ANTHROPOMETRY OF USERS OF WHEELED MOBILITY AIDS: A CRITICAL REVIEW OF RECENT WORK

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An understanding of individual and population anthropometry is key to successful universal design. It is not enough to understand the capabilities of a group of people – the designer must also understand the body size and shape characteristics of the people who possess those capabilities. In the 1990s, the U.S. Access Board, realizing the importance of anthropometry in the design process, sponsored a review of the then-current state of the art. The goal was to "to assimilate the information gathered in Task I [an annotated bibliography], to identify further anthropometric research needed to update guidelines and standards for accessible design, and to recommend the means of carrying out such studies" (Bradtmiller and Annis, 1997).

At that time, we recommended some near-term research strategies, which included:

- Determining the target population
- Establishing sampling strategies
- Standardizing measurement procedures

As longer term strategies, we recommended investigating the use of 3-D body imaging (scanning) for the collection of data, and the use of digital human models in the design process.

Since that time, some studies have been undertaken to collect anthropometric data on persons with disabilities, specifically on the sub-population that uses wheeled mobility aids. This brief review discusses a few of those studies and how they may fit into larger research efforts. I also review the transition of anthropometric data from research findings into standards and design guidelines.

Determining the Target Population

There seems to have been little debate on who outght to be the target population for design. Despite this lack of discussion, anthropometric studies suggest the consensus has settled on those who use wheeled mobility devices. [The studies reviewed here are all based on users of wheeled mobility aids.] This makes sense from a design point of view – the person and the chair together are much different, anthropometrically, than a person alone, or a person with a cane. Because they are so different, they represent a significant design challenge. By designing to accommodate persons in wheelchairs or scooters, it may be the case that other classes of persons with disabilities will be accommodated as well.

One question to be addressed is, "Should children be included in the population to which we design?" Stait and coworkers (2000) included children in their sample. They did not analyze the children separately, although they provide an appendix consisting of data excluding children. Naturally, these smaller persons will have the effect of lowering the values of the summary statistics describing the sample. Clearly children need to be accommodated in design. But, in the absence of a focused debate on who the target design includes, it will be difficult to compare studies if some include children and some do not.

Even if priorities are clear, sometimes research reports do not make clear who is targeted. A set of design guidelines for automated teller machines (ATM) produced by the Centre for Accessible Environments (1999) speaks of accommodating 80 – 90% of the user population. It is not clear whether this means 80 – 90% of all users, or 80 – 90% of people with disabilities. Since people with disabilities – especially if the discussion is limited to those using wheeled mobility devices – are a minority in the population, accommodating 80 – 90% of all users might effectively disaccommodate *most* people using wheeled mobility aids. Designing for one group or the other will obviously result in different designs.

Establishing Sampling Strategies

Since it is impossible to measure everyone in the target population, we use samples of a few people to represent the larger group. The more carefully a sample is drawn from the larger population, the more successfully it represents that population.

Sampling for anthropometric studies has historically been focused on age, race and sex, all of which are significant influencers of body size and shape. In military studies, sometimes sampling also includes type of occupation, or whether the person is an officer or an enlisted person. While these demographic characteristics continue to influence anthropometry in persons with disabilities, their influence is dwarfed by other considerations. It is these other considerations that should drive the sampling for these populations.

One approach, suggested by Kumar (1997), would be to segment the population by the medical or physical condition that necessitates wheelchair use. Thus one would seek proportional representation of people with arthritis, people with cerebral palsy and so on. This is clearly important, as these conditions can have dramatic effect on anthropometric characteristics. My reading of Ringaert (et al., 2001) and the work of KRW (1995) indicates that the characteristics of the mobility device itself are as important as the medical and physical condition of the user. Ringaert's thorough study on a small sample took measurements of chairs and scooters, as well as measurements of the persons using the chair or scooter. Table 1 is taken from Ringaert et al., 2001.

TABLE 1 Selected Dimensions of Wheelchairs and Scooters

(values in mm)

	Range of Power Chair Dimensions	Average of Power Chair Dimensions	Range of Scooter Dimensions	Average of Scooter Dimensions	Significant Difference
Seat Height (from floor)	420 – 650	527.71	520-630	572.33	*
Device Length	820 – 2030	1172.00	1050 – 1400	1254.67	*
Device Width	560 – 680	605.43	570 – 810	630.00	

Note the range of seat heights. This will dramatically affect someone's overhead and forward reach. Similarly, the range of device length is very large. The longest power chair is 2-1/2 times as long as the shortest one. When reach is measured from the plane of the back of the seat, as Ringaert did, the full variation is not directly added to anthropometric variation, but at least half of it is. The ranges are smaller but sill dramatic in scooters. And, it should be noted that Ringaert's was a Canadian study. It is possible that even greater variation is found in the U.S., which presumably has a larger market, and may experience a greater number of chair models from which to choose. If a study was biased in terms of the frequency of chair or scooter brand and type, the anthropometric results would be similarly biased.

Indeed Ringaert acknowledges that their study may be biased (with respect to Canada generally) because it takes place in Winnipeg, where the Manitoba Motorised Wheelchair Program and Manitoba Health favor one particular type of chair for which those organizations have negotiated a favorable price.

The Ringaert team made a valiant attempt to get market share information from manufacturers and distributors of wheeled mobility aids in order to create a sound sampling strategy, or to at least allow them to assess their results. Unfortunately, this did not produce very helpful results. Kaye and others (Kaye et al., 2000) analyzed the results of the National Health Interview Survey (U.S.) and have good, solid, information on the relative frequencies of wheelchairs, manual or electric, and scooters. While that is a good start, the other piece of critical information for developing a sound sampling strategy is the frequencies of the specific models used.

It is certainly understandable that, for business reasons, companies want to keep sales information private. However, it seriously hampers the successful conduct of this important research. Perhaps this is an area where the government can be persuasive, or act as a non-commercial repository for this information.

The excellent study by Stait (et al., 2000) used a serendipitous sampling plan by accessing visitors at a wheeled mobility show. The Mobility Roadshow, held every 2 years in the U.K., draws 25,000 visitors during the 3-day event. The researchers used a photographic method which was very quick, enabling them at access over 900 people in the three days. Some 745 people provided useful data and were included in the final data set.

Having such a large sample reduces the need for targeted sampling, since significant variability is likely to be found in such great numbers. There was a potential sampling bias in that the Mobility Roadshow is “predominately concerned with personal motorized transport”. Persons who do not use, or have no interest in, a motorized chair might not have attended such a show. There is no way of knowing whether those using motorized devices are anthropometrically different from those using manual chairs, so it is not possible to measure the influence this bias might have on the resulting anthropometric statistics.

Stait provides statistics on the type of chair, as well as various demographics on the user population which might be compared with those reported in Kaye (et al., 2000).

However, the demographics were done by observation (age, sex), rather than by inquiry. Comparing their data to a 1991 study in the U.K., provides useful information on the change in chair type frequency over the 8 years between the studies. There were some differences by demographic group in the type of chair use. This underscores the importance of obtaining accurate and up-to-date data on the specific chairs and scooters being used.

Standardizing Measurement Procedures

One of the most difficult tasks in an anthropometric study is determining how measurements should be done. This is particularly difficult when the population is as varied as the group of people with disabilities. One of our recommendations had been to include measurements of the person and the chair as a unit. We felt that this had more applicability to the design problem than measurements of persons alone.

Stait and colleagues (2000), reported just such data. The Stait study collected just a few anthropometric dimensions (all including the chair) – sitting height, weight, knee height, shoulder width and ankle height. Since they used a photographic technique, presumably other dimensions might be collected later. They grouped results by chair type (including electric scooter as one of 5 types), recognizing the important contribution of the chair to the total chair/user package.

The photographic method probably has some drawbacks in accuracy, but using this approach the researchers were able to gather information on a vast number of subjects (745) in three days, so the large sample size might compensate for any loss of accuracy.

The Ringaert study (Ringaert et al., 2001) used traditional means to measure a much larger series of measurements on the envelope of the chair/scooter and the user. They measured:

- Eye height
- Lap height
- Seat height
- Armrest height
- Handle height (power chairs)
- Overall length
- Overall width
- Forward reach with bending
- Side reach with bending
- Forward reach without bending
- Side reach without bending

The techniques they used were taken from the KRW (1995) study, for chair/scooter dimensions, a Canadian Standards document (CSA B651-95, Appendix B), and some that they modified from the standards document for use here. Unfortunately measurement techniques are only offered where they differ from the earlier standards document. It would have been useful to have all the techniques described together in the reporting document.

The ATM guideline document (Centre for Accessible Environments, 1999) makes reference to a study of “300 disabled people” on whom the standards are based. There is no description of measurement techniques, or even a list of dimensions, although they provide the design guidelines in terms of a series of reach envelopes and ranges of vision. One might assume that they had measured these reaches and vision envelopes on their 300 subjects, but that is not clearly stated.

It appears unlikely that funding for a major anthropometric survey of persons with disabilities, or even just wheeled mobility aid users, is going to be immediately available. So, researchers will need to continue to put together the results from smaller studies done around the U.S. and around the world. In order for users to understand and properly use the resulting data, it is critical that clear documentation of measurement techniques, preferably with photographs or drawings, accompany the resulting summary statistics. Without such documentation, it will be impossible to combine knowledge from different research centers.

Transitioning Anthropometric Data from Research into Standards and Guidelines

Before anthropometric data are placed in standards, they must be analyzed. Most of the time, simple summary statistics will suffice. These include, mean, standard deviation, and a variety of percentile values. In one of the reviewed studies (Ringaert et al, 2001), there was an assumption that the 5^{th} percentile to the 95^{th} percentile of a given dimension should be accommodated. This assumption will be discussed in more detail below. However, the authors did not calculate the 5th and 95th percentiles directly from the data, by ranking observations and then identifying cutoff points. Instead, they estimated the percentiles by taking the mean value and adding/subtracting 2 times the standard deviation. This approach generally works well with anthropometric dimensions when the populations are large, and the distributions are normally distributed. However, we may reasonably suppose that dimensions in this population might not be normally distributed. Indeed, their table 4.6.1, shows that for forward reach (low) with bending, the estimated 95th percentile is actually larger than the maximum for the sample. This indicates that the dimension is not normally distributed. Without the raw data, it is not possible to tell how many other dimensions have non-normal distributions, but it would not be surprising if this were a common problem. When percentiles are used, they should be calculated directly from the raw data, and not estimated from the mean and standard deviation.

The second issue in standardization is what percentage of the population should be included in the standard. Traditionally, it has been assumed that, because of the bell shape of the normal distribution, accommodating individuals at the tails of the distribution requires much more design adjustability, and so is more expensive, than accommodating people closer to the center of the distribution. Usually the anthropometric extremes have been left out of design for these presumed cost savings. In many products and workspaces, a common goal is to accommodate 90% of the general population. Designers often use a design range created by selecting, for a given dimension, the 5th percentile value from the female distribution and the 95th percentile from the male distribution. When males and females use the product/workspace in equal proportion, and when there is only 1 dimension that is critical, this approach can work well. However, there is nothing sacred about that 90%. It has become the traditional target in non-life-endangering design, but in most cases is not legislated as a requirement.

Of course universal design generally does not accept the premise that only the central 90% should be accommodated. Nevertheless, until universal design is a reality, it seems likely that some compromises will be made. This raises the issue, then, about which anthropometric values should be used in design. That is a question for policy-makers, surely, but the scientific question has to do with whether the 95th percentile of our sample of perhaps 50 individuals really represents the 95th percentile of the total population. It may be the case that if we have not sampled the population accurately, that the 95th percentile of the sample is really only the 92nd or the 90th or some other percentile, since the anthropometrically extreme individuals found it perhaps too difficult to come to the measuring facility. One could make the case that so little is known about the anthropometric variation in the population of those who use wheeled mobility aids, that we should design to *all* the variability in our sample, hoping that we have captured 90% of the variation in the true population.

As noted above, the Centre for Accessible Environments (1999) produced guidelines for ATM machines. The design problem with a wall-mounted ATM machine is to make it low enough that a seated user can reach and see it, while making it high enough that an ambulatory person can reach and see it. Their appendix has graphs showing reach contours presumably associated with certain portions of the population (expressed as percents). In the case of the contours they indicate which population they are referring to. They do this for two viewing angles of persons with 95%ile stature. However, it is not clear whether the stature (appears to be about 1820 mm) is the 95^{th} percentile of the general population, or 95^{th} percentile of ambulatory disabled population. We will assume it is of the general population.

When the authors move to discussions of persons seated in the chair, they talk about 5^{th} percentile stature. It is not clear here whether they really mean stature, which is not especially relevant for the seated condition, or whether they really mean sitting height, measured from the chair seat, or whether they mean the height from the ground to the top of head. It is especially a problem that no measurement techniques are given, since there are a number of ways to measure reach, and they all give different answers.

In trying to use the design guidelines, I started first with the two standing figures. The overlap of reach and vision for the two illustrations (lowest viewing angle, and highest viewing angle) is at about 300 mm from the toes, and about 1000 mm in height. Applying this point to the wheel chair occupants (these are based on their sample of 300, I believe), assuming a knee cutout (which most ATMs do not have, at least in the U.S.), there is no overlap between the standing and seated positions. With a cutout, about 10% of the seated persons could reach, with the comfortable reach. With an extended reach, about 30% of the seated people can reach, assuming a knee cutout. Without the cutout, no one can reach.

With a sideways approach and sideways reach, about 30% can reach comfortably, and about 80% can reach with the extended reach. The final figure in the series is a person without disabilities. At the 300 mm, and 1000 mm height, only about 20% could reach, but there is no reason that ambulatory persons could not move closer.

Since there is essentially no overlap between the successful range for ambulatory persons and persons in wheelchairs, this shows, presumably the difficulty of designing for the whole population. But since there is no real solution for 80 – 90% of persons, it is interesting that the authors do not simply state this. It all assumes that the reach measurements are useful and can be applied to the problem at hand. Instead, the only solution based on the values given is to install separate ATMs for seated and standing persons. Indeed the specific values recommended for placement of ATMs will accommodate only those using wheeled mobility devices. Nearly all ambulatory persons would be disaccommodated.

The difficulty of using the data displays in this document serves as an illustration of why anthropometric data and reports should be separate from standards documents. The standards document should show the decision process, including what section of the population is to be accommodated, and provide a method of how to go from anthropometric data to a standard, and then to a design. The anthropometric data should be independent. When new (or better) data are available, the design can be updated without updating the standard. It also would serve to help make clear the distinction between science and policy.

Conclusion

A number of anthropometric studies on people with disabilities, especially wheelchair users, have been conducted in the last half-dozen years since our earlier review. They provide interesting data from a number of places in North America and the U.K. These studies have sometimes been used to create new standards, and sometimes their data were compared to existing standards. In both cases, they underscore the importance of a clear understanding of who is included in the target population, a clear method for sampling that population, and a clear description of what anthropometric characteristics are measured and how the data are collected. When new standards are created, the standards process should include a discussion of the method used to create the standard from the anthropometric data, while the data sources themselves should remain separate from the standards so they can be easily updated.

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