collect. However, classifying people into weight categories on the basis of accepted cut-points, using self-reported heights and weights, yields inaccurate prevalence estimates (Australian Bureau of Statistics 1998; Flood, Webb et al. 2000). According to the Australian Bureau of

Statistics, when self-reporting both males and females significantly overestimate their height and underestimate their weight. 33% of males and 25% of females overestimated height by 3cm or more and 16% of respondents underestimated their weight by 5kgs or more. This was not evenly distributed with lighter people more accurately estimating their weight than heavier people (Australian Bureau of Statistics 1998).

Problems with data in Standards

The introduction of AS1344-1997*, Size coding scheme for women's clothing* gives the sources of data used, yet the tables given for average women are inconsistent with this. The tables given in AS1344-1997 for average women show fixed incremental growth in bust, waist and hip girth which indicates that, "the body measurements are not taken directly from survey data. Also, the tables present a progressive increase in height with increase in girths (Winks, 1997, pg 48)".

As Winks goes on to assert,

> As if to support this error, body length components such as waist height and hip height, are proportionally presented but the figures include an increase in crotch height which is the opposite to that found in practice. Crotch height (i.e. inside leg length) reduces slightly in higher girth values, as survey data show (Winks 1997: 48).

The use of AS 1428.2-1992. (*Design for access and mobility. Part 2: Enhanced and additional requirements – Buildings and facilities)* is called up into law by the Building Code of Australia requiring architects and builders to adhere to the standard. Yet the standard is vague about what anthropometric data for disabled people were used and how the standard was derived from these (Nelson 2008). Although an anthropometric data source is quoted, only 76 males and 28 females, all paraplegics from the National Spinal Injury Centre, Stoke Mandeville, UK were measured (these included dynamic reach measurements) in 1966. Body measurements only were taken on a further 15 male and 8 female quadriplegics, and reach was not measured as they had little or no arm movement (Floyd et al, 1966).

The AS 1428 - Supplement 1-1988 (*Extracts –Design rules for access by the disabled) (a supplement to AS 1428 -1977)* quotes work done by J.H. Bails, *Project Report of the Field Testing of Australian Standard 1428-1997*, commonly known as the 'Bails Data Base'. The aim of the research was to determine the suitability for use by disabled persons of 'particular facilities' (not defined) referred to in AS 1428-1977. Some of the research was carried out using 1/5 scale models and manikins, but which tests were done using live subjects and which in 1/5 scale is not recorded. This database does not contain anthropometric measures of its variously disabled test subjects (including blind, ambulant, electric wheel chair users and wheelchair users) (Nelson, 2008: 9).

The authors propose that some Standards, accepted in the marketplace as credible or being enforceable by law, may be flawed, inaccurate and potentially misleading.

The limits of anthropometry

Whatever its application, anthropometric data need to accurately reflect the user population; if this is not the case, then necessarily design results will be haphazard. So, for any anthropometric data, the definition of the user population is critical in the first instance. In this section the strengths and weaknesses in anthropometric data are discussed.

One dimensional

Strengths

For the non-technical designer 1D data, such as summary statistics, means, percentiles and so on, are attractive because they are easy to use although they can sometimes be hard to find and access.

Whether the use of 1D data is classified as a strength or a weakness depends on how complex the problem is to solve and what answers are 'good enough'.

They are particularly useful for comparing samples from different populations to determine size and variation differences. Examples include a biological anthropology study of trends such as evolution of man or the stature of Australian military males compared to Indonesian military males or comparison of civilian to military populations. This may conceivably be important for some design applications, however, in the main they are insufficient for engineering anthropometry (Robinette and Hudson 2006 : 337).

When only one parameter is needed to create a design solution 1D data may be adequate. For example, stature plus clearance could be used to determine door height.

Weaknesses

Some 1D data may be adequate in some situations and not adequate in others. For example in order to allow wheelchair access into buildings (and to comply with legislation) architects designing public buildings would seek data about humans in wheelchairs to define the width of doorways and turning circles for ramps. The relevant Australian Standard (Standards Australia AS-1428-2: 1992. *Design for access and mobility, Part 2: Enhanced and additional requirements - Buildings and facilities or Building Code of Australia*) (Standards Australia 1992a) points to the use of 1D data, being the width of the widest wheelchair (A80).

This standard seems to have been an acceptable base for design in the past. However when scrutinised by the Human Rights and Equal

Opportunities Commission (HREOC) it was found that the standard on one hand mandates compliance but on the other hand does not give enough raw anthropometric information to conclusively test specific access situations (see for example, HREOC 2000; HREOC 2004). For example, Australia Post is being required by HREOC to lower the height of all post boxes (contrary to international requirements) to satisfy the reach requirements of wheelchair users; a decision that appears to have been made on inadequate and/or conflicting anthropometric data and in a keenly litigious environment. It highlights the plight of designers or certified ergonomists, who somehow have to bridge the gap between inadequate anthropometric data and the production of workable designs, workplaces or access to workplaces. Once a design is established and commissioned in the workplace changing it can be extremely expensive as the example above illustrates.

Designers increasingly call for 3D databases and human models, but the currently available databases and models are not connected and interactive. Digital man models such as *Ramsis*, *Jack* and Safework are built using old (1D) data and do not characterize individual subjects. That is, whilst they may be considered by users to be sources of 3D data, they are not, they are 1D data represented in 3D format. They attempt to characterize humans using a variety of aggregate data, such as means or least squares regression, and then predict surfaces from the aggregates. The quality of the output depends on the quality of the input data and how closely the original template model matches these input data. So if the model was created using 50th percentile information and the input data are 50th percentile, the shape might be quite comparable with an actual person of those dimensions, however when the input data moves to the extreme, such as representing obese people, the models often show unrealistic distortions and additive errors (Robinette and McConville 1982) as evident in Figure 1, which is built from only 95 percentile measures.

Figure 1: A distorted model built from 95th percentile data

Thus, digital man models are unable to characterize the more accurate and detailed new data for individuals, such as from body scans, that are now obtainable. If the most up-to-date data cannot be entered into these models, then those data are unable to be used by designers; this renders them effectively useless. There is an urgent need to make the data-import into CAD programs seamless and straightforward so that designers can take advantage of recent improvements in anthropometric data collection and have accurate data, from a wide variety of sources, at their fingertips.

Early (and perhaps still popular) design methods used percentiles combined with trial and error. Using percentiles for more than one dimension in a design will accommodate less than the proportion of population indicated by the percentile (Robinette and Hudson 2006: 325). In addition, when a design requires conflicting or interacting measurements percentiles will not be effective (Robinette and Hudson 2006: 323).

An example is the use of percentiles in cockpit accommodation as discussed by Robinette and Hudson (2006: 323). Early practice used the 5th or 1st percentile female and 95th or 99th percentile male as the extremes for which to design. This decision was made on the assumption that if the design fits the smallest reasonable person (say the 1st percentile female) and the largest reasonable person (say the 99th percentile male) then everyone in between these two extremes for size would fit that environment or design. A candidate aircraft for the US Air Force T-1 program was computer modeled and a 1st percentile female added to test it. The seat needed to be raised so she could get line of sight over the nose cone and then moved forward so she could reach all the controls. This was done and the design worked well. Then the design was tested on the 99th percentile male. Again he was accommodated well with some adjustments; the seat needed to be lowered and adjusted so his head did not hit the canopy and he was not too cramped. The seat needed to be sufficiently far back so that in an emergency egress (seat ejection) his knees and legs would not hit the control panel and damage or amputate them. Thus, the design passed the test of theoretically being able to meet the widest range of users.

So, did the design work well for real people when it was built? Unfortunately the dimensions of real people are not all 1st or all 99th percentile in each person but mixed combinations of percentiles. So when a real person, a 5th percentile female for height but 50th percentile for thigh circumference, tried to operate the controls in this cockpit there were problems. With the seat raised as was done in the accommodation trial, her thighs hit the yoke (steering apparatus) and she did not have the degree of movement required for safe control of the aircraft. This problem was not identified using the contrived 1st percentile female because she also had tiny 1st percentile thighs and abdomen giving her room in this area (Robinette and Hudson 2006: 323). To avoid these types of problems, case studies using 3D body scans of real people with different combinations of key dimensions should be used to test the design so it really does fit all the variations or real people who will use the space or equipment. This is only possible with 3D data built from real people.

In complex cases percentiles do not contain enough information for a design team to do their job effectively. When used inappropriately they result in poor fit between products and workspaces and their user population; errors that are often not identified until it is too late and the design is in production and in use.

Two dimensional

Strengths

2D data such as physical templates and CAD drawings which represent shapes of people are fast, cost effective and easy to use. They have been used in design, especially in the ergonomics field, for at least 60 years.

> Simplified 2-D drawing analysis may be the preferred means of supporting early choices about the configuration and approximate size of things before investing in a more comprehensive 3-D CAD model (Ward 2008).

This method is a very fast way of creating an estimate of what a finished design might include.

More intuitive than 1D data because the limb and torso segments are in recognisable human form as distinct from a table or graph, they can also move in ways that intuitively look ‘right’ to a novice user. This is very easy to use and understand. There is no specialised knowledge of CAD computer programs or skills required to move around a physical template. But there are also considerable disadvantages and limitations not immediately apparent to the novice user, these are discussed below.

Examples of 2D templates include both computer CAD files and plastic cutout human shapes. At this stage only the simplistic idealised 2D shapes based on 1D data are available (see below). CAD examples using 1D data as a base include *The Measure of Man and Women* (2002, Tilley and Dreyfuss) and less commonly used *ergopix© CAD outlines*, developed in Australia by Stephen Ward, and used in the UNSW Design Program. There is anecdotal evidence that individual designers often create their own 2D templates based on *Bodyspace*, *Humanscale* and various standards or combinations of the above and their own data. This is a very inexpensive approach.

Weaknesses

2D data such as physical templates and CAD drawings are fast, cost effective and easy to use but in common with 1D data they represent a simplified approximation of people’s size and shape and can only move in simplified, flat 2D-planes. Although they may look intuitively ‘right’ to a novice user, this can be misleading because the inaccuracies of joint positions and movement necessitates approximations, especially the compound movements of shoulder, neck and back, which are not adequately encapsulated (Ward 2008). Also the use of intuition in the subjective visual assessment of the template's fit in the design can vary greatly between individual users and is not readily repeatable.

If templates are built on 1D data such as *Bodyspace* (Pheasant 1988) and *Humanscale* (Diffrient, Tilley and Bardagjy 1974), then they inherit the problems associated with the original 1D data already outlined above. Inconsistency of views: front, side and top, can be a problem as the application of 1D data is not specific enough to define shape. Often some 1D measures can conflict with others in the translation into 2D because the percentiles are not additive (Robinette and McConville, 1982) so compromises need to be made.

Unfortunately there are too many choices for compromise solutions and the only way to determine which is the most biofidelic (life-like) compromise is to intuitively 'eyeball' to the result. These problems could be mitigated by using statistically selected 3D body scan data (Robinette and Hudson, 2006) instead of 1D as a base, if appropriate raw data were available. Thus these limitations are not a problem inherent in 2D templates, rather it is a lack of appropriate input where 3D data, such as a sagittal (longitudinal plane diving body into left and right parts) silhouette of body scans, would be a better alternative to the problematic, simplistic percentile 1D data (Ward 2008, from telephone interview with Veitch).

> 2-D anthropometric tools should be seen as complimentary to 3-D tools and both could be derived from the same 3-D databases to provide continuity of user representation throughout the design process (Ward 2008).

The authors are unaware of any work that has yet applied 3D data to 2D templates in a systematic way.

Three dimensional

Strengths

An outstanding strength of the use of actual 3D body scan data is the improved accuracy of the modeling that is available to aid complex design solutions creating an ability to visualize cases with respect to the equipment or apparel they wear or use (Robinette and Hudson, 2006:336). Recent improvements in the statistical method of multivariate analysis allows case studies to be selected that can be used in prototype modeling for testing. They give a much better approximation to real life than was given by contrived 3D modeling built from 1D (often percentile) data, and lead to better outcomes, such as improved accommodation envelope (fit more people in the same space or product) and much greater safety (such as ensuring it is possible to exit dangerous situations without injury).

Better anthropometric information about users' external dimensions and kinematics also reduces the cost of the design phase by providing real information instead of the more time-consuming reliance on trial and error to create designs. Better informed designers, able to quantify outcomes, have increased flexibility in their work as they are able to selectively and effectively separate out and test those features of a design that are safety critical or that impact on accommodation. Other elements of the design that are non-safety critical, such as appearance, can be considered separately.

Use of 3D data allows a new dimension of measurement adding shape and posture to the previous 1D value, which usually represents size, such as illustrated in Figure 2. It also allows calculation of volume (e.g. they might be used to calculate bust volume), surface area (might be used to help burn victims) and curvature (might be used for chair design). These are all relevant to design for the workplace.

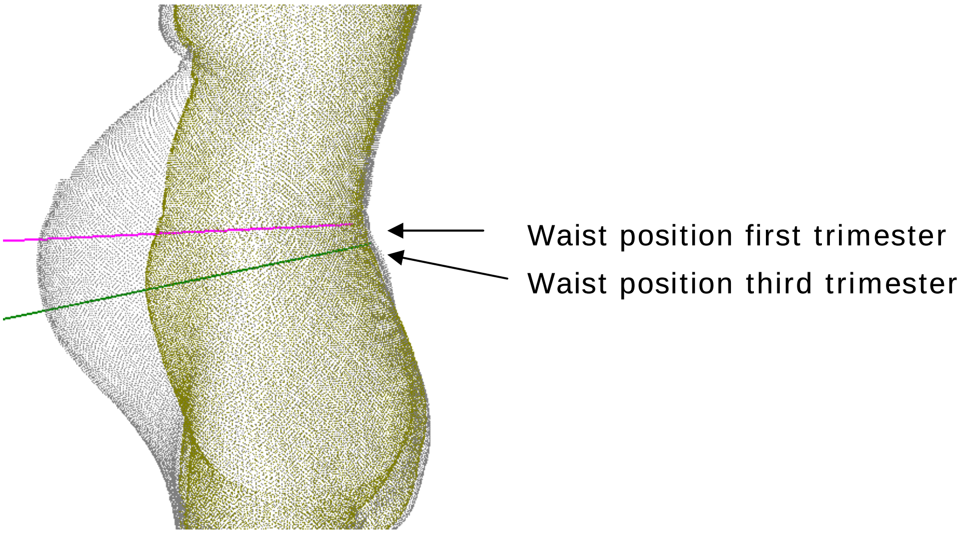

Figure 2: 3D body scan of lateral view of a pregnant women in first and third trimesters of pregnancy, showing the added dimension of shape to size.

Weaknesses

3D anthropometric data are relatively new and their use requires skill and knowledge. They need to be accessible and usually require the user to learn specialised software. Because they are new there are few standards and their quality is not consistently controlled. Some 3D data are of much better quality than others but designers are unlikely to be aware of the differences. Designers often believe that 1D data extracted from 3D data are the same as 3D data, but this is not the case, as discussed above.

The most prevalent misuse of '3D' data is the current trend in the apparel industry to rely on 1D measures, usually circumferences such as waist, hip and bust, extracted from 3D scans and presume that these data are superior to traditional 1D measures taken using a tape measure. Not only are they not comparable but these data are not reliable and are not 3D.

Access to data

Anecdotally designers use 1D anthropometric data such as *Humanscale*, Pheasant, Woodson and the various standards that are readily available and discussed above. The difficulties with their use in all but the most limited circumstances have already been discussed and these data sources are not adequate for effective design of even slightly complex spaces and products. Further, their use by designers in the belief that they “better than nothing” may be false is the resulting designs are flawed and potential harmful for end users. Despite this, as part of the ongoing grey literature search involved in this project, designers told us that the use of these data is valuable, but the same designers also told us that specific anthropometric data relevant to Australians needs to be developed and their future design requirements will require more accurate and reliable data suited to a larger range of user sizes. This suggests that although people have to work and deliver designs, they are aware that there is a gap between what they are forced to use and what they really need.

Unfortunately, relevant anthropometric data are currently difficult to find and use. Designers may have access to anthropometric data on their target population, but it is likely to be in the form of printed texts with summary statistics for 1D data (mean, standard deviation and percentiles). (For examples see: Robinette and Hudson 2006; Harrison and Robinette 2002; Gordon, Churchill et al. 1989; Pheasant 1988; Jürgens, Aune et al. 1989). While these statistics are helpful for comparing datasets and populations, they have been shown to be inappropriate for most engineering or design problems.

More than 50 years ago Daniels (1952) demonstrated that no-one is average in every dimension. Out of more than 4,000 men he confirmed that none were within the middle 1/3rd for all of 15 measurements. Everyone was some different combination of small, average, and large proportions. Figure 3 illustrates the importance of this observation with simple 3D boxes representing three subjects of different small, average, and large proportions. Their three dimensions are shown and the average of the three subjects is calculated and illustrated beside them as the pink cube. Because they are all ‘average’ in different ways the pink cube, the average of the three subjects will not ‘fit’ any of them. It is too small for 100% of the subjects and it is proportioned differently than all three as well. If it is scaled up it could fit over all three subjects but it would be very large in at least one dimension.

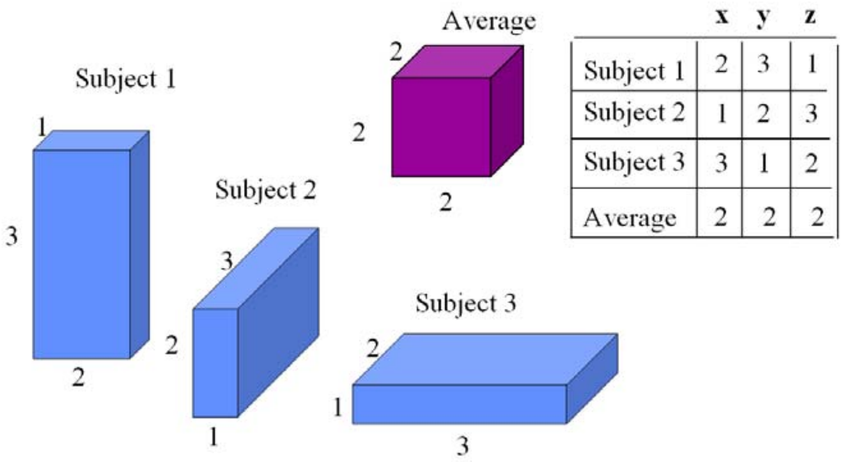

Figure 3: Illustration of the problem with averaging for design

Robinette and McConville (1982) illustrated that using percentiles to represent people, such as the 5th percentile female to the 95th percentile male is worse. These values do not even add up such that a figure can be created that is 5th percentile or 95th percentile for every dimension. Searle and Haslegrave (1969) illustrated the very large errors that resulted in crash manikins that used 95th percentile values.

Difficulties in interpretation

The situation is further complicated because even if designers do locate appropriate and accurate data, they are unlikely know how to interpret it because this task is not necessarily straightforward.

The latest best practices publications by the US Human Factors and Ergonomics Society (HFES 300 Committee Santa Monica 2004) and others (such as Robinette and Hudson 2006) provide alternatives to averages and percentiles, but the alternatives require the use of raw data specific to the target population. Some 1D raw data from traditional tape measures, anthropometers and calipers is available by survey in spread sheets but it is hard to find and can be difficult to use. For example, raw data for the first subjects from one survey available on the Human Systems Integration Information Analysis Center, HSIIAC website [http://www.afrl.af.mil/wrslibrary/he.cfm] is shown in Figure 4. It takes some effort, skill and knowledge to be able to decipher and separate the numbers from one another and determine what the actual measurements are, using a computerized statistical analysis package.

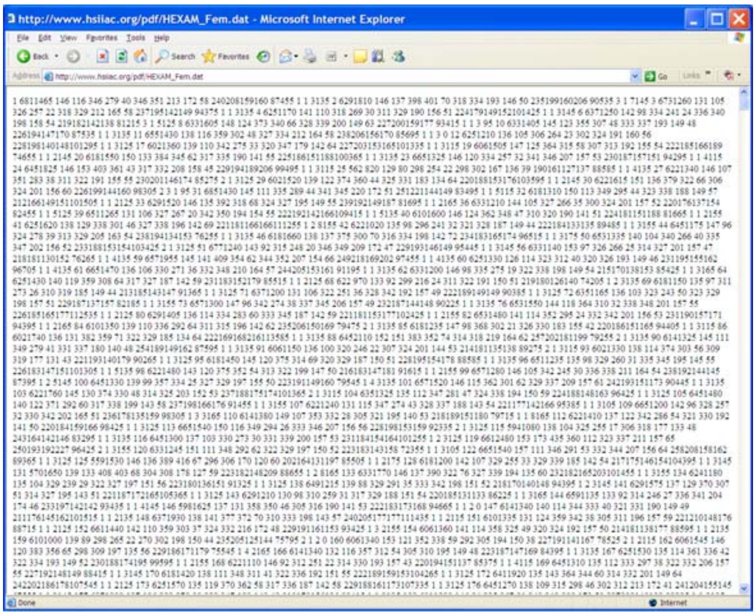

Figure 4: First page of raw traditional data from the HSIIAC website

Furthermore, the best anthropometric data are not sufficient by themselves to create good design if the relationship between the product and anthropometry is not known. Fit mapping is the study of this relationship and examples are described in Robinette and Hudson (2006).

Multiple standards

It should not be a surprise that anthropometric studies conducted over decades by organisations throughout the world use different methods and terminology. Once data are found and deciphered it is necessary to study the different samples in order to align like measurements and separate different ones. There has been a general lack of standardisation in data collection, or perhaps more correctly there are too many different standards. Even single organisations can have multiple standards for the same things. For example, the International Standards Organization (ISO) has three different standards specifying how to take anthropometric measurements, ISO 3635 (1981), ISO 7250 (1996) and ISO 8559 (1989). In addition, another standard, ISO 15535 (2003) relates to requirements for establishing anthropometric databases. In some cases measurements with the same name are actually different measurements, and measurements with different names are the same measurement. For example, bizygomatic-breadth (The width or breadth of the face from the widest part of one cheek bone arch to the widest part of the other) and face-breadth can be the same measurement. Head-length might be taken horizontal to the floor when the head is in the Frankfurt Plane (anatomical position for the skull where lower margins of the eye orbits and upper borders of ear canals are on a horizontal plane) by one group, but may be the maximum length of the head in the mid-sagittal plane as taken by another.

Lack of a unified, internationally accepted standard measurement and naming system has hampered the generation and use of anthropometric data for many years. Given the subtleties in understanding and using these data, it is little wonder that the designer (who is unlikely to have either specialist anthropometry knowledge or access to a skilled anthropometrist) in sincerely trying to input end-user data, ends up making fundamental errors.

World Engineering Anthropometry Resource (WEAR)

WEAR (Veitch and Robinette, 2006) is a not-for-profit, international collaboration of organisations that generate or use anthropometric data. WEAR's mission is to actively promote the dissemination and development of knowledge in anthropometry, ergonomics and human factors to contribute to the improvement of health, safety and the wellbeing of people. Based at the Universite Paris 5 in France, WEAR is dedicated to collecting and providing readily accessible and useful anthropometric data for world-wide use. The members of WEAR come from a range of organisations spread over 10 countries, including Australia. Over the last few years they have met twice a year (including in Adelaide, Australia in 2007) to discuss the databases available to the group.

Currently WEAR has collected and is assessing 145 anthropometric databases and is applying strict quality assurance guidelines to them. The databases include 1D, 2D and 3D raw data of populations from all over the world. There is a mix of military and civilian data. In all, there are measures on over 250,000 subjects. WEAR is developing an ontology process that will unify these data and allow sophisticated searching across and between the databases. This exercise, which is exhaustive, will not need to be repeated by future users. Some applications have already been developed, and others will be developed in the future to enable the collected and networked data to be used by ergonomists, designers and other end-users of anthropometric data. These data will all be accessed through one central web portal; that is, they will be available internationally and on-line. So, for example, an Australian designer engaged to develop mining equipment would be able to key in search parameters for specific data on 18 – 45 year old men of particular ethnic backgrounds and resident in Australia. Provided the data were held by WEAR the designer would have fast access to them. WEAR plans to release the beta-version of its software and web portal at the International Ergonomics Association Congress in Beijing, 9-14 August 2009. Figure 5 illustrates how WEAR will fit into the world of anthropometry and interface with designers in the future.

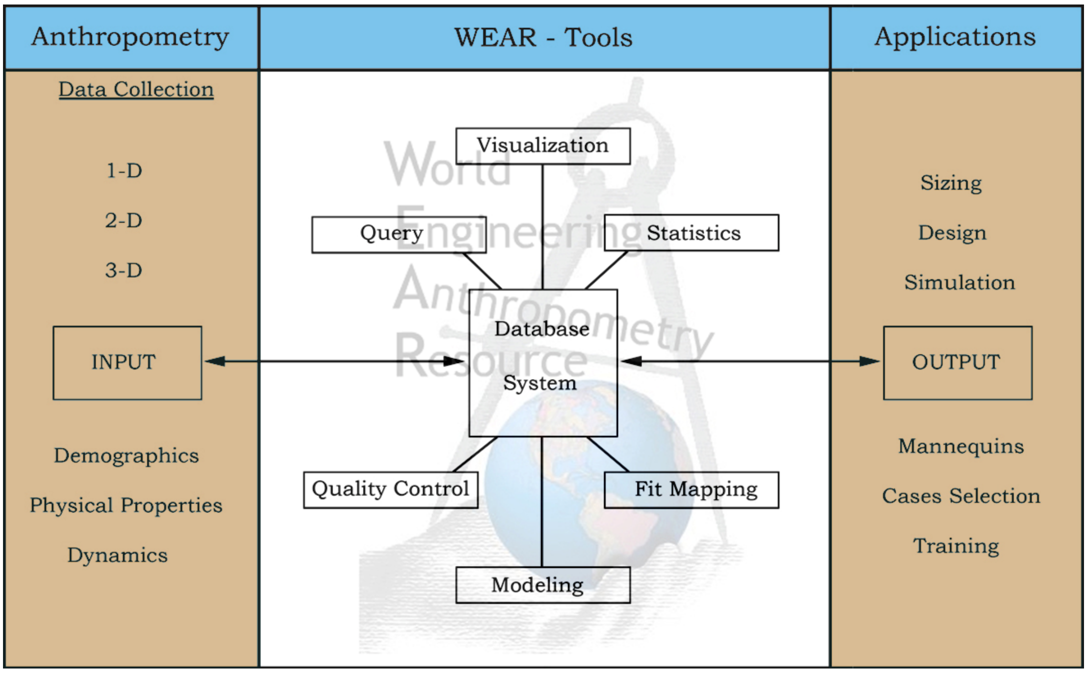

Figure 5: A diagram showing how anthropometry interacts with tools to provide design solutions (WEAR Strategic Plan, 2008).

The development of WEAR has introduced a new future to the use of anthropometric data for designers. When the WEAR database is launched in 2009 subscribers will have access to the most current and accurate anthropometric data. They can incorporate the data into design tools and use the data for more accurate representations of their application needs. For example if a 2D tool is required they can take a slice from the 3D data for an accurate representation. This is not possible with current 1D data.

The future of anthropometric data collection will be based on current and emerging 3D collection methods and access to the data from online searchable databases such as WEAR.

Potential tools in the WEAR resource would include query and interrogation ability of 1D, 2D and 3D data, statistical tools, visualization such as shape searching of body scans, modeling capability, guidance or intelligent agents for using the information effectively including fit mapping examples, biodynamic data and vital quality control procedures that allow continual updating of the resource with new data. Users would be able to get valuable guidance on anthropometric survey techniques, including lessons learned, to continually improve the quality of data collected and to ensure comparability. Researchers and students would be able to access high quality, low cost raw data to write software for new applications and tools, do new analyses and conduct research.

WEAR was recognized by CODATA, International Council for Science: Committee on Data for Science and Technology in 2004 as the 'Task Group on Anthropometric Data and Engineering'. CODATA's mission is to strengthen international science for the benefit of society by promoting improved scientific and technical data management and use. http://www.codata.org/taskgroups/TGanthro/index.html

During the course of this research the authors have heard suggestions that WEAR will provide a base for ISO standards in the future. This idea was circulated amongst the WEAR group for comments and the consensus was that WEAR is significantly different from ISO and no formal link between the two is likely in the future. The value of WEAR is allowing innovation by facilitating access to individual data and tools to use these data in non-standard ways for any application. This will enable people all over the world to build products that are suited to target populations. WEAR is likely to raise awareness about the appropriate use of anthropometrics in design, and become a trusted source of information and data.

Standards are valuable when used appropriately. With the support of standards, industrial products and systems should be safe, available and accessible for all people throughout the world. To further this, some members of WEAR are participants on various ISO Technical Committees (TC). Thus, ISO TC159/SC3[1] has made standards for compatibility of body measurements, but at this stage there are no standards for scanners, their calibration or precision measurement. WEAR members could contribute to the development of standards in these areas as well as in defining resolution and eye safety when using lasers. Other potential standards could describe documentation and the knowledge base needed to test and assure the collection of good quality, reliable, anthropometric data.

[1] Dr Masaaki Mochimaru, WEAR member is the chair of ISO TC159/SC3 (*Ergonomics/Anthropometry and Biomechanics*).

What is *not* required are standards containing anthropometric data or standards that define how products are designed[2] because the data are constantly being updated and altered; at a pace with which standards could not keep up. One of the difficulties with standards developing bodies is the length of time it takes to build a standard, and the consensus model on which they are built. ISO requires regulated protocols and consensus of member bodies (including developing countries) and it is difficult to arrive at consensus quickly. Moreover, because they can force designers to produce products in prescribed ways, standards sometimes hold back innovation. Thus ISO allows considerable time to pass before the standards relating to advanced and emerging technologies, such as 3D body scanning, are published. Because building standards is a slow process, it is difficult for standards bodies to keep pace with innovations in design.

WEAR is a forum of anthropometrics experts, rather than a standards-building organisation. It makes its decisions according to the needs of its members, rather than for a wide range of stakeholders with conflicting requirements. Therefore, it can make fast decisions and decisions that are at the cutting edge of advanced technologies. WEAR's current focus is on advanced issues, such as XML description of anthropometric data and ontology of landmarks and dimensions.

Most importantly for designers of Australian workplaces and products, WEAR can provide a framework for housing Australian anthropometric data that will make it accessible internationally. Of course, this can only happen if there are appropriate 3D anthropometric data that reflects the user population—the Australian working population—and this is currently not the case as no sizing survey of 3D body scans of the Australian working population has ever been undertaken. Were these data obtained

[2] Personal communication, Kathleen Robinette to Daisy Veitch, June 2008.

and included in the WEAR database, this then would be a rapid and reliable way for Australian designers, international designers who wish to sell to the Australian market, and evaluators of design for the Australian workplace to find appropriate information that would allow them to do their job better.

Anthropometry Resource Australia Special Interest Group (ARASIG)

Following its meeting in Adelaide in February 2008, the WEAR members conducted a conference on the use of anthropometry that was attended by nearly 50 designers, ergonomists and researchers. The conference was conducted under the auspices of the Human Factors and Ergonomics Society of Australia (HFESA) and attendees expressed interest in forming a network of interested people that might remain in contact and develop a link with WEAR. The Anthropometry Resource Australia Special Interest Group (ARASIG) was formally recognised by HFESA at its Annual General Meeting in November 2007. Since that time its membership has steadily grown until at the time of writing there are about 75 members. This is indicative of the growing level of interest in anthropometry and its value as a design and evaluation tool. ARASIG is chaired by industrial designer, Stephen Ward, from the University of NSW and two of the authors of this report (DV and VB) are the current committee members. The very existence of ARASIG reinforces the timeliness of this pilot research. ARASIG may provide access to the network for those interested in communicating to designers and users of anthropometric data, such as the ASCC.

Summary

Existing anthropometric databases available to designers of workspaces and products for the Australian workplace consist of a range of 1D, 2D and 3D data that do not necessarily provide adequate representation of the Australian workforce. This means that in the main designers work with inadequate tools for determining the nature of the product for the end-user. Inevitably this results in errors in design that may have health and safety implications for workers. It is only designers working in very specific areas who may be able to collect adequate data about a given user population, but because this is expensive and requires specific skill, most designers rely on publicly available data.

Some Australian Standards including some which relate to workplace health and safety, may contain or have provisions based on out of date anthropometric data and so may be unreliable. This issue is particularly important where Australian Standards are referenced in legislation. This potentially places designers in a difficult position if they are required to develop solutions based on these documents.

Emerging anthropometric data sources are all 3D or derivatives from 3D data. These methods for data collection hold great promise for designers and end users because the data are fast and simple to obtain and have a high degree of accuracy. Although they are becoming both more sophisticated and less expensive, 3D body scanners are still costly and require skilled operators and data interpreters. It must be noted that scanners provide computer aided anthropometry which is an additional tool anthropometrists can use – they are not a complete replacement for anthropometrists. Scanners provide 3D data, but designers still need traditional 1D techniques as a means of verification and for quality assurance. Nonetheless, 3D scanners are the way of the future.

WEAR, with its international, non-profit status, has access to a widening array of databases from across the world. It is likely that by default this database will become the international standard for anthropometric data in the next few years. Australia has a small presence in WEAR but interest is growing. WEAR will not make Australian data redundant, rather it will provide an international base and context into which Australian data will fit in the future.

The rest of this report is devoted to the method and findings of the pilot research project, further building on the findings of the literature review.

Chapter 3 Method

Introduction

The method for this pilot project was designed to be as participative as possible within the confines of time and budget. The authors aimed to include designers who design Australian workplaces or products for use in Australian workplaces as well as those people who advise these designers or who write briefs for these designers. The authors also sought to include government technical staff who evaluate safe design for Australian workplaces. Because of the budget constraints a decision was made to contain face-to-face contact to people in South Australia and Victoria where the researchers are domiciled.

Exclusions

Given our focus on Australian workplaces the authors excluded designers of domestic products and spaces (such as fashion garments, domestic kitchens, homes and the like) even though some of these designers expressed interest in the project and seek information about and access to anthropometric data that represents their target markets.

Data collection

With staff from the Office of the ASCC the authors agreed upon a list of key companies and agencies that would be invited to participate in this pilot research project. Each participant was contacted by email or phone or both and was asked to complete the survey and send a representative to the focus groups in either Adelaide or Sydney. The authors conducted informal telephone interviews with those representatives whom were able to contacted and who expressed a willingness to participate.

Survey

A survey form (Appendix One) was developed for this pilot research project based on the earlier work of Ward (2006). This was piloted and redesigned over several iterations to capture the widest possible data about their use and the projected use of anthropometric data. Given the authors expected a small sample of users, survey instrument was designed with significant redundancy for most users – that is it was designed to collect information from the most sophisticated respondent. This ultimately meant that the instrument was too sophisticated for most respondents, some of whom reported that this was intimidating. This may have affected the quality of the data, but because of the small sample size the authors are not able to confirm this. The survey instrument is attached as Appendix 1. The survey data were analysed by statistician, Dr Stephen Cox (Stephen Cox Consulting). The sample size (N = 32) was too small to reliably differentiate between different types of respondents, so in the main, the data are presented in aggregate form. That is, designers of all sorts and advisors to designers (whose use of data might be different or more or less sophisticated) are considered together. However, despite the limitation of the data being indicative rather than representative, the results allow us to make useful observations when taken into consideration with the qualitative data gathered from interviews and focus groups. The findings provided a number of useful case studies from designers that gave insight into the research questions; these data are incorporated into our discussion and findings.

About the respondents

Seventeen of the respondents were men, and 15 were women. Three quarters of the survey respondents held tertiary qualifications and had worked for more than 10 years in the design industry. Respondents were asked to indicate from a list of six design domains those in which they 'developed, designed or evaluated' for the Australian workplace. On average, respondents designed in 2.6 domains, with only 11 respondents indicating that they designed in only one domain. The domains in which they work are illustrated in Figure 6. As respondents selected multiple domains they are all included in this table.

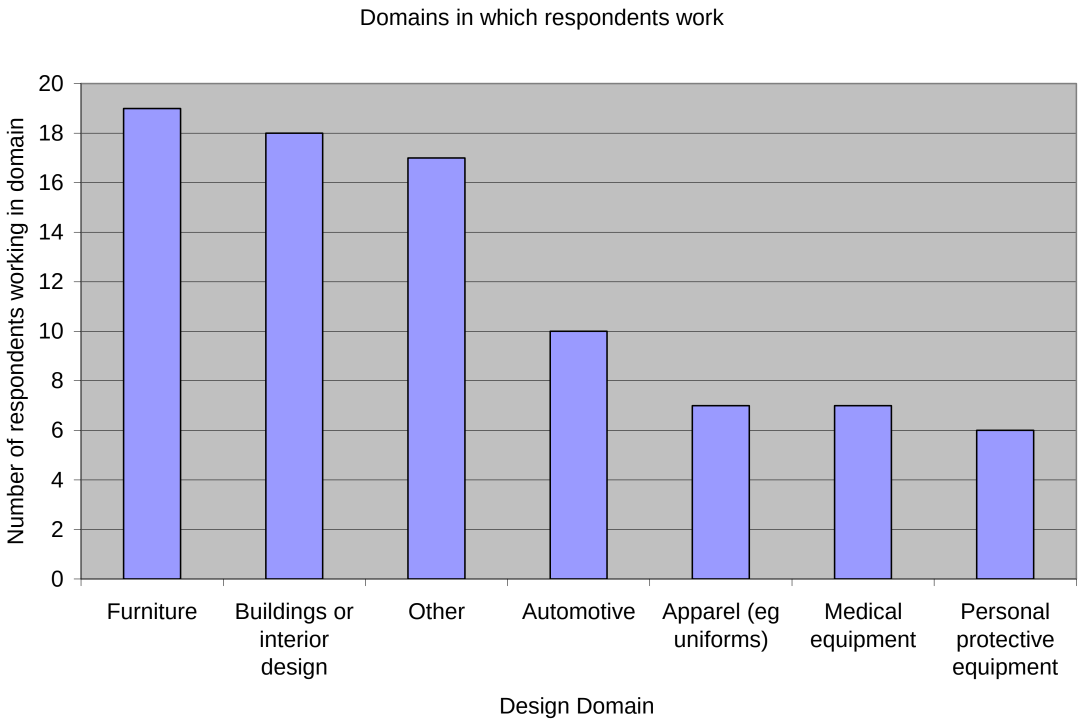

Figure 6: The design domains of survey respondents *Note: Total adds to more than 32 due to multiple responses being possible*

Although 80% of respondents were located in either Victoria or South Australia, a few were from NSW/ACT, Queensland and Western Australia. Over half (68%) of the respondents worked in small or medium enterprises with the rest in large firms. Ninety percent of respondents reported that they have used anthropometric data in the last 12 months.

Designers of products, plant, machinery, equipment and workplaces were all represented in the survey respondents, however, half the respondents were solely educators, ergonomists or evaluators of designs. A further seven respondents undertook some educating or evaluating work as well as design work. This is illustrated in Figure 7.

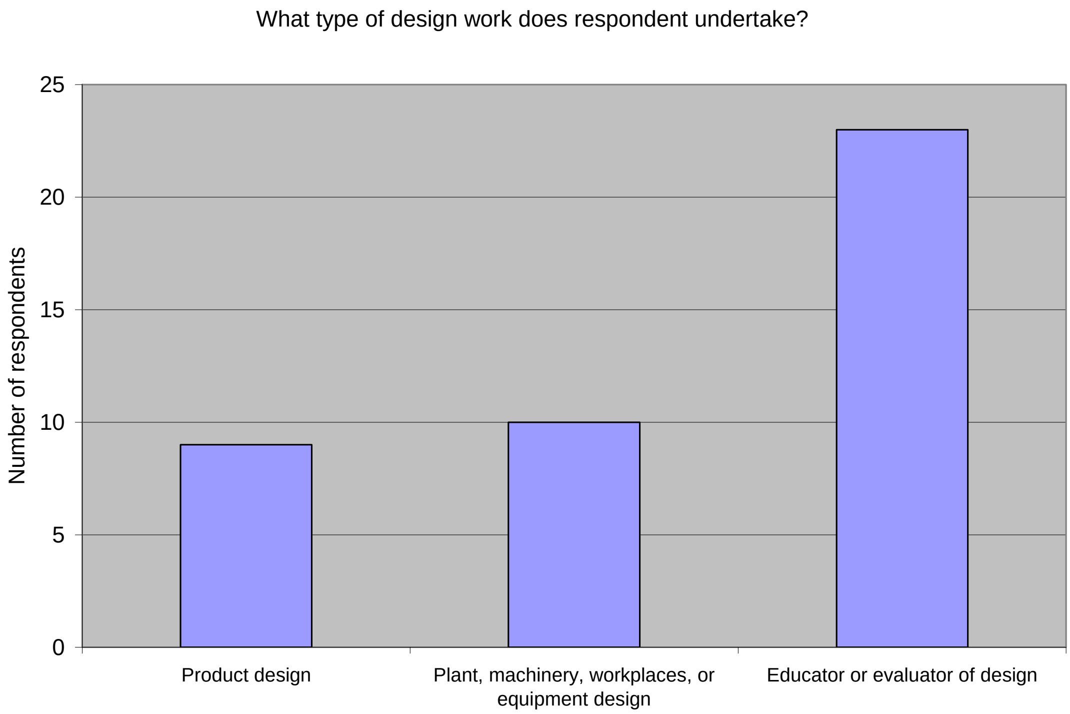

Figure 7: The types of design work of survey respondents.
Note: Total adds to more than 32 due to multiple responses being possible.

Focus groups and interviews

Qualitative data were gathered in two focus groups held in Melbourne and Adelaide. Participants in these events were self-selected from a large invitation list that included designers, ergonomists and others who advise designers, those who develop briefs for designers, as well as government technical staff involved in the evaluation of safe design within Australian workplaces. Each of these areas was well represented. The focus groups were conducted using a semi-structured format; the Interview Schedule for the focus groups is attached as Appendix Two.

A note on participants

Participants in this research were from a cross-section of our target audience – however, it is important to note that they were not necessarily *representative* of that audience. Indeed, given that respondents to the survey needed to put aside a considerable amount of time to complete the form and those who came to the focus groups put aside the best part of a morning, with a very early start, the authors were confident that their willingness to participate indicated their strong interest in the topic. They are likely to be a skewed proportion of the target population that represents the 'best case'. There were many other designers who either failed to respond, or who actively told us the topic was not relevant to them. Thus, our data cannot be construed as being definitive; but nonetheless it provides more than anecdotal evidence in answer to the research questions. The authors believe that it is sufficient to provide guidance on how to obtain more reliable data in the future.

Chapter 4 Project Outcomes

What anthropometric data are used?

What anthropometric data are currently being used to help create design solutions for Australian workers? The following sections of this chapter deal with this question. The authors explore the nature of the data that are used, where they are sourced, how they are used and how useful designers consider them to be in various design processes. The authors also consider the levels of sophistication in the use of the data by designers for the Australian workplace. Throughout this chapter we refer to the survey outcomes and the information from interviews and focus groups conducted for this pilot project.

How do designers find anthropometric data?

Designers of Australian workplaces use a wide variety of means to obtain anthropometric data about the end user, as illustrated in Figure 8. The most frequently used data were reference books and tables, although more than half the respondents observed end-users with their product, interviewed end-users about their design or used themselves or other accessible people as 'subjects' in their design approach. Respondents to the survey cited the following data sources:

- *Humanscale* (Diffrient, Tilley, & Bardagjy, 1983); a series of anthropometric charts that are visual in nature and very easy to use.
- *The Measure of Man and Woman: Human Factors in Design* (Henry Dreyfuss Associates & Tilley, 2001). A book of anthropometric tables from the US.
- *Human factors design handbook* (Woodson, Tillman, & Tillman, 1992).
- *Bodyspace* (Pheasant, 1988); anthropometric tables based on data from the UK in the 1980s.
- Snook Tables (Stover H. Snook, 1978; Stover H. Snook & Ciriello, 1991); US data relating to force capacities of male and female workers.
- University of Michigan 2D Static Strength Prediction Program™ (2DSSPP) and 3D Static Strength Prediction Program™ (3DSSPP); models for measurement of static strength capacity (Chaffin, 1997).
- Australian Standards, including AS1248, relating to access and egress (Standards Australia, 1992a, 1992b, 2001, 2002).

- Previous designs of products, plant and machines as working prototypes for measurements used in new or updated designs.
- Data derived from workers, students, or self that were considered to relate to the workforce and application for the design.

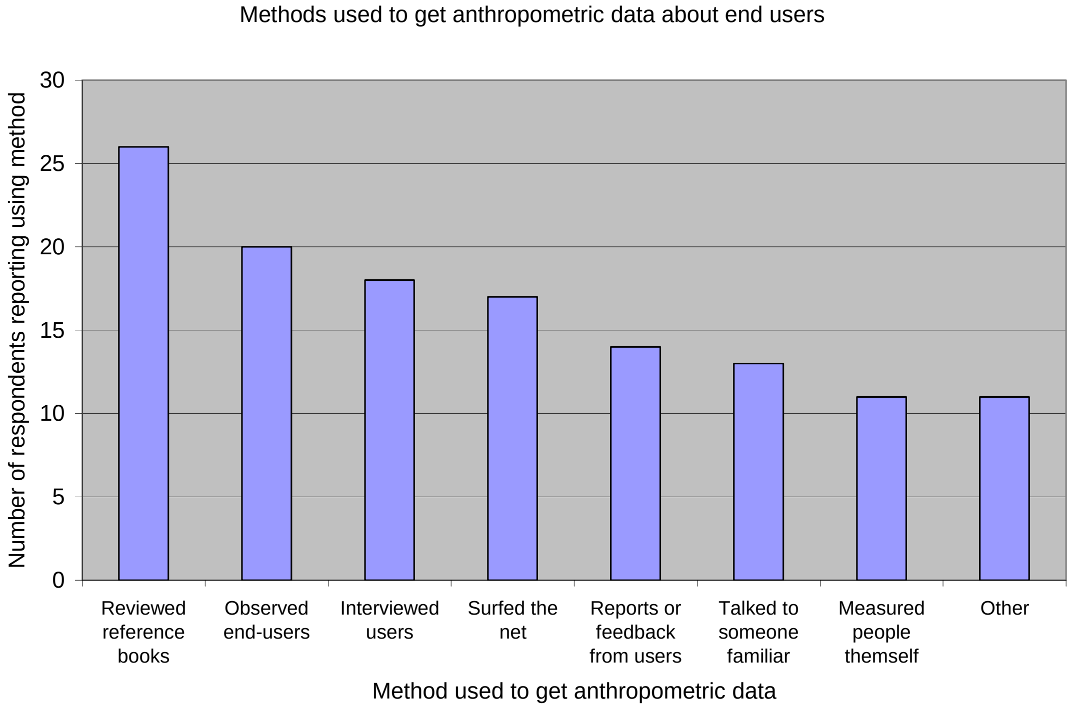

Figure 8: Methods designers use to get information about end users. *Note: 'Other' includes: Engaging a consultant; examining sales data; and analysing generic market research information.*

The majority of respondents (24) accessed data from multiple sources, with four respondents indicating that had found data from five or more different sources. As Figure 9 illustrates, the most widely used source of information was reference texts. About half of the designers used the internet in anticipation of finding relevant and up to date information. Even amongst this group of respondents there were very few (less than five) who used consultants, such as ergonomists, to help them source appropriate data.

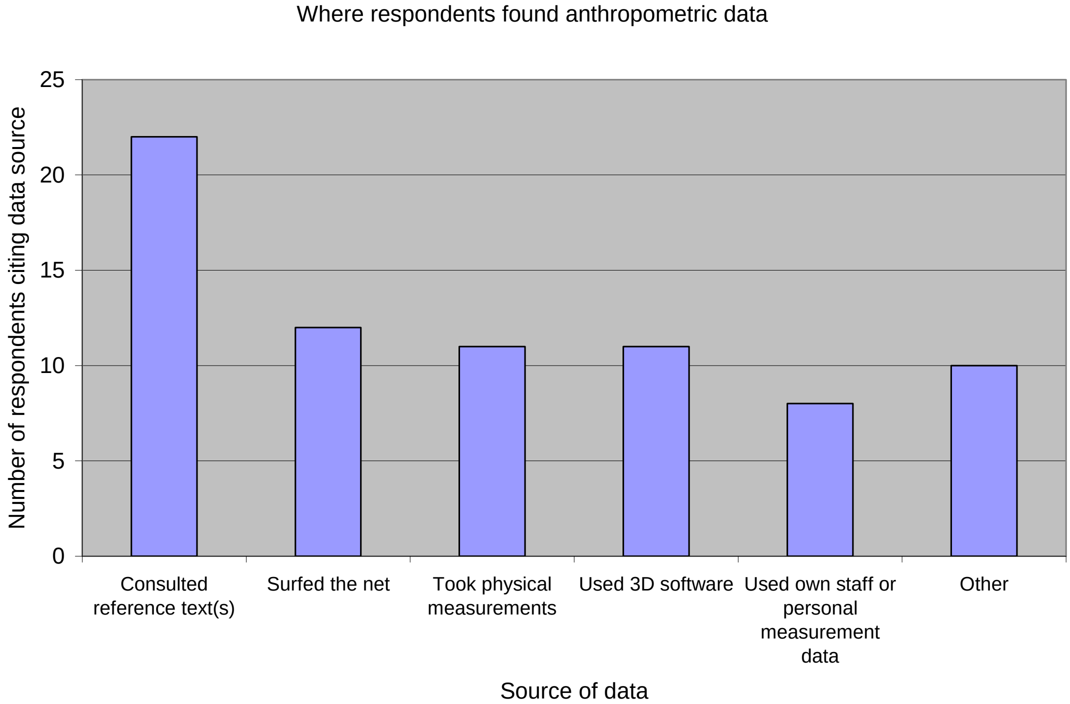

Figure 9: Where respondents found anthropometric data *Note: 'Other' includes: Used an external consultant; Took 3D scans/landmarks; Used 2D software.*

How do designers use anthropometric data?

Participants in the focus groups told us that the majority of designers that they know of either do not use anthropometric data at all, or have difficulty in finding any data that they would consider to be relevant and reliable for their specific needs.

Those who do use anthropometric data tend to be dependent on one-dimensional (1D) anthropometric data sources such as the tables found in some standards, text books and tables of measurements collected from military and small sample populations, as illustrated in Figure 10. They had concerns about the reliability and validity of these data in representing the existing Australian workforce because many were collected in other countries and/or the data were old; in some instances dating back to the 1970s. However, they continue to use these data in the absence of better resources on the assumption that they are "better than nothing".

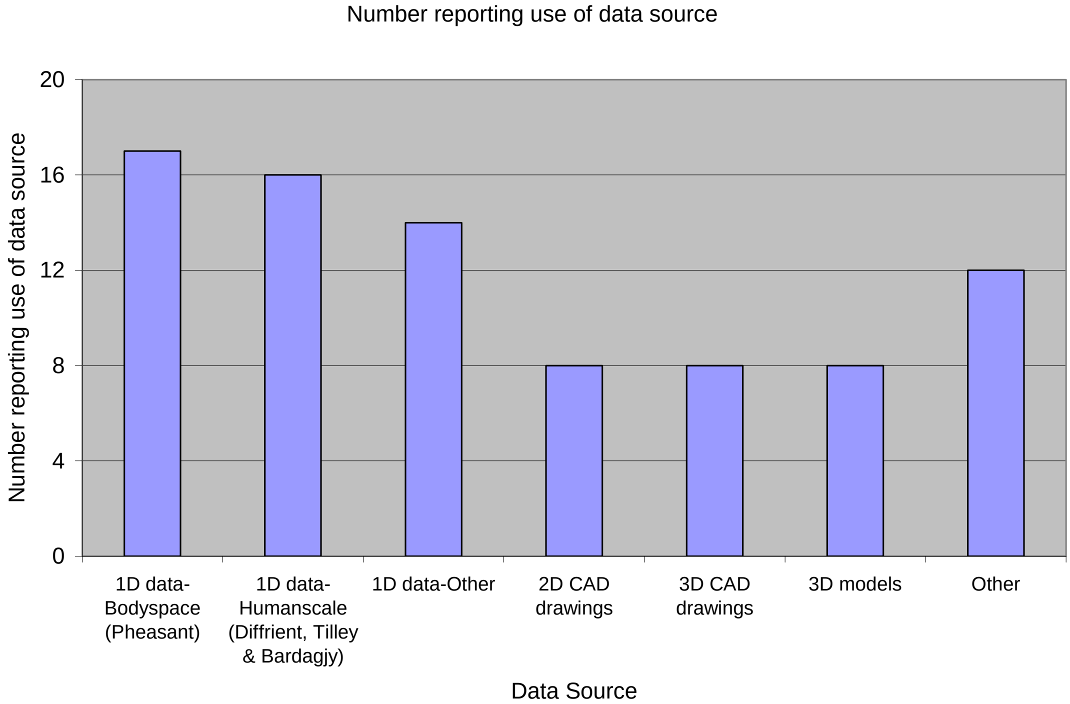

Figure 10: The range of data sources used by respondents.
Note: 'Other' includes: 1D data; Anthopometry (Singh); 2D Data: 2D patterns;2D models; 3D data: 3D patterns;3D body scans.

Whilst 1D data are most commonly used, a few participants in the focus groups and respondents to the survey had experience with the three-dimensional (3D) body-scanning methods that have become available in recent years, as illustrated in Figure 11. As yet, there is only a very small group within Australia that have both access to the technology and the expertise and to collect 3D data. This expertise is predominantly based in Department of Defence and a few universities where body scanners are used for the collection of anthropometric data for research purposes. 3D body-scanners are expensive items with differences in accuracy between both scanners (image acquisition) and software (image merging and measurement extraction). However, participants were interested to learn about 3D data at the focus groups and considered that these data were likely to be the only type of data that are sufficiently accurate and reliable for determining the shape component of future anthropometric data base development in Australia (1D data are still essential for quantifying size and enabling comparisons with older databases).

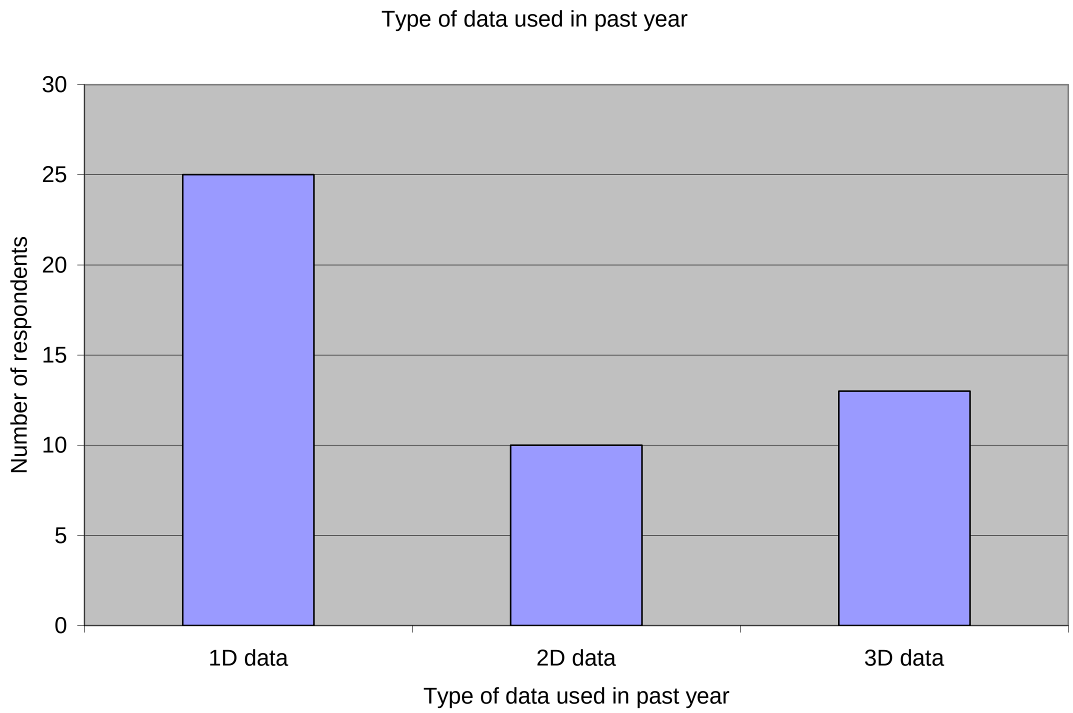

Figure 11: Type of data used by designers in the previous year.

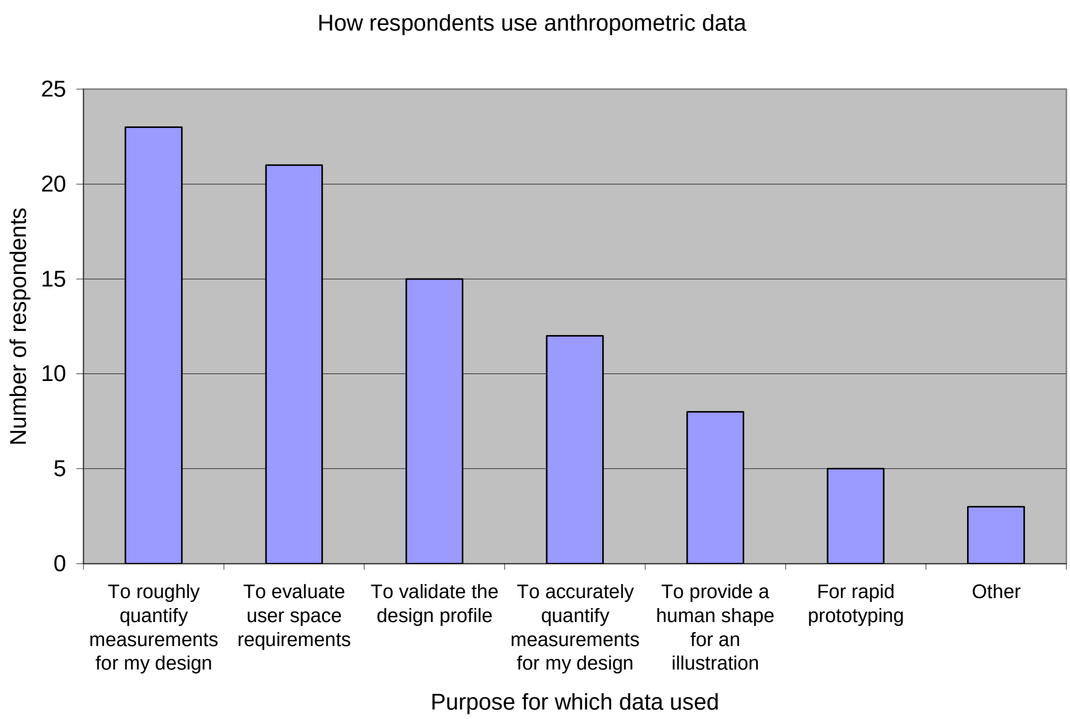

Figure 12: How designers use anthropometric data

Designers indicated that in the main they use whatever data are available to determine approximate fit, as the survey answers indicate in Figure 12. This indicates that designers do not always use the anthropometric data as the basis for human representation in their design if other methods seem more reliable for their needs. The focus groups participants reported that designers generally do not use the specific data as prescriptive measurements for input into their design process. Instead they tend to use the data as a “rough guide” as to the measurements that they would expect; that is, to affirm what they already believe is logical, at least for the “normal” population.

Dealing with the extremes of the population - the smallest and largest percentiles - is a different matter. Here people reported that there were often discrepancies between the anthropometric data in the current literature and actual measurements of a user group. Rather than use the anthropometric data from the literature for these sub-groups they tended to take their own measurements and conduct verification trials to produce design solutions that suit the population’s needs.

How sophisticated is the use of the data?

The overall impression from the focus groups and the surveys was that anthropometric data are generally used in an unsophisticated manner. There was a lack of confidence about the validity of the data for the cohort of the population under review. There were also questions about the suitability of generic anthropometric dimensions for a given specific application required for the design. For example, the generically available dimensions for hand size may not reflect the specific group of individuals that may be required to hold and operate a powered hand-tool.

Textbooks containing anthropometric data tables (1D data) and forms (2D data) are used in the education of design students to enable them to relate the human form to the application of their design. However, educators told us that when students are required to use and apply these data in their design projects they have great difficulty in understanding which data to use and how to apply those data in the design process.

This highlighted the difference between the questions relating to the suitability and representation of the actual data for the target population, from the presentation of the data as a useful source of information to incorporate into a design process. The range of use and sophistication in the use of anthropometric data are summarised in Table 1.

Table 1: Range of approaches used by designers showing the progressive sophistication in the use of anthropometric data.

Level of Sophistication	Determination of Anthropometric Fit	Comment from subjects
Least Sophisticated	1. Use of "point of sale" data to determine the retail preference of products selected by the consumer and industry sector, eg, the suitability of clothing sizes to suit the working population.	The use of sales data is strongly confounded by a range of variables not relevant to anthropometry. This may be the selection of materials, colour, aesthetics, price, brand credibility, etc.
	2. Comparisons of designs of similar product.	This is part of a "continuous improvement" approach to design. However, it is possible that the same errors relating to human fit are repeated from one design to another without a clear understanding of the anthropometric requirements.
	3. User requests. This involves the client making specific requests to the designer about their perceived needs from an anthropometric perspective.	The user's assumptions and expectations may be false and too subjective. They may also be in conflict with the knowledge of the designer and the recommendations derived from the available anthropometric data.
	4. Reference to anthropometric data confirmed by the user populations. For example the designer may select data from Dreyfuss for the 5th, 50th and 95th percentile. They then may find individuals from the target workforce who meet these criteria. These criteria will often be based on stature and they will then use the subjects as part of their design, development and evaluation process.	This process combines using anthropometric data and user testing. It is confounded by the often false assumption that the stature percentile is representative of other body part percentiles. Eg, that a 5th%ile female for height will also have 5th%ile leg length, reach and hand size. 3D anthropometric data, and our participants, confirmed that this is not the case.
	5. User "fit trials". These are simple fit trials involving available workers and staff, self (designer), or students. How representative these individuals are of the intended user population cannot be determined with any certainty.	The use of "fit trials" also includes prototype evaluation using simple models. Participants had confidence in this method and preferred to use it. The feedback from potential users at a trial can confirm the design or lead to ideas for change. But because worker population sizes and shapes are not defined, who is accommodated can be haphazard depending on who happened to be included in user trials.
Most sophisticated	6. Use of 3D anthropometric data incorporated into a CAD modeling process. This modeling allows designers to provide an accurate representation of the workplace design. Used in the design of assembly line workstations in the automotive industry. This is best when used in conjunction with sophisticated "fit trials" using a representative sample of intended users from the prospective population selected using multivariate accommodation models and fit criteria, eg fitmapping.	Whilst the 3D modeling process appears to be the most sophisticated used by participants, the automotive assembly line designers still validate their data using real workers before final sign off and commissioning of their design because real people are the closest approximation to reality. The selection of these individuals is crucial to its success. Thus this technique is especially powerful when built upon very good quality, representative anthropometric data.

How useful are the data?

Respondents to the survey and participants in the focus groups confirmed that 1D data are the most frequently used form of anthropometric data, but these data score well below 3D data on a scale of perceived usefulness or confidence in the data. This is illustrated in Figure 13, where 1 on the scale equals *least useful* and 5 equals *most useful*. At the very least this demonstrates a lack of satisfaction with the anthropometric data that are currently available and affirms our earlier observations about designers' lack of confidence in the popular and readily available 1D data.

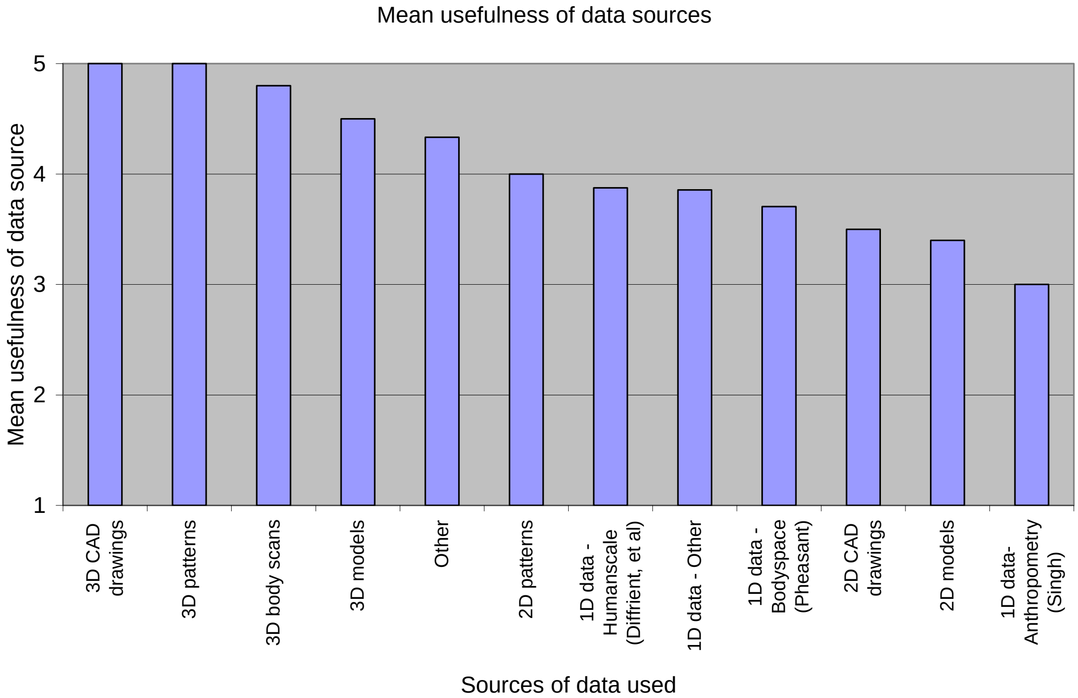

Figure 13: Perceived level of usefulness of anthropometric data

Summary

Designers who design for Australian workplaces place heavy reliance on 1D data, where they use anthropometric data at all. They do this despite the reservations they have about the 1D data currently available in Australia. The reservations spring from the age of the data (some popular data dating back to the 1970s), and because most readily available data is sourced from the US or the UK; but not Australia. Currently available 1D data helps them to confirm their own observations about end-users, but some will measure people at the extremes of the population distribution because they are not confident that these people are well represented in published data.

2D data (body forms or silhouettes) are used by designers in sketch designs to set the scale and see how a person might fit the design. They are used to introduce students to the concept of using anthropometry in design.

The most sophisticated users turn to 3D body scans for anthropometric data, but as there are few scanners and expert operators in Australia and only a very small number of databases available, this option is not freely available yet. However, there is considerable interest in this technology and its potential to provide high quality data about the Australian workforce in the future.

Do current data reflect the Australian working population?

Do the data adequately reflect the requirements of the contemporary Australian workforce? The authors respond to this question in the following sections of this chapter and discuss the adequacy and currency of existing data that is readily available to designers. Observations about the data made by participants to this pilot research, with reference to the survey outcomes and the information from interviews and focus groups are also reported.

How adequate are the data?

As stated in Chapter 1, to confirm whether this data adequately represents the contemporary Australian workforce would require an Australia-wide sizing survey. This study is however report what participants in this pilot project consider to be the adequacy of the data based on their experience in using the data in design projects.

In the survey respondents were asked to rate a list of statements from *strongly agree* to *strongly disagree*. These results contradicted what focus group participants said. Respondents disagreed with the statements: "*Specific anthropometric data relevant to Australians and Australia needs to be developed*" and "*Future design situations will require more accurate/reliable data*", and agreed with the statements: "*Current anthropometric data reflects the contemporary Australian workforce*", "*My anthropometric data requirements are satisfied by the currently available data sources*" and "*The anthropometric data available in Australia for Australians is reliable and accurate*". Therefore the survey participants said that they found the existing data sources adequate for their needs.

However, during the face to face focus groups and interviews, participants suggested that future requirements for anthropometric data of the Australian workforce will need to have different data parameters than those currently available. In particular, future designs will need to be suited to a larger range of user sizes than is currently the case. Participants told us that they are not at all confident that the current data set adequately reflects the extremes of the percentiles of the population in Australia. This is particularly true for the largest percentiles, where the data do not adequately represent the reality in a range of dimensions. Participants may not use percentiles in the future rather the superior statistical methods such as multivariate accommodation case studies.

Bariatric people are generally defined as those individuals with a body mass in excess of 120kg. The designers suggested that the inclusion of this group in population data sets has the potential to skew the entire distribution to the detriment of design for those near the mean. From a design perspective they considered that the extremes of the population need to be treated as a special group with specific needs and be eliminated from the overall data set.

This has already been done in the case of ambulance design for patients with complex needs, including bariatric patients. Specially equipped ambulances are being built for the Australian Metropolitan Ambulance Services for this class of patients. This eliminates the (expensive) need to engineer the standard ambulance design to cater for these patients.

Within one hospital environment, the same principles are applied to the design of patient handling equipment. Specialist equipment is provided for the handling of bariatric patients, rather than over-engineering all of the handling equipment, which would only create additional hazards for patient handling staff.

Other dimensions represented in the available data, such as hand size and foot size, are also considered to inadequately represent the actual size of hands and feet that are part of the safe design requirements. For example, the anthropometry for hand clearance in machine guarding was raised by one of the designers as not reflecting the actual anthropometry of small hands. People with small hands may therefore not be adequately protected under the existing Australian Standard. Conversely, respondents reported that personal protective equipment, such as gloves and shoes, do not adequately meet the fit requirements for larger hands and feet in the Australian working population.

Practitioners also advised us that anthropometric data alone do not reflect the reality of individual differences within the working population. For example, data relating to hands does not necessarily include the impact of health conditions such as osteoarthritis or calluses on the hands. Similarly, the data do not include frequently seen medical conditions such as bunions or claw toes on feet.

Currency of existing data

Participants regularly expressed concern and lack of confidence about the existing data because of their currency. Most of the data in the resources that participants told us they use regularly were obtained from military and population sources during the 1960s – 1970s. There are very few databases in the public domain that have been collected in the last decade. That population sizes change with time is well known to anthropometrists, so it is likely that data collected two generations ago will not represent current populations, even if all other things (such as ethnic mix) are equal.

Participants recognized that for anthropometric data to be useful when designing for the Australian workforce they need to reflect the existing Australian workforce. Such data are simply unavailable in the public domain. In addition, these data need to be collected in an ongoing manner so that databases are updated and kept current as the population changes. The University of Adelaide has conducted a longitudinal study of children which tracks a set of data points during their growing years. However, the authors have been unable to identify any longitudinal studies following adults in the Australian workforce.

Smoothing of the population data through migration patterns

Participants told us that in their experience the Australian population has changed in the last 30 years, with people becoming a little taller and with increasing circumferences. However, they recognized that there is little evidence to back up that assertion. Even though these changes may be occurring, they suggested that migration patterns may provide balance in population-level anthropometric data. That is, if there is predominantly Asian migration, of people with possibly smaller stature, an increase in the smaller end of the population may help balance out the observed changes in the population. Thus, existing anthropometric data may continue to represent the population, especially around the mean, although the mix within the population has probably changed and the extremes may vary.

Inconsistency between Australian Standards and other design standards

Concerns were raised during the focus groups about the anthropometric data incorporated into Australian Standard AS1428 *Design for access and mobility - General requirements for access - New building work*. This Standard specifies access and egress requirements for people, including those with disabilities. Architects reported that the Standard does not adequately meet their requirements in public spaces, particularly where large movements of people may be involved, for example, in airports. They have also identified inconsistencies between Standards; for example, between AS 1428 and the telephony (all things having to do with telephones and telephone services) standards in Australia. These relate to the requirements for placement of emergency telephones, intercoms, etc which need to meet the requirements of disabled and able-bodied workers as well as members of the public. Further, they have found that both are inconsistent with the functional requirements in the workplace. As a result, architects are tending to use Disability Consultants to assist them in making an informed design decision where the dimensional recommendations from these Standards are in conflict or do not reflect the design brief requested by the client. Where contracts specify to the designer that they must meet particular Australian Standards, doing so becomes a legal obligation. This may be a significant design constraint when the Standard in a contract is inconsistent with other Standards or does not reflect the anthropometric needs of the user group. It also begs questions about potential legal liability for the designer and the client in the case of failed design. Some designers refer to a consultant to seek advice in an attempt to resolve these issues. Thus the matter of design for safe use becomes confounded by design for legal requirements based on poor data.

Credibility of data in Australian Standards

Participants, particularly those who were industrial designers, engineers or architects, were concerned about the credibility of Australian Standards that contain anthropometric data. Their concern is exacerbated because clients routinely demand compliance with Australian Standards as part of their internal Quality Assurance processes. As a result, designers must often make compromises in design unless the client is well educated in anthropometrics and/or OHS. Participants reported that they will sometimes use a specialist OHS consultant's advice as an alternative to strict compliance with the Standards.

The development of the international WEAR database, which contains a considerable amount of current 3D data, was expected to be a credible resource for use in Australia in the future. If WEAR is recognized by an international authority, such as the International Standards Organisation (ISO), then there would be an opportunity for individual countries, such as Australia, to focus on this resource as the place to deposit current and future anthropometric data, as already outlined in the literature review.

One participant advised us that the Australian government has traditionally used *Humanscale* (Diffrient, Tilley, & Bardagjy, 1983) as the standard for anthropometric data when evaluating projects for Australian government departments. The use of this resource was apparently agreed in 1972 by the then Whitlam government as a means of reducing conflict between the industrial parties. Agreement to use one, standard resource was considered a sensible way to proceed as all parties to an agreement (or disagreement, as the case may be) would be starting from the same data. It is understood that this agreement is still current, but this has not been confirmed.

Static versus dynamic anthropometric data

Participants told us that static anthropometric data have sometimes insufficient functional value. Of more value is anthropometric data that actually follow the dynamic movement profile of the body. For example, when considering the ability of the body to reach forward the static measure that would be used is "arm length". However, dynamic analysis of a person reaching forward shows that the shoulder joint also moves forward with the arm thus increasing the forward reach capacity beyond the static length of the arm. Dynamic movement analysis of the body is regarded as useful anthropometric data. Its value would be even greater if this were 3D data that show the actual position of movement of the body when adopting a particular range of postures. Similarly, when video analysis is undertaken of a simple task such as gripping a powered hand tool, the data do not provide a realistic interpretation of the anthropometry of the hand, wrist and forearm in adopting the range of grip postures. The currently available 2D and 1D data do not have sufficient information to allow accurate interpretations that can be applied to design solutions.

Some designers reported using video analysis as an alternative to static anthropometric data. The video analysis enables them to analyse the dynamic movements associated with the task and to overlay the images for different percentiles of the targeted population of workers and users.

End users may have a very limited capacity to understand the implications of a given design from examining technical drawings. This limits the value of consultation, which can be a necessary step if there are OHS implications in a design. Simple prototypes are an important and useful means to facilitate consultation as they provide a tangible example of the design that enables representatives of the user group to clearly understand the design. Prototypes can also be used with video analysis for a comprehensive understanding of the fit of the user population. If anthropometric data are incorporated into the prototype end users (and designers) can make informed decisions about the acceptability of the design.

Skills for using anthropometric data

A consistent theme that emerged from the consultation with participants was that the anthropometric data are only able to be used effectively by designers who have had training in ergonomics, or specifically in the use of anthropometric data. Designers need data that are configured to suit the needs of their design questions; that provide an information match. But even with the best data, participants recognized that skill is required to apply the data to a design.

Educators who participated in this project reinforced this observation. One educator of industrial designers told us that students become skilled at using 2D templates in their design work but even after training in anthropometry they are unable to interpret 1D data presented in anthropometric tables and apply them successfully to a 3D design. This is because there are inherent problems in taking this step, as outlined in the literature review. Educators need 3D data that are presented in a way that allows straightforward translation into designs.

Participants were keen to see the development of anthropometric data, and tools for using those data in design, that could be applied in educational and professional development settings. They considered that this would be most useful if it incorporated case studies about the application of the data, rather than theoretical explanations on the use of tables and charts. Participants indicated that the use of case studies showing the method and benefits of using the data would assist the general and specific understanding and credibility of its use.

Designers often have extremely short deadlines in their work; they told us they often don't have time for the niceties of examining user populations as this is not a primary concern for the commissioning client. So the effective use of anthropometric data depends not only on its intrinsic accuracy in reflecting the end-user, but also on accessibility, cost and the ease and speed of use of the data in the design process.

As a general principle, participant designers indicated that in the future, the anthropometric data should sit behind tools that would be used by the designers. Hence, the data itself should be collected in a way that would be compatible with a range of tools accessible for their use. This would generally not be in the form of static 1D tables, but would use dynamic 3D data that could provide interactive information on movement within software design packages; that is, the data would allow a 3D mannequin to be manipulated using a design on a computer screen.

The use of ethnic derived data compared to using the total profile of a population of workers

Discussions occurred during the focus groups about the methods of collecting data based on ethnic backgrounds of the population within the workforce. This was the basis of research undertaken by WorkSafe Australia during the 1990s. A comment from one of the major researchers in anthropometry at the workshop indicated that this approach was based on the ethnicity of the population alone and did not reflect the total human needs in a segment of the work force. They commented that good information includes an understanding of total variation, including sources of variation such as gender, socio-economic, genetic and environmental differences and there is little point in looking at subgroups if it is not necessary. Thus factory workers in Adelaide might have no significant difference to workers from the city centre in Perth, but without good information this cannot be ruled out. It would save time and energy to be able to reliably group data. Once designers have the information about what forces are shaping human variation in Australia it would be much easier to identify gaps and overlaps in data.

Ethnic background of the population mix was thought to be only one of the variables that might lead to variation in anthropometric data, and participants did not consider it to be the primary determinant in applying anthropometric data to design. The data that the designers were more interested was that which related to the particular cohort of workers or anticipated users of the products and systems that were being designed. For example, within the Health Care sector looking at workplace layout and design, the architect is interested in the anthropometric requirements of nurses and hospital staff. In the transport sector, the designers of public transport are interested in the anthropometric data requirements of the public cohort that uses the transport system.

Use of anthropometric data in clothing sizes

Participants from the apparel design sector told us that consumer expectations of clothing sizes continues to be an ongoing source of questioning and debate. While this is a very significant issue in the fashion industry, it is also a matter of concern for those who design uniforms, protective clothing and personal protective equipment (PPE) for the Australian workforce.

The lack of quality anthropometric data results in a range of indirect measures in determining clothing sizes. These include previous sales data and the feedback from whatever small cohort of body shapes is accessible to the designer. These methods are not accurate. Because input sizing data are inadequate designers are forced to use whatever information is available to them. The result is wasted time and resources in product development, design, pattern making and grading process and results in ill-fitting and/or unsaleable garments in the marketplace. 'Ill-fitting' can be a significant concern where garments or PPE depend on good fit to be effective against hazards in the workplace.

The Council of Textile and Fashion Industries of Australia (TFIA) indicated that they have not started to use 3D scanned forms as a basis for more accurate determination of body shape in the clothing design process, but this significant industry body wishes to facilitate the use of technology that would result in better products.

Collection of anthropometric data in Australia

Currently there is no coordinated process in place for collecting and aggregating anthropometric data across Australia. There are some Australian universities using body scanners to collect anthropometric data for research purposes, but these data are not generally publicly available.

In the last five years the cost of 3D scanners has come down from around $1M to around $100,000-$250,000 per scanner and the quality, reliability and sophistication of the units has improved; however they are still out of reach for most users of anthropometric data. Participants suggested that strategic location and access to 3D scanners across Australia would facilitate the collection and use of anthropometric data in a coordinated manner.

Participants valued this ASCC pilot project as a demonstration of leadership in assisting industry to understand anthropometric resources and their use. Their expectations are that anthropometric data will one day be cheaply or freely accessible and available using interactive media such as the internet.

Emotional reactions to design

Participants in this pilot project came along with an interest in the use of anthropometric data in design but sought to place these data in context in the design process. They recognized clearly that consumers of their designs do not necessarily look primarily for anthropometric fit – even when this is critical to usability. Instead their emotional reaction to a design is often given higher priority than usability by workers and buyers alike. That is, appearance and fashion are more relevant to the acceptance of the design (and indeed to its correct use) than the application of quantitative anthropometric data. For example, making protective equipment such as eye wear, clothing, face masks and gloves appear more like fashionable designs will potentially make them more acceptable for workers to use. It is important, then, that functionality and appropriate fit are not lost in the design or made subordinate to making them more “fashionable”.

For example, in the area of office furniture, the design of adjustable workstations has been based on anthropometric data so that small people are encouraged to use low desk heights. However, there are social determinants of desk height, such as being able to make eye contact with colleagues while seated that play an important role in the choice of desk height. Accordingly, some workers will choose to use their adjustable work station at the “standard height” and supplement their height with a footstool to maintain eye contact. The acceptability of workstation furniture and equipment in a workplace may be based on an emotional or social reaction from the users before the anthropometric fit.

Summary

Although the authors are unable to definitively state that anthropometric data currently available to designers who design for the Australian workplace are not a good reflection of the actual working population, participants reflecting on this question expressed concern about these data. There are limited data based on measurements of the civilian Australian population, and what does exist is mainly proprietary and not publicly available. Designers have empirically found that US and European data may be useful when designing for populations around the “mean”, but when designing for very small or very large people the data are simply not available. This means that designers resort to measuring small samples or “bend” existing data in an intuitive manner. Australian and International Standards also provide little comfort. In fact, they generate confusion, particularly when they are based on old data, are found wanting, but are called up into legislation. Increasing emphasis on the designer’s OHS responsibilities is engendering concern because this group does not have the necessary information available to it to make informed design decisions. This is particularly concerning for those designers who want to design well.

There is considerable interest amongst designers in the emerging 3D scanning technologies that are becoming available and participants could immediately imagine a design world that incorporated these tools. They considered that were they to be freely available on-line, and regularly or continuously updated, that these data would provide a significant tool for improvement in design for the Australian workplace.

Chapter 5 General Findings

The most referred to anthropometric data sources by ergonomists and government Inspectors are *Humanscale* (Diffrient, Tilley et al 1983) and *Bodyspace* (Pheasant, 1987, Pheasant, 1988). Both are 1D databases based on USA military data from the 1970s with no civilian data nor verification that the data, especially for women, meets our present day needs in Australia.

Architects and designers who used tools that incorporate anthropometric data use summary 1D data from Woodson (1992). This uses the 5th, 50th and 95th percentile data from the USA military. Again, there is no evidence that these data accurately represent the Australian population. Generally designers most commonly use 1D data, but they considered them the least reliable and useful, especially when compared with 3D databases.

Designers tend to use 1D anthropometric data as a rough guide as they are not confident in its representation of their particular population of workers. This is due to data being not Australian, the age of the data (1970s or older) and the differences observed particularly with the extremes of the population sizes and shapes.

The majority of anthropometric data used is 1D, showing single linear measurements. The inadequacies of these data in defining shape and in a dynamic work environment are acknowledged and other sources of verification are used. These include user trials, prototypes and measuring a sample of the target population.

The CEASAR (Civilian American and European Surface Anthropometry Resource) database is currently the most comprehensive 3D body scan database. It can be purchased from SAE International or accessed via a Cooperative Research And Development Agreement (CRADA). Its current use in Australia is extremely limited.

The CEASAR database will be incorporated into WEAR (World Engineering Anthropometry Resource) which will be launched in August 2009.

There have been civilian population anthropometric surveys in Australia, for example, The University of Adelaide and SHARP Dummies Pty Ltd measured 1,265 adult women and 135 men in 2002. A further 65 sets of data were collected on women as part of the National Size and Shape survey of Australia in 2004. These included full laser body scans.

In 2003 the University of Adelaide and Rip Curl Pty Ltd measured 2,200 girls and women although the results are unpublished. Anecdotal evidence in the focus groups indicated that some companies conduct their own data collections to suit their design needs.

There have been at least four military studies conducted in Australia. The most recent being the *MIS 872, ADF Aircrew and Crewstation Anthropometry(2006)*. The measurements taken in this latest survey are extensive, including 3D body scans.

Access to anthropometric data are more useful to designers when incorporated into design tools rather than as raw data. The most useful data are the 3D body scan data which captures shape information. They are capable of representing the dynamic movement interactions between body parts when participants are scanned in various postures. For example, when a person reaches forward they can exceed the arm length by moving their shoulder forward. This is not clearly defined in 1D data. Designers are keen to have up-to-date, 3D anthropometric data made freely available to them to enable them to make their design decisions on the basis of valid and reliable data.

Australian designers are sceptical about the value of the anthropometric advice contained in Australian Standards. There are conflicts between Standards (such as access requirements for disabled persons and design Standards for telephone installations in public spaces). The source of the anthropometric data in the Standards is dated and is likely to be unrepresentative of the current Australian workforce.

Simple 2D tools can be developed using the existing data to enable designers to provide a rough representation of their design requirements. This is an inexpensive approach, although the accuracy is limited.

Integrating anthropometric data from multiple studies is problematic due to different measurement methods. For example, shoulder width may be measured using a tape or spreading caliper, giving different results. The WEAR database uses an integrated quality assurance process to ensure that data measurements are comparable.

The cost of 3D scanners, currently used in some Australian university research centers, are now reducing to the level where the option of using this technology for future anthropometric data collection is becoming realistic.

Specialist data are required for bariatric (or extremely large) persons. They are generally dealt with as a sub-population and designs are produced that are tailored to their specific needs. Removing the extremes from the population database avoids skewed distributions of data.

There is a need for training in the use of anthropometric data by designers. This training would benefit from a series of case studies to show how the design process works, demonstrating examples of the tools that can be used by the designer.

Significant resources continue to be wasted in the product development process for apparel and protective equipment due to the lack of quality 3D anthropometric data. There are many dissatisfied customers of apparel and PPE.

The relevance of anthropocentric data as a basis for design must be kept into perspective. There are also psychological and emotional expectations that users have; especially about the fashionable aspects of design such as colour, shape and feel.

Chapter 6 Conclusions

This pilot research project aimed to find the answers to two research questions:

- What anthropometric data are currently being used to help create design solutions for Australian workers?
- Do these data adequately reflect the requirements of the contemporary Australian workforce?

This report is based on a review of the international literature, including 'grey' literature, a survey of users of anthropometric data and a series of focus groups and interviews of people with research interest or user interest in anthropometric data in Australia. This study was a pilot study with a small sample primarily drawn from respondents from South Australia and Victoria so should be viewed as indicative only. The sample is likely to be biased towards those designers and users of anthropometric data with an interest in the area of the research, people likely to have a better knowledge of anthropometrics than might generally be the case. That is, they may represent the best-case scenario.

There are anthropometric data available in Australia, however many of these data are proprietary or commercial-in-confidence. Of the publicly available data much is out-of-date or of military origin, not civilian population-based, and thus it is of limited value when applied to civilian populations. For example, the ABS data are limited to height and weight and are self-reported (while there has been a correction using a validation process, there are acknowledged inaccuracies) and data in Australian Standards are old and sometimes conflicting. There are international data available but they are not necessarily relevant to the Australian population. In general, there is a paucity of good quality, reliable anthropometric data on the Australian working population that is available to designers of Australian workplaces and products used in Australian workplaces.

There is anecdotal evidence that the Australian population is changing over time, and existing evidence supports the trend that Australians are getting heavier but not much taller, which must be accounted for in future workplace and product design. However, without good data, the extent of the changes in the population over time will not be known.

The increasing accessibility of technology to collect 3D data and the access to online databases such as WEAR provides the ASCC with a range of new opportunities to access and promote anthropometric data for designers. The development of case studies showing the tools used by designers that incorporate current anthropometric data would assist in the training and dissemination of resources for designers. The professional societies, in particular the Human Factors and Ergonomics Society (with ARASIG, its Special Interest Group in anthropometry), may provide a useful distribution network or conduit for data that could be made available to designers.

Anecdotal information the authors have received thus far tells us that designers currently rely on readily available 1D data sources to tell them about users. These data are almost certainly misleading most of the time, so even with the best will in the world, errors are designed in from the start. In any case, when these data are used they are not always used in a reliable and statistically robust way. These difficulties are increased when data contained in standards are conflicting or inaccurate and the standards are called into legislation, or are a design criterion in contracts. The designer is left with an uncertain level of responsibility; an uncomfortable place to be in an increasingly litigious society.

Optimally these problems would be avoided by having the correct information to hand during the design and testing phase to enable good design solutions to be prepared in the first place. This can only happen with an up-to-date, relevant, Australian anthropometric database that includes 3D body scans. The database needs to be available at low cost because the design and testing phases are still expensive and it needs to be available so that designers can verify and fine tune their designs. These data are an investment in the future. They will enable Australian designers to produce their work using a scientifically reliable base for safer, better designed workplaces and products for all Australians.

Bibliography

Aird, W. M., F. R. Bond, et al. (1958). Australian Army. Part 1: Clothing Survey. Report No. 3/58. Canberra, Australia, Army Operational Research Group, Australian Military Forces.

Army Inspection Service Headquarters (1970). Anthropometric Survey: Body Dimensions - 1970. Melbourne Australia, Australian Army.

Australian Bureau of Statistics. (1998, Released at 11:30 AM (CANBERRA TIME) 06/10/1998, page last updated 08/12/2006). "4359.0 - How Australians measure up." Retrieved 22/02/2008, 2008, from http://www.abs.gov.au/AUSSTATS/abs@.nsf/productsbyCatalogue/B66CED7E47B041B5CA2570B50017FFB8?OpenDocument.

Beurier, G. and X. Wang (2004). Motion Conversion between Digital Human Models: A Case Study from Ramsis to Man3D: 2004-01-2194. Digital human modelling for design and engineering symposium, Oakland University, Rochester, MI, Society of Automotive Engineers (SAE).

Chaffin, D. B. (1997). "Development of Computerized Human Static Strength Simulation Model for Job Design". Human Factors and Ergonomics in Manufacturing 7(4):305-322

CODATA (2008) http://www.codata.org/taskgroups/TGanthro/index.html. Accessed june 2008.

Daanen, H. (2008). 3D data collection methods. WEAR Conference. Tokyo, WEAR Group.

Daniels, G. S. (1952). The Average Man: TN-WCRD 53-7, Wright-Patterson Air Force Base, OH: Wright Air Development Center. (AD 10 203).

Diffrient, N., Tilley, A. R., & Bardagjy, J. C. (1983). *Humanscale*. New York: MIT Press.

Department of Defence, 2000. "Royal Australian Navy Anthropometric Reference Data: AO 16541" DoD:Canberra.

Flood, V., K. Webb, et al. (2000). "Use of self-report to monitor overweight and obesity in populations: some issues for consideration." Australian and New Zealand Journal of Public Health 24(1): 96–99.

Floyd,W.F., Guttmann, L., Noble, C.W.,Parkes, K.R., Ward, J. 1966. A study of the space requirements of wheelchair users. Paraplegia 4 (1) : 24-37. May

Gordon, C. C., T. Churchill, et al. (1989). 1988 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics. Technical Report NATICK/TR-89/044. Natick, MA, US Army Natick Research, Development, and Engineering Center. (ADA225094).

Harrison, C. R. and K. Robinette (2002). CAESAR: Summary Statistics for the Adult Population (Ages 18-65) of the United States of America, AFRL-HE-WP-TR-2002-0170. Wright-Patterson AFB OH 45433-7022, United States Air Force Research Laboratory, Human Effectiveness Directorate, Crew System Interface Division.

Henneberg, M. and D. Veitch (2003). National size and shape survey of Australia. Kinanthreport 2003: Newsletter of the International Society for the Advancement of Kinanthropometry. 16: 34-39.

Henry Dreyfuss Associates, & Tilley, A. R. (2001). *The Measure of Man and Woman: Human Factors in Design*. New York John Wiley and Sons.

HFES 300 Committee (2004). Guidelines for Using Anthropometric Data in Product Design. Santa Monica, CA, Human Factors and Ergonomics Society: Santa Monica.

HREOC (Human Rights and Equal Opportunity Commission) (2000). Mr. Trevor Harrison ATS Australian Postal Corporation: Settled 1st November 2000, South Australia.

HREOC (Human Rights and Equal Opportunity Commission) (2004). Access for All Alliance Inc (Qld) on behalf of Mrs Glenise Staff ATS The Australian Postal Corporation : Settled 31st March 2004, Queensland.

Hin, A. J. S. and A. Krul (2005). Performance of *Human Solutions* body dimension analysis software. Sosterberg, The Netherlands Organization (TNO).

Huxley, J. S. and G. Tessier (1936). "Terminology of Relative Growth." Nature 137: 780.

ISO (1977). ISO 3637:1977. Size designation of clothes — Women's and girls' outerwear garments, International Standards Organisation.

ISO (1981). ISO 3635:1981. Size designation of clothes — Definitions and body measurement procedure, International Standards Organisation.

ISO (1989). ISO 8559:1989. Garment construction and anthropometric surveys — Body dimensions, International Standards Organisation.

ISO (1996). ISO 7250:1996. Basic human body measurements for technological design, International Standards Organisation.

ISO (2000). ISO 15534-3:2000. *Ergonomic design for the safety of machinery — Part 3: Anthropometric data*. Edition 1, International Standards Organisation.

ISO (2002). ISO 14738:2002. Safety of machinery — Anthropometric requirements for the design of workstations at machinery. Edition 1, International Standards Organisation.

ISO (2004). ISO 15537:2004 Principles for selecting and using test persons for testing anthropometric aspects of industrial products and designs. Edition 1, International Standards Organisation.

ISO (2005a). ISO 13232-3:2005 Motorcycles — Test and analysis procedures for research evaluation of rider crash protective devices fitted to motorcycles — Part 3: Motorcyclist anthropometric impact dummy. Edition 2, International Standards Organisation.

ISO (2005b). ISO 20685:2005. 3-D scanning methodologies for internationally compatible anthropometric databases. Edition 1, International Standards Organisation.

ISO (2005c). ISO 15536-1:2005. Ergonomics — Computer manikins and body templates — Part 1: General requirements. Edition 1, International Standards Organisation.

ISO (2005d). ISO 15830-3:2005. Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side-impact dummy — Part 3: Electronic subsystems. Edition. 1, International Standards Organisation.

ISO (2005e). ISO 15830-4:2005. Road vehicles — Design and performance specifications for the WorldSID 50th percentile male side impact dummy — Part 4: User's manual. Edition 1, International Standards Organisation.

ISO (2006a). ISO 15535:2006. General requirements for establishing anthropometric databases, International Standards Organisation.

ISO (2007). ISO 15536-2:2007. Ergonomics — Computer manikins and body templates — Part 2: Verification of functions and validation of dimensions for computer manikin systems. Edition 1, International Standards Organisation.

ISO (2008). ISO 7250-1:2008. Basic human body measurements for technological design — Part 1: Body measurement definitions and landmarks. Edition 1, International Standards Organisation.

Jürgens, H. W., I. A. Aune, et al. (1989). International anthropometrischer Datenatlas. Schriftenreihe der Bundesanstalt für Arbeitsschutz Fb 587. Dortmund, Germany, ?

Kunelius, A., S. Darzins, et al. (2007). "Development of normative data for hand strength and anthropometric dimensions in a population of automotive workers." Work 28(3): 267-278.

Nelson, A (2008) Review of the 'Project Report on the Field Testing of Australian Standard 1428 - 1977' of J.H.Bails (the 'Bails Data Base'). ME-064 Committee and with the BCA authority, Canberra (pending 2008).

Pheasant, S. (1987). Ergonomics Standards Guidelines for Designers. London, British Standards Institution.

Pheasant, S. (1988). Bodyspace: Anthropometry, Ergonomics, and Design. London, Taylor & Francis.

Pheasant, S. (1986). Bodyspace: Anthropometry, Ergonomics, and Design. London, Taylor & Francis.

Robinette, K. M. and J. Hudson (2006). Anthropometry. Handbook of Human Factors and Ergonomics. G. Salvendy. New York, NY, John Wiley & Sons: 322-339.

Robinette, K. M. and J. T. McConville (1982). An Alternative to Percentile Models: SAE Technical Paper 810217. 1981 SAE Transactions. Warrendale, PA, Society of Automotive Engineers: 938-946.

Ross, J., Doyle-Bogicevic, A., Olds, T., Singh, B. & McGrath, B. (2006). Australian Defence Force (ADF) aircrew and crewstation anthropometry. Aerospace Medical Association 78th Annual Scientific Meeting.

Searle, J. A. and C. M. Haslegrave (1969). "Anthropometric Dummies for Crash Research." Monthly Summary of Automobile Engineering Literature Motor Industry Research Association (MIRA) Bulletin no. 5: 25-30.

Slice, D. E. and J. Stitzel (2004). Landmark-based Geometric Morphometrics and the Study of Allometry. Digital human modeling for design and engineering symposium, Oakland University, Rochester, MI, Society of Automotive Engineers (SAE).

Snook, S. H. (1978). The design of manual handling tasks. *Ergonomics, 21*(12), 963-985.

Snook, S. H., & Ciriello, V. M. (1991). The design of manual handling tasks: revised tables of maximum acceptable weights and forces. *Ergonomics, 34*(9), 1197-1213.

Standards Australia. (1992a). AS1428.2-1992 Design for access and mobility - Enhanced and additional requirements - Buildings and facilities. Sydney: Standards Australia.

Standards Australia. (1992b). AS1428.3-1992 Design for access and mobility - Requirements for children and adolescents with physical disabilities. Sydney: Standards Australia.

Standards Australia. (2001). AS1428.1-2001 Design for Access and Mobility - General requirements for access - New building work. Sydney: Standards Australia.

Standards Australia. (2002). AS1428.4-2002 Design for access and mobility - Tactile indicators. Sydney: Standards Australia.

Standards Australia and Standards New Zealand (1997). AS 1344:1997 - Size coding scheme for women's clothing – Underwear, outerwear and foundation garments. Sydney, Standards Australia/Standards New Zealand.

Standards Australia. (1988). AS 1428 - Supplement 1-1988. Extracts –Design rules for access by the disabled (Supplement to AS 1428 -1977). Sydney Standards Australia.

Stevenson G., and Phillips S., (YYYY). An Anthropometric Data Base For The Australian Workforce. Ergonomics Unit, Worksafe Australia, Sydney.

Strength Simulation Model for Job Design. *Human Factors and Ergonomics in Manufacturing, 7*(4), 305-322.

Tilley A. R., and Henry Dreyfuss Associates, 2002, The Measure of Man and Woman: Human Factors in Design. New York, NY, John Wiley & Sons

Tillman, B. (2000). "Customer review: good news!" Retrieved 26/2/08, 2008, from http://www.amazon.com/review/RXNZQNG14ZRZL/ref=cm_cr_pr_viewpnt#RXNZQNG14ZRZL.

Veitch, D., L. Veitch, M. Henneberg. (2007). "Sizing for the Clothing Industry Using Principal Component Analysis—An Australian Example." Journal of ASTM International 4(3).

Veitch,D., Robinette, K., (2006) "World Engineering Anthropometry Resource (WEAR): A Review". Paper presented at the Annual Conference of the Human Factors and Ergonomics Society of Australia, Sydney, New South Wales.

Ward, S. (2006) "Designers and users: A survey of user research methods employed Australian industrial designers". Unpublished thesis, Master of Science (Research), University of New South Wales.

Ward, S. (2008) "2-D representations of the user: still needed in a 3-D world". Paper presented at the Annual Conference of the Human Factors and Ergonomics Society of Australia, Fremantle, Western Australia.

Ward, S (2008) IDES2201 Ergonomics, course notes University of New South Wales, unpublished.

WEAR Strategic Plan 2008. WEAR Conference Handbook, Proceedings of the WEAR Conference Adelaide, South Australia, February 2007. Human Factors and Ergonomics Society of Australia Inc. NSW

WEAR (2008) World Engineering Anthropometry Resource http://wear.io.tudelft.nl/. Accessed June 2008.

Winks, J. M. (1997). Clothing Sizes International Standardization. Manchester, UK, The Textile Institute.

Woodson, W. E., Tillman, P., & Tillman, B. (1992). Human factors design handbook: Information and guidelines for the design of systems, facilities, equipment, and products for human use (2nd ed.). New York: McGraw-Hill.

Appendix One

Survey Instrument

Designing for the User Questionnaire - PILOT

About the project

This questionnaire is part of a pilot research project looking at how products for Australian workplaces and work spaces are designed.

David Caple & Associates Pty Ltd has been engaged by Safe Work Australia (SWA) to find the answers to the following questions:

- What information, including anthropometric data, is currently being used to help create design solutions for Australian workers?
- Do the data adequately reflect the requirements of the contemporary Australian workforce?

In addition to the survey questionnaire, we will be interviewing representatives of key organisations that represent designers as well as designers themselves.

We will report the findings of the project to SWA for their consideration.

If you have any questions about the project or this survey, please don't hesitate to contact one of the following:

Daisy Veitch:	T 08 8370 0202	M 0414 386 791	Email <daisy@internode.on.net>
David Caple:	T 03 9499 9011	M 0419 339 268	Email < davidcaple@pacific.net.au>
Verna Blewett:	T 08 8361 2501	M 0402 990 066	Email: <verna@newhorizon.com.au>

How to complete this questionnaire

Thank you for completing this questionnaire[1].

This questionnaire asks you about the way in which you go about your work as a designer or developer of products or spaces for people at work in Australia.

The questionnaire is anonymous and the only people to see your answers will be the consultants engaged in this work.

There are no right or wrong answers. Feel free to write any extra comments to clarify your answers.
The results of the questionnaire will only be available as grouped data so that it is not possible to identify the answers of individuals.

How to return this questionnaire

Please return the completed form by 22 March 2008
You can complete the form and return it in the stamped envelope enclosed, or to:

David Caple and Associates Pty Ltd
PO Box 2135
East Ivanhoe, Victoria 3079

Instructions

- **Please mark the box of the correct response(s).**
- **Please write the correct answer in the space provided.**

Who should complete this questionnaire?

1. Are you a:

☐ 1 Designer—go to Question 2

☐ 2 Product developer—go to Question 2

☐ 3 An educator or adviser to designers or product developers—go to Question 2

☐ 4 None of the above— thank you for your time, you do not need to answer further questions.
Please return this questionnaire to the address above.

[1] This questionnaire is based on work by Ward (2006) and WEAR (2008)

About you

2. Your gender:

- ☐ 1 Male
- ☐ 2 Female

3. What is the highest level of education that you have?

- ☐ 1 Year 11 or earlier
- ☐ 2 Year 12 (VCE or equivalent)
- ☐ 3 Trade certificate
- ☐ 4 Diploma
- ☐ 5 University degree
- ☐ 6 Other—give broad description

4. What products do you develop or design for the Australian workplace?

- ☐ 1 Furniture
- ☐ 2 Automotive
- ☐ 3 Buildings or interior design
- ☐ 4 Apparel (eg uniforms)
- ☐ 5 Personal protective equipment
- ☐ 6 Medical equipment
- ☐ 7 Other, please specify

5. How long have you worked as a designer or product developer?

Give time in years and months

6. How long have you worked in your current position?

Give time in years and months

About your workplace

Please provide some information about the nature of your work.

7. Where is your workplace located?

- ☐ 1 Victoria
- ☐ 2 South Australia
- ☐ 3 New South Wales/ACT
- ☐ 4 Queensland
- ☐ 5 Western Australia
- ☐ 6 Tasmania
- ☐ 7 Northern Territory

8. Does your organisation service clients:

- ☐ 1 Local state only
- ☐ 2 Nationally
- ☐ 3 Internationally

9. What type of organisation are you currently working in?

- ☐ 1 Firm that designs/develops its own products
- ☐ 2 Firm that designs/develops products for others
- ☐ 3 Firm that assesses the designs/products of others

… for use in **Australian workplaces**.

10. How many FTE people work in your firm or department?

- ☐ 1 1 - 4
- ☐ 2 5 - 10
- ☐ 3 11 - 19
- ☐ 4 20 - 50
- ☐ 5 51 - 199
- ☐ 6 200 or more

11. What **proportion** of **time** did you spend on design work in each of the following categories **during the last year**?

Please estimate the percentage in every row.

1	Furniture	
2	Automotive	
3	Buildings or interior design	
3	Plant, equipment or machinery	
4	Apparel (eg uniforms)	
5	Personal protective equipment	
6	Medical equipment	
7	Other	
	Check that this adds up to:	**100%**

How you work

These questions are about how you get and apply information about the users of your designs or products.

12. During the past year, have you **used** anthropometric data about potential end-users of something you were designing or developing?

- ☐ 1 Yes—go to **Question 13**
- ☐ 2 No—was this because:
  - ☐ 3 You didn't need it
  - ☐ 4 It's too expensive
  - ☐ 5 You couldn't find it
  - ☐ 6 Some other reason, please describe:

Now go to Question 18

13. During the past year, which of the following **method(s)** have you **used** to get anthropometric data about potential end-users of something you were designing or developing?

Select as many of the options as apply to you.

- ☐ 1 Observed end-users using existing products
- ☐ 2 Engaged a consultant with user research expertise; eg an ergonomist or market researcher
- ☐ 3 Examined sales data
- ☐ 4 Analysed generic market research information
- ☐ 5 Reviewed reports or feedback from users of existing products
- ☐ 6 Talked to someone familiar with the target user group
- ☐ 7 Interviewed users (individually or in groups)
- ☐ 8 Reviewed reference books, eg for ergonomics or anthropometric information
- ☐ 9 Surfed the net for reference materials
- ☐ 10 Measured people yourself
- ☐ 11 Other, please specify

14. During the past year, where did you **find** the anthropometric data that you **used**?

Select as many of the options as apply to you.

- ☐ 1 Consulted reference text(s). Name text(s):
- ☐ 2 Surfed the net for reference data
- ☐ 3 Used an external consultant to find the data
- ☐ 4 Took physical measurements of the target user group
- ☐ 5 Used own staff or personal measurement data
- ☐ 6 Measured 1D data
- ☐ 7 Took 3D scans/ landmarks
- ☐ 8 Used 2D software Name software:
- ☐ 9 Used 3D software (i.e. CAD drawing programs) Name software:
- ☐ 10 Other, please specify

15. Please indicate **how you use** anthropometric data in designing for Australian workplaces.

Select as many of the options as apply to you.

- ☐ 1 To accurately quantify measurements for my design
- ☐ 2 To roughly quantify measurements for my design
- ☐ 3 To provide a human shape for an illustration
- ☐ 4 To evaluate user space requirements
- ☐ 5 To validate the design profile
- ☐ 6 For rapid prototyping
- ☐ 7 Other, please describe

16. This question contains a list of anthropometric measurement methods.
Which have you **used in the past year**?

b. 1D measurement tools eg calipers and tape measures	☐ 1 Yes	☐ 2 No
c. 2D measurement tools eg head boards or silhouette scanners	☐ 1 Yes	☐ 2 No
d. 3D measurement tool eg Faro Arm	☐ 1 Yes	☐ 2 No
e. 3D scanners:	☐ 1 Yes	☐ 2 No

Name scanner(s) used

17. This question lists anthropometric data **sources**. Please estimate the usefulness of any that you have used **during the past year**. Note that: 1-D = Length, or height, or breadth 2-D = x,y points in 2D space 3-D = x,y,z, points in 3D space	Very Useful	Qutie useful	Moderately useful	Somewhat useful	Not at all useful
a. 1D data—*Humanscale* (Diffrient, Tilley & Bardagjy)	☐	☐	☐	☐	☐
b. 1D data—*Bodyspace* (Pheasant)	☐	☐	☐	☐	☐
c. 1D data—*Anthropometry* (Singh)	☐	☐	☐	☐	☐
d. 1D data—Other	☐	☐	☐	☐	☐
e. 2D CAD drawings	☐	☐	☐	☐	☐
f. 2D patterns	☐	☐	☐	☐	☐
g. 2D models	☐	☐	☐	☐	☐
h. 3D CAD drawings	☐	☐	☐	☐	☐
i. 3D patterns	☐	☐	☐	☐	☐
j. 3D models	☐	☐	☐	☐	☐
k. 3D body scans	☐	☐	☐	☐	☐
l. Other, please list:	☐	☐	☐	☐	☐

18. Your opinions and attitudes are very important to this research project. Please rate these statements from *Strongly agree* to *Strongly disagree*. **When I am designing for Australian workplaces:**	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	I don' know
a. available anthropometric data can be usefully applied in most design projects.	☐	☐	☐	☐	☐	☐
b. the current anthropometric data is relevant and suitable for the populations I design for.	☐	☐	☐	☐	☐	☐
c. the current anthropometric data is relevant to the Australian population	☐	☐	☐	☐	☐	☐
d. the anthropometric data available in Australia for Australians is reliable and accurate.	☐	☐	☐	☐	☐	☐
e. anthropometric data relevant to my needs are easily available.	☐	☐	☐	☐	☐	☐
f. current anthropometric data reflects the contemporary Australian workforce.	☐	☐	☐	☐	☐	☐
g. the Australian population is anthropometrically unique in the world.	☐	☐	☐	☐	☐	☐
h. my anthropometric data requirements are satisfied by the currently available data sources.	☐	☐	☐	☐	☐	☐
i. specific anthropometric data relevant to Australians and Australia needs to be developed.	☐	☐	☐	☐	☐	☐
j. future design situations will require more accurate / reliable data	☐	☐	☐	☐	☐	☐
k. my future anthropometric data needs will require different data parameters than are currently available.	☐	☐	☐	☐	☐	☐
l. future designs will need to be suited to a larger range of user sizes.	☐	☐	☐	☐	☐	☐

19. This question contains a list of **types** of anthropometric data. Please estimate the usefulness of these for **your future projects** when designing for the Australian workforce.	Very Useful	Qutie useful	Moderately useful	Somewhat useful	Not at all useful
a. Ethnicity-related data	☐	☐	☐	☐	☐
b. Gender-related data	☐	☐	☐	☐	☐
c. Age-related data	☐	☐	☐	☐	☐
d. Changes that may affect anthropometric data (i.e obesity)	☐	☐	☐	☐	☐
e. 1D anthropometric data (i.e. stature / limb lengths)	☐	☐	☐	☐	☐
f. 2D anthropometric data (i.e. X and Y axis data)	☐	☐	☐	☐	☐
g. 3D anthropometric data (i.e X, Y and Z axis data)	☐	☐	☐	☐	☐

Case studies

Case study 1

Please provide details about a design project or product development for an **Australian workplace** that you have worked on **in the last year**.

20. Project/product description:

21. What specific population (if any) was the project/product designed for?

22. What data (if any) did you use to define the end-user?

23. Where did you source these data?

24. How accurate were these data for your needs?

25. What (if any) assumptions did you need to make in order to make the data relevant?

26. What (if any) additional data would you have liked to make your project more successful?

27. Any other comments about this design project or product development?

28. For this project/product please indicate which **Australian anthropometric data** *were used*, or *would have been useful*.	Data used	Would have been useful
a. Body stature	☐	☐
b. Reach capabilities	☐	☐
c. Body circumference, length, limb sizes including hands and feet	☐	☐
d. Body weight	☐	☐
e. Strength	☐	☐
f. Disabled users' data	☐	☐
g. Circulation space	☐	☐
h. 3D body shape data	☐	☐
i. Other data, please indicate:	☐	☐

Case study 2

Please provide details about a design project or product development for an **Australian workplace** that you have worked on **in the last year**.

29. Project/product description:

30. What specific population (if any) was the project/product designed for?

31. What data (if any) did you use to define the end-user?

32. Where did you source these data?

33. How accurate were these data for your needs?

34. What (if any) assumptions did you need to make in order to make the data relevant?

35. What (if any) additional data would you have liked to make your project more successful?

36. Any other comments about this design project or product development?

37. For this project/product please indicate which **Australian anthropometric data** *were used*, or *would have been useful*.	Data used	Would have been useful
a. Body stature	☐	☐
b. Reach capabilities	☐	☐
c. Body circumference, length, limb sizes including hands and feet	☐	☐
d. Body weight	☐	☐
e. Strength	☐	☐
f. Disabled users' data	☐	☐
g. Circulation space	☐	☐
h. 3D body shape data	☐	☐
i. Other data, please indicate:	☐	☐

Write any other comments here

Thank you very much for your help in completing this questionnaire.

Please return this questionnaire as instructed on Page 1.

Appendix 2

Interview Schedule for Focus Groups and Interviews

ASCC Anthropometric Data Focus Groups

29th April – Melbourne

30th April - Adelaide

Timing

7.30am	Introductions & Welcome	David Caple
7.45am	Background on project	David Caple
7.50am	Overview of Stage One - Literature Review	Daisy Veitch
8.00am— 9.25am	If it was the perfect world and you had access to the anthropometric data you needed to design for the Australian workplace, what would it: ▪ Look like? ▪ How would you find/access it? ▪ Who would provide it? ▪ What cost would you be prepared to pay?	Verna Blewett Daisy Veitch David Caple
9.25am— 9.30	Where to from here Session CLOSE	David Caple – MEL Daisy Veitch - ADL

Prompt Questions:

Topic One

- How do you currently assess designs from the human perspective?
- What data or methods do you use?

Topic Two:

- How suitable do you find your current methods to meet your design needs?
- What are their strengths and limitations?

Topic Three:

- What data would assist you in the future to better represent the human aspect in design?
- From where would you expect this data to be available?

ASCC Anthropometric Data Focus Groups

29th April – Melbourne

30th April - Adelaide

Thanks for being part of this focus group on the use of anthropometric data in design for the Australian workplace.

Our brief is to find out what anthropometric data designers currently use, how they use it and what they'd like to have in the best of all possible worlds.

With this in mind, we pose the following questions:

If it was the perfect world and you had access to the anthropometric data you needed to design for the Australian workplace, what would it:

Look like?

How would you find/access it?

Who would provide it?

What cost would you be prepared to pay?

Our discussion this morning will be framed around these questions.

Once again, thanks for your participation.

Daisy Veitch

David Caple

Verna Blewett