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Collection of anthropometry from older and physically impaired persons: traditional methods versus TC² 3-D body scanner

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Abstract

With advances in technology it is now possible to collect a wide range of anthropometric data, to a high degree of accuracy, using 3D light-based body scanners. This gives the potential to speed up the collection of anthropometric data for design purposes, to decrease processing time and data input required, and to reduce error due to inaccuracy of measurements taken using more traditional methods and equipment (anthropometer, stadiometer and sitting height table). However, when the data collection concerns older and/or physically impaired people there are serious issues for consideration when deciding on the best method to collect anthropometry. This paper discusses the issues arising when collecting data using both traditional methods of data collection and a first use by the experimental team of the TC² 3D body scanner, when faced with a 'non-standard' sample, during an EPSRC funded research project into issues surrounding transport usage by older and physically impaired people.

Keywords

Anthropometry, body scanner, disability

1. Introduction

Traditional methods of collecting anthropometric data involve the use of standardised postures (BS EN ISO 7250: 1998), with the distance between body landmarks (often bony points, such as the acromion and patella) being measured using a range of equipment including stadiometers,

anthropometers, sitting-height tables, and the tape measure. Stadiometers and the like require calibration (especially after transit), and measurements taken are only as accurate as the person taking the measurements. For this reason it is often advised that multiple measurements are taken and the average calculated. There are also possible differences between measurements taken by different people (although this can be reduced with consistent training), and there can be difficulty in locating the required body landmarks. This may be especially problematic in people with more body fat over the bony landmarks (Olds & Honey, 2005), or people in wheelchairs where it can be hard to gain access to the required landmarks. In addition, the standardised postures required for the measurements to be taken assume the person being measured can adopt (and maintain during measurement) that posture. It is difficult to assess the impact of, for example, a slouched posture as this will directly impact measures such as sitting height.

Body scanners offer the opportunity to harness new technology and remove some of the inaccuracies of traditional anthropometric measurements. One of the earliest scanners was the Loughborough Anthropometric Shadow Scanner (LASS) (Jones et al, 1989), developed and used to digitise the human body, but required some manipulation of data to allow body measurements to be taken from the scan. Brooke-Wavell et al (1994) compared LASS anthropometry measurements with measurements taken using traditional methods of anthropometry. Ten participants were measured on seven body dimensions, with it being found that the measurements obtained using the two methods were similar. For women, statistical differences ($p < 0.05$) were found between measurements of neck and chest circumferences, waist width, depth and height, whilst for men a significant difference was only found between the measurements of waist depth ($p < 0.05$). These differences were explained as being due to the positioning of site markers used in the study and difficulties making horizontal measurements with the tape measure. Recent papers have addressed the issues of accuracy with location of landmarks (Kouchi & Mochimaru, 2010), constant body ratio benchmarks (Wang & Chao, 2010) as well as comparing the data collected using traditional methods against those obtained using body scanners (Han et al, 2010; Feathers et al, 2004). Kouchi and Mochimaru (2010) discuss the fact that body dimensions are based on body

landmarks, but that the amount of error in identifying landmarks is not well known. They compared repeat landmarking of 40 individuals by experienced and novice markers, by comparing differences in measurements taken based on the landmarks identified. Differences in measurements obtained due to intra- and inter- observer error were such that it was suggested that explicit definition of landmarks in more detail might reduce landmarking errors. They also conclude that, when scanner-derived measurements are used, there is no widely accepted protocol for 3D anthropometry. Wang and Chao (2010) discuss how existing anthropometric data can be updated using constant body ratio benchmarks so that accurate, up-to-date data can be generated from existing databases. They identified 483 unique constant body ratio benchmarks that are least affected by gender and age, allowing anthropometric data to be updated accurately and at low cost.

Han et al (2010) compared body scanner measurements and measurements obtained using traditional methods in Korean women. They found that torso circumferences had the largest differences between scanner and traditional measurements, and also age-related differences for under-bust circumference, bust circumference and shoulder length. The difference in measurements between scanner and traditional methods increased as body-mass index increased for most circumferences. They provided a list of guidelines for those using scanner measurements to minimise these effects. Feathers et al (2004) studied measurement consistency in both traditional and scanner anthropometry, finding that significant differences occur across measurers, methods, the interaction with clothing, and between method and measurer, introducing systematic error contributions for these variables. They also studied measurements obtained using traditional and scanner measurements for 10 wheelchair users who were not able to maintain the erect seated postures required for the measurement protocols. The inability to maintain the required posture may have resulted in greater differences than the maximum tolerable differences found in other anthropometric studies, changes in posture between measurements would also result in inconsistent results.

Zwane et al (2010) discussed comparisons of scanned and manual measurements of body girths, using a TC² body scanner. 56 women were scanned using purpose-designed scanning garments. Stature was not measured using the body scanner due to the extracted measurement being accurate due to “the obstruction of the subjects’ hair”. Manual measurements taken were waist and hip measurements, and when compared to scanned measurements extracted, it was found that larger differences in measurements were found with participant with more body fat. Manual measurements were found to be generally lower than the extracted measurements from the scans, primarily down to compression of soft tissues and possibly participants ‘breathing in’ during manual measurements. No discussion is made about whether the scanning garments influenced dimensions obtained (for example by compressing tissues or lifting the bust). It was found that the (able-bodied) participants were largely accepting of the technology and happy to be scanned with no undue problems.

Jones and Rioux (1997), Daanen and van de Water (1998) and more recently Olds and Honey (2005) discuss the use of 3D whole-body scanners in anthropometry as a whole, giving a good overview of the evolution of body scanning technology and the different scanners in use at the time. Scanners using white light are generally cheaper and faster than laser scanners, but can produce lower quality scans, with areas of data missing (Olds and Honey, 2005). They go on to discuss the need for software to process the raw data before anthropometric measurements can be extracted, and the variety of formats that the resultant images can be presented in, with the amount of processing being needed varying with the scanner and the software it comes with. Olds and Honey (2005) conclude that body scanners are expensive, require technical expertise, cannot measure skin-folds or compressed bone lengths, but offer the ability to collect greater amounts of data, including extracting data from that collected when the participant is no longer present. The data collected can also be used directly in computer-aided design software applications. McKinnon and Istook (2001) compared two scanners available at that time from TC², finding that the newer scanner (the 2T4) was an improvement on the older scanner (the 3T6), producing data that more closely replicated that obtained using traditional measurement methods, and anticipated that the

extraction of fast and accurate anthropometric data would be possible in the future.

Brunsmann et al (1997) discussed optimal postures and positioning when using body scanners, realising that a standardised posture is required and investigating which postures reduce the amount of data 'lost' due to shadowing. Three postures were proposed, standing with arms slightly out to the sides, seated with knees and elbows bent at 90° to the body, and seated with arms raised to either side of the head, elbows bent at 90° (the "stick-em up" position). The first two postures are very similar to those found in the standard BS EN ISO 20685: 2005, 3D body scanning methodologies, which has worked towards standardising the procedures used in 3D body scanning. This standard, along with previous work on collection of anthropometry using body scanners, has not included consideration of the additional issues that may arise when measuring older and/or physically impaired participants. The data that are collected for design purposes are based on the practicalities of traditional data collection methods, which typically involve identification of obvious bony landmarks, standardised postures and so on. It is possible that modern technology, including body scanners, could result in a change in the data that is required and collected, rather than simply using the technology to automate the traditional methods. Issues arising with both traditional and 3-D body scanning data collection methods when collecting data from a non-standard sample, and the applicability of these data to the designers who may wish to use these data, has been little explored.

This paper presents analysis conducted on data arising from an EPSRC funded research project into Accessibility and User Needs in Transport within the Sustainable Urban Environment initiative (AUNT SUE), which aimed to investigate transport usage in socially excluded groups and develop tools to promote and support policy makers, design professionals and urban planners in creating more inclusive transport environments. The objectives of the study were to collect data from a wide range of people to investigate transport usage. This included collecting data from older and physically impaired people as well as others who experience problems using public transport, including collecting anthropometric data so that the participants could be recreated as digital human

models in a virtual environment (Porter *et al*, 2004). These data were to be used to allow estimation of which individuals within a computer-based design tool would be able to complete tasks within a virtual environment, to support and promote a 'design for all' methodology. The 'design for all' or universal design philosophy has the aim of increasing the usability of mainstream products for all people by increasing the consideration of older and less able members of the population during the design process. At the same time as the data collection trials were being conducted, a TC² 3-D body scanner became available to the experimental team, and it was decided to conduct an initial investigation in to the issues of collecting anthropometry using the scanner alongside the traditional methods being employed. The experimental team had no previous experience with 3-D body scanners and took the opportunity to investigate the issues arising with using the scanner alongside traditional methods. This paper presents a comparison between the anthropometric data collected using traditional methods (all participants) and TC² 3-D body scanner (participants that were willing and able to be scanned), in particular it reports issues that arose when using the scanner with older and disabled people.

2. Methods

2.1 The scanner

The scanner used for data collection was the TC² NX12 body measurement system (TC², 2010). This is a white-light based scanner developed primarily for the clothing industry, and as such the measurement extraction software reflects this in the options available for body dimensions that can be obtained. Many of the default measurements that can be extracted using the scanner software are surface measures that mimic those that would be captured with a tape measure by a tailor, for example sleeve length and arm and leg circumferences. This scanner was chosen, primarily due to financial constraints, and due to having been used in the SizeUK (SizeUK, 2010) and Shape GB (Shape GB, 2010) projects, where collection of anthropometry from large numbers of able-bodied people was conducted.

However, using the standard 'standing' posture software and the specially developed 'seated'

posture software it is possible to extract a number of the more traditional anthropometric measures that could be directly compared with measurements obtained using traditional methods and equipment. The 'standing' posture required for the scanner involves the person standing upright, with feet placed apart on the floor, and both hands held out from the body, optionally holding onto handles within the scanner apparatus (see right image in Figure 2), this posture matches that described within BS EN ISO 20685 (2005) . The 'seated' posture requires participants sitting within the scanner, on a stool arranged so that the seat height results in the left thigh being parallel to the floor, with the left knee bent at 90° and the right leg straight out in front of the person with the foot flexed. The left arm is held in front of the person, parallel to the floor, and the right arm vertically straight up from the shoulder (Figure 1). This posture differs from the seated posture described by BS EN ISO 20685 (2005) but is the posture required by this particular scanner for the software to extract seated measurements, and is essentially the same as required for the collection of anthropometric data using traditional methods.

Figure 1: standing (left) and seated (right) postures required to be adopted in the body scanner.

Figure 2: TC² NX12 body measurement system, external and internal views

Figure 2 shows the scanner, with a view of the outside (with the changing vestibule to the left), and the inside of the scanner itself on the right. For the internal photograph the black cloth door panels

were removed, when the scanner is in use these fully enclose the scanner and serve to ensure that there is no ambient light within the scanning volume. The handles that are held during the standing scan, and the footprints on the floor to mark the stance of the standing scan posture, are clearly seen in the internal view.

2.2 Data collection

A total of 103 people took part in data collection trials. These data collection trials were primarily to obtain physical, emotional and cognitive data from people with a range of transport-related 'issues', for use in a database and computer-based design tool, and proposed personal journey planner. Further details about the project as a whole can be read in Porter *et al* (2004) and Sims *et al* (2006). However, a key part of the research was the collection of anthropometric data from the participants to allow the creation of 3D human models of individual participants within a digital human modelling system. Ethical approval for the project was sought and gained from the Loughborough University Ethical Advisory Committee prior to the commencement of the study.

Prior to the trials, participants were informed that they would have the option of being scanned using the body scanner. This would require them to wear specific clothing (see 3.2 *Issues arising with scanner usage*, and as described in BS EN ISO 20685: 2005). The scanning apparatus includes an enclosed changing area, to preserve the privacy of the participants. As many of the participants were older and/or physically impaired they were informed that if they needed help with undressing/dressing, then they would need to bring their own assistant with them. Of the 103 participants, 54 agreed to be scanned using the TC² NX12 body measurement system.

The sample for the data collection aimed to have broad representation across five categories of mobility:

- Ambulant disabled (18-59 years, anyone with an impairment but able to walk either independently, for example with hearing or visual impairments, or with the aid of stick(s), crutch(es) or wheeled frame).

- Older ambulant physically disabled (60 years and over, as above).
- Able-bodied (18-59 years, anyone without a measurable impairment)
- Older able-bodied (60 years and over, as above although there might have been some age-related issues but not to a degree that could be recorded)
- Wheelchair users (those who spend the majority of their time in a wheelchair or scooter).

Anthropometric data were obtained from all participants using traditional methods (including: stadiometer, sitting height table, anthropometer), with 26 measurements being recorded (Table 1). Measurements were taken according to the protocols described in BS EN ISO 7250 (1998). Participants who agreed to be scanned were shown the scanner apparatus, the procedure was explained to them, they were shown the position to stand/sit in, and then left to get changed. As anthropometry was only one element of the data being captured during these trials fatigue was a potential concern (see Marshall *et al* (2009) for full details). If a participant was obviously fatigued or if the trial was approaching a deliberately imposed two hour limit, then the experimenter used their discretion and did not ask the person to attempt to use the scanner. An experimenter was present outside the scanner at all times, and in verbal contact throughout the process.

Measure	Measure
Stature / height of top of head from floor	Arm length
Abdominal depth –standing	Upper arm length
Thigh depth – standing	Elbow to shoulder
Knee to Hip	Wrist to elbow
Ankle to knee	Abdominal depth –sitting
Ankle height	Thigh depth – sitting
Foot length	Knee height
Sitting height	Shoulder breadth
Sitting shoulder height	Hip breadth
Hip to shoulder	Hand length
Chest height	Hand grip length
Chest depth	Buttock knee length
Head height	Eye to top of head

Table 1: Body measurements taken

2.3. Extraction of data

Of the 54 people who agreed to be scanned, 33 were over the age of 60 or had a physical impairment of some kind (Table 2). 48 usable 'standing' scans were obtained, with the remaining scans being unusable due to missing data.

	Men	Women
Able-bodied (18-59yrs)	6	9
Older able-bodied (60+ yrs)	4	11
Ambulant disabled (18-59yrs)	2	3
Older ambulant disabled (60+ yrs)	4	7
Wheelchair users	1	1

Table 2: Number of participants by gender and physical ability level

As discussed earlier the scanner data extraction software has primarily been designed for the clothing industry, and as such the available measurements do not necessarily match those taken using traditional anthropometry methods. With the combination of standing and seated scan software (the latter being designed specially for more traditional anthropometry collection), it was possible to extract 14 dimensions (stature, arm length, abdominal depth standing, foot length, sitting height, sitting shoulder height, chest depth, head height, abdominal depth sitting, thigh depth sitting, knee height, shoulder breadth, hip breadth, and buttock-knee length) that could be directly compared with traditional anthropometric measures. Comparison was expected to be possible due to the similarity of the postures that the body part(s) were in during measurement (for example, for knee height in both traditional methods and the scanner posture, the leg to be measured was bent at 90° at the knee, with the thigh parallel to the floor and the lower leg vertical). Circumferences were not measured due to expected differences when comparing 'uncompressed body tissues in the scanned image to measurements obtained using a measuring tape directly on the body. There were some interesting differences between the 'standing' scan and the 'seated' scan measurement extraction systems. Arm length in the seated scan was more akin to that obtained using traditional anthropometry, whereas that obtained using the 'standing' posture reflected the clothing industry origins of the TC² NX12 body measurement system, taking the measurement from an imaginary seam on the shoulder, along the arm surface to the cuff. Standing abdominal depth and chest

depth required the construction of a measure by the experimenter, calculating the horizontal difference between two given points at the front and rear of the torso, and was not automatically calculated by the software.

For standing scans data could not be extracted on all dimensions, for all participants, possibly due to participants not being able to get into the required 'standard' postures, or due to 'missing data' in the scans (Figure 3) meaning that it was not possible to transform the data point clouds into body models which is required by the software for analysis to be carried out. Analysis was done on those possible. The seated scan software was not obtained until near the end of the data collection phase, and as such only 8 participants were scanned in this posture. Due to the small sample size no statistical analyses to investigate potential differences in measures were performed. However a crude comparison was made by simply looking at the data and comparing the numbers, so more general implications of the need for a seated posture for subjects who are older or physically impaired are discussed later.

Figure 3: Body model generated by the scanner software, showing missing data for this participant, including the top of the head and 'gaps' in feet and hands.

3. Results

3.1 Comparison of traditional data and scanner data

The data from the standing scans were entered into SPSS software for statistical comparison. Paired comparison t-tests were used to compare the data collected for each body dimension that yielded comparable data from the scanner. Of the 26 dimensions measured using traditional

anthropometry methods (Table 1), it was only possible to extract data from the 'standing' scans for 7 dimensions, and for the 'seated' scans for 8 dimensions. It was not possible to obtain scan data for: thigh depth (standing), knee to hip, ankle to knee, ankle height, hip to shoulder, chest height, upper arm length, elbow to shoulder, wrist to elbow, hand length, hand grip length, eye to top of head. When the statistical analysis was conducted, it was found that of the 7 'standing' dimensions, 2 were found to be comparable to that obtained using the scanner with no significant difference between the measures. Table 3 shows the body dimensions for which there was no significant difference between data collected using the two methods (top half of the table) and those where there was a significant difference found between the two data sets (bottom half of the table).

	T	df	Sig. (2-tailed)
No significant difference found			
Abdominal depth (standing)	-0.084	42	0.934
Shoulder breadth	0.347	43	0.731
Significant difference found			
Stature	14.529	42	0.000
Arm length	53.909	38	0.000
Foot length	3.168	39	0.003
Chest depth	2.280	42	0.028
Head height	4.771	41	0.000

Table 3: Body dimensions with no significant difference / significant difference between data collection methods.

Due to the low sample size statistical analysis of the 'seated' scan data was not possible. However, BS EN ISO 20685 (2005) details the maximum allowable difference between extracted values and traditionally measured values. Table 4 shows the mean allowable difference between measurements obtained using the 3D body scanner and traditional anthropometry measures (according to BS EN ISO 20685, 2005), compared to the observed mean differences in this study between measures extracted from the scanned data and traditional methods. It can be seen that, from the 'seated' scans, the difference between observed and allowable mean difference for arm length and buttock knee length was only 2mm. For the other 'seated' scan dimensions extracted the observed mean difference was considerably larger than the allowable mean difference. For the

'standing' scans the observed mean difference was less than that allowed for abdominal depth and shoulder breadth, as would be expected given the statistical analyses of these data that showed these measurements showed no significant difference (Table 3).

	Max mean allowable difference (mm) BS EN ISO 20685:2005	Observed mean difference (mm)
Extracted from 'standing' scan		
Arm length	5	197
Height of head from floor	4	62
Shoulder breadth	4	1.7
Hip breadth	4	15
Abdominal depth – standing	5	0.32
Chest depth	5	45
Foot length	2	10
Extracted from 'seated' scan		
Arm length	5	7
Buttock knee length	5	7
Sitting height	4	18
Sitting shoulder height	4	16
Knee height	4	20
Hip breadth	4	37
Abdominal depth – sitting	5	21
Thigh depth – sitting	5	28

Table 4: maximum allowable mean difference (in mm) between 3D body scanner dimensions and traditionally-measured dimensions (BS EN ISO 20685:2005) compared to measured mean difference between methods in this study.

3.2 Issues arising with scanner usage

3.2.1 General issues

The equipment is large, measuring approximately 3m by 3m (consisting of scanner and changing area), requiring a reasonable size of room for set-up, and the location needs to be accessible, with accessible toilets nearby. Due to the participants being asked to undress, there is an issue with the warmth of the room, and privacy is of the utmost importance. Even though participants are inside

the changing area or scanner cubicle throughout, it was still deemed important to emphasise that the room was not overlooked, windows could not be seen through by passers-by, and that the door was locked to avoid people walking in without warning. Due to the size of the equipment, it is a requirement that participants have to be able to come to the laboratory, unlike data collection using traditional, more portable methods. The scanner *is* portable, but needs approximately half a day to set it up. Scanning is actually very fast, roughly 8 seconds for the scan to be completed, although participants obviously need additional time for getting undressed and redressed. The scanner does not cope well with contrast or reflections, so participants are required to wear close-fitting and/or minimal clothing (for accuracy of measurements), in a colour neutral to their skin tone. As an example, men in underpants alone and women in brassiere and knickers, with colours for white Caucasians being white, beige, cream, and pastel shades. Few participants had darker skin tones, those that did were able to wear brighter/darker colours, such as orange, and even black on occasion. The scanner cubicle itself is dark, so that the only light source is the scanning beam, but some participants found this to be claustrophobic and opted not to be scanned.

The scanner required calibration on a daily basis whenever it was being used. Environmental changes such as changes in room temperature were enough to require re-calibration. In itself this was not a problem, as the process is relatively quick, but it was required that the calibration process be integrated into the daily routine of the experimenters. Two scan postures were obtained, one with the participants standing, and the second with participants seated, as described earlier. For the seated posture a 'stealth stool' (one that was fully covered in a black cloth) was required due to the issues with contrast and reflectance, and to avoid the stool itself being scanned and recorded as being an attachment of the person sitting on it. The seated scan extraction software is very sensitive to the left thigh being parallel to the floor, which did cause some problems within the range of adjustability of the stool and the length of leg of the person being scanned. Some participants were unable to be scanned due to reasons such as incorrect colour of underwear being worn, being uncomfortable with getting undressed, and finding the scanning cubicle 'claustrophobic' when they viewed it.

3.2.2 Issues when involving older and/or physically impaired people

The length of time taken to get changed before and after the scans could be significantly increased for less able participants. Also some participants required physical assistance in this matter, which needed to be provided by someone they brought with them, as for ethical reasons the experimenters could not get involved with helping participants get undressed and redressed. The size of the changing area could cause restrictions for those who require more space to get changed (and the more recent version of this scanner (TC² NX 16) has an even smaller footprint, which could exacerbate the problem), especially if the subject is in a wheelchair or requires another person to be present and assisting at the same time. Some participants refused simply due to not wishing to get undressed in such circumstances. Some participants were not able to achieve the standard posture required within the scanner. Whilst this is tolerated within certain limits (which have not been fully explored at this point), and a scan will still be produced of the person, beyond these limits the scanner does not recognise the human form and it is not possible to extract data from those scans. Participants in wheelchairs were impossible to scan unless they could transfer to the 'stealth stool', due to problems with the reflectance of metal parts of their own wheelchairs, and issues such as the arm rest and back rest obstructing the scanning beam.

4. Discussion

Significant differences were found between the measurements obtained using the two methods for many of the anthropometry measures taken. The dimensions that did not result in significant differences, indicating close similarity between the measures obtained using the two methods, were those that use the more easily-identifiable bony landmarks (e.g. floor to top of knee, sitting height, sitting shoulder height, buttock-knee length). The measurement of stature using the two methods was found to be significantly different due to the different posture adopted, and to the scanner missing the top of the head (even in bald participants, so the suggested use of skull caps would not improve this), and is the same when considering head height. A similar effect with the ends of extremities, such as hands and feet is also likely to explain the significant difference found between

measures of arm length and foot length (see Figure 3). It may be that the use of markers on bony landmarks could increase accuracy, as found with other body scanners (Daanen et al, 1998). Measures such as chest depth and thigh depth (sitting) may be affected by the 'fleshy' nature of the part being scanned and the lack of obvious landmarks for measuring, which may mean that the point of measurement was different in the scanned data extraction to that used by the experimenter using the traditional measurement techniques, which could explain the significant difference between the methods seen. Also, when measuring fleshy body parts it is likely that compression will occur when using traditional methods that will not apply to the scanned measurements (McKinnon & Istook, 2001).

From the specification of the accuracy and repeatability of the scanning system the scanning procedure is theoretically capable of yielding accurate results, however the current measurement extraction software is not adequately geared towards the needs of the ergonomist or human factors specialist looking to obtain traditional measures. This limitation has been addressed to a degree with the introduction of the 'seated' scan software, which does provide more classic anthropometric measures, and is an issue that TC² could address in the future. The lack of experience of the experimenters with the use of scanners for collecting anthropometry could also have played a role in the results obtained, which is harder to quantify. However, what is clear, is that using the TC² NX12 scanner for the collection of anthropometry is not as straight forward as it may appear, as reported by Zwane et al (2010) and McKinnon and Istook (2001).

The scanner is already being used for mass data collection, for example during SizeUK (SizeUK, 2010) and Shape GB (Shape GB, 2010) projects. During these projects the known limitations with capturing stature, and measures involving extremities were mitigated by taking additional manual measures of these areas (SizeUK, 2010). In addition, scans were only taken from people who could stand and so did not include wheelchair users or other people with physical impairments that could not adopt the appropriate postures. This potentially skews the data to the able-bodied population which will then almost certainly be used as 'population' data in the future where such

subtleties are likely to be lost. When designing products for the mass market, including people who are older and/or physically impaired, following a 'design for all' philosophy, can increase the market for the product or system being designed. Regardless of the issues, the use of scanning technology as opposed to traditional methods is considered to be significantly quicker and more reliable for these types of large scale data collection projects. Investigating the potential for scanning less able people could lead to the development of tools and methods that do allow scanning of large numbers of older and/or physically impaired people, allowing population data to be more truly representative.

A further significant benefit of collecting data via the body scanner is the possibility to re-process the scan data and extract other measures after the event. This enables further dimensions to be taken without needing to rescan the participant, which has a distinct advantage over traditional anthropometry where getting further data requires revisiting the original participant which has obvious implications for time, availability, being able to contact them at all, and so on. This could be especially useful with less able participants who may be more at risk of fatigue during and due to trials and just getting to the scanner, getting undressed and dressed again, and may also experience fluctuations in their impairments resulting in them being unable to return for further trials if their condition worsens. Scanned images also allow the whole body to be seen and assessed, removing the problem of traditional anthropometry being seen to 'segment' people into univariate dimensions, which cannot then be related back to each other to create real, multivariate, individuals.

The trend therefore appears to be towards future anthropometric data sources being obtained using 3D scanning methods. What appears to have not been fully investigated is whether this approach holds any implications or problems for these future data sets. In particular there is a need to question our view of what anthropometry we need and evaluate whether the traditional measures are still the most appropriate measures to support the subsequent use of the data.

With regard to people who are in wheelchairs it would be interesting to know if the scanner software could, for example, be adapted to allow extraction of measurements from someone sitting in a 'recognised' wheelchair, or whether measurements obtained from a scanned image which is (for example) a person-plus-wheelchair image could still be extracted and useful for design purposes. It is also possible that the software could be developed to be more tolerant of, for example, missing limbs or lack of data on one area of the body. Currently the software does not allow extraction of any data from a scanned image that is not recognised as a 'body model', even if data is present for part of the participant that has been scanned. This means that partial scans have to be discarded from any analysis or data extraction, when the data (even if incomplete) could still be useful. For those people with non-standard body sizes and shapes or unable to adopt standard measuring postures such data collection could be invaluable, and allow a database of anthropometry to be collated for use by design professionals, to increase consideration of 'design for all' more effectively. Traditional measures are open to inaccuracies in measurements due to incorrect location of markers, inter-rater reliability issues and repeatability, which scanned measurements should remove or reduce. Differences in measurements do not necessarily indicate that one is 'wrong', but that the methods of obtaining the measurement itself impact on the measurement obtained. With traditional methods there may be compression of the body tissues by the anthropometer or the experimenter when locating landmarks, whereas the scanner will collect dimensions without this risk of compression, but possibly in a different posture which again could impact on the similarity of the resulting measurement.

Further work, involving a greater number of participants being called back in to be scanned in the seated position is also required to verify the results that were obtained from only a small sample due to time constraints. At this stage it is not possible to compare the results of traditional anthropometry and the seated scan measures due to the small sample size of seated scans. It is also imperative that a 'stealth' seat suitable both for the scanner and less able participants be designed and investigated, as potentially the seated scan is more accessible for the less able participants, provided they are able to transfer or be transferred onto it and sit securely without the

chair interfering with the scanning process.

The results suggest that, for ergonomic purposes, more work is required before the 3D body scanner replaces the use of traditional methods in collecting anthropometry, especially when collecting data from less able participants or those unable to adopt current standard postures. In terms of day-to-day use of this scanner with less able participants, there are a number of issues that are potentially harder to resolve, especially those surrounding space required for getting changed with assistance and transferring to and from wheelchairs. For people who are unable (or unwilling) to get undressed, it is possible that the use of markers could improve the accuracy of measurements obtained using the scanner when the participant is clothed. The TC² scanner does not currently have the facility to use markers on the body.

Traditional anthropometry has always been a compromise, using bony or other easily identifiable landmarks to make measurement more accurate and repeatable. However, these measures are not always the most functional or applicable measures especially with the increasing use of human modelling software. The body scanner provides the potential to capture data not constrained so rigidly to traditional landmarks, providing flexibility in the data captured to meet the needs of the end user, and the ability to capture a full 3D image of the individual body. Ultimately this suggests the need for a rethink of which body dimensions are actually needed, with the current postures possibly being updated or replaced. Further work is needed with this particular scanner to determine solutions for the problems encountered and to allow comparison of different groups, for example younger and older individuals, as well as able and less able people. With willing, able-bodied participants, and further software development for the extraction of required measurements, the scanner could become an invaluable tool. At the moment though, the issues and problems for less able participants remain a significant limitation.

5. Conclusions

There is clearly potential in the use of body scan data in modern computer-aided design

applications that can make use of the flesh measures available in the body scanner in addition to 'link' lengths through the identification of joint centres. Discussion is needed with design and other professionals to discover which anthropometric measures are most sought and if there are any 'missing' which would be more useful in real world applications of anthropometric data. An important part of these discussions would be to understand the use of the data. Through an understanding of its use, it would then be possible to evaluate the data required and subsequently develop a more appropriate methodology for data collection. For example, data are increasingly collected in 'functional' postures such as grip reach. Grip reach provides the length of the arm to the centre of a grasping fist. This is a much more 'applicable' measure than the arm length to the fingertip of an outstretched hand, as for any given application how far someone can reach to grasp an object is much more useful than the maximum length of their arms. However, with any data collection process the number of measures collected will be finite. Thus there will only ever be a limited number of data that can be used by practitioners. Given the potentially infinite number of data required for an infinite number of tasks to be evaluated or products to be designed there will always be a shortfall in what is available. It is likely that the current standardised measures could be supplemented with new measures (and associated postures) relevant to users' needs. However, there is unlikely to be a universal list of measures that will be applicable in all situations and so further research is required to address these issues.

In conclusion, this work has given an insight into the issues arising from the use of the TC² body scanner for obtaining anthropometry data from participants, especially older and disabled people. This was very much a pilot study in terms of using this scanner to collect data from older and disabled people and to investigate the issues arising from that. Due to the complexity of the data obtained using these systems there is a need for further work to investigate which dimensions are most useful to design professionals and others who use such data, and whether the scanner is best suited for collecting those dimensions or whether traditional measures are still preferable, especially when considering a 'non-standard' sample. At present it is clear that the TC² 3D body scanning system alone is insufficient, being incapable of fully capturing data from the extremities of the

human body. In addition there are more manageable issues to do with contrast of clothing worn, hair and the posture needed to be adopted. There is also a clear need for further investigation into making body scanners more accessible to less able participants, with consideration being required into making wheelchairs that can be used within the scanner, how to deal with space issues for people requiring assistance with undressing/dressing, and related issues that have arisen through trying to collect scanned anthropometry data from people with non-standard postures.

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Figure 1



Figure 2



Figure 3

