Preliminary validation of a tool for visualizing anthropometric data

Christopher J. Garneau *† and Matthew B. Parkinson ‡

† Department of Mechanical and Nuclear Engineering, Penn State University

‡ Assistant Professor of Mechanical Engineering, Industrial Engineering, and Engineering Design, Penn State University

Abstract

Accurate representations of anthropometry are necessary for effective digital human models. It has been known for decades that inappropriate application of univariate anthropometric data to multivariate problems yields suboptimal design performance. However, traditional design tools including textbooks and univariate data tables do not foster an understanding about appropriate means for solving multivariate problems. On the other hand, quantitative design tools that permit visualization of large anthropometry datasets are better suited for exploring more complicated problems with multiple dimensions. One such tool—a dynamic web interface—is investigated in the present research and its performance is compared with an existing technique—univariate tables—for incorporating anthropometric data into design. This paper presents preliminary research for developing intuitive tools that enable designers to properly solve multivariate problems.

A web-based pilot study involving 40 participants from Penn State University and the Army Research Lab at Aberdeen Proving Ground was devised to evaluate an interactive web interface for working with anthropometric data. A within-subjects study was designed to assess each the ability of participants (i.e., designers) to correctly identify the range in anthropometry necessary to achieve a specified accommodation level in a timely fashion. Self-rated subjective measures of performance were also obtained. The performance of the participant using the web tool was compared with their performance using a similar tabular tool, wherein percentiles of the requested anthropometric dimensions were supplied. For both tools, the US Army's ANSUR data were used, but any large anthropometric database composed of a variety of measures could be substituted without affecting the methodology or findings.

The results of the pilot study show that responses exhibited better accuracy and estimates of population accommodation using the web tool compared with the tables. Subjective measures of performance indicate that participants judged the results of the web tool to be more likely to influence non-expert decision makers, better aid their understanding of the characteristics of accommodated data, and provide more compelling evidence for decision-making, compared with the tables.

Keywords: Anthropometry, visualization tools, decision making

1. Introduction

The foundation for any effective digital human modeling (DHM) technique is an accurate representation of the *anthropometry* of the user population under consideration. Many techniques for specifying the anthropometry within a model are possible, including *proportionality constants* to scale detailed anthropometry (Drillis and Contini 1966) with a readily available population statistic (i.e., stature), a *detailed representative database* (e.g., ANSUR, Gordon, et al. 1989), or a combination of the two wherein *regression models* or *principal components analysis* are used to predict detailed measures from known anthropometry (Parkinson and Reed 2009). These techniques for generating relevant anthropometry may then be utilized in assessments of *accommodation*, wherein representative users (i.e.,

*Corresponding author. Email: cjgarneau@psu.edu

sets of anthropometry) are determined to experience either adequate or inadequate fit and/or comfort. The goal of an accommodation assessment is usually to specify a boundary of design dimensions to meet some target level of accommodation for a broad population of users (Roe 1993), often expressed as a percentage.

While user preference (Garneau and Parkinson 2009) and designer discretion impact design performance, there is a strong link between the representativeness of the anthropometry used in a given model and the ability of that model to assess accommodation of broad populations. However, designers often may not fully understand this connection, or the assumptions upon which a given DHM is built. Tools traditionally used to teach engineers and designers about anthropometry, such as univariate tables (Chaffin 1999) or paper templates (Tilley 2002), may contribute to uncertainty over appropriate assumptions regarding anthropometry. Dynamic tools that permit designers to better visualize anthropometry, understand relationships between anthropometric measures, and more clearly relate anthropometry to accommodation are proposed to alleviate impediments designers face when dealing with users' body dimensions in design.

The potential benefit of new tools is particularly pronounced in multivariate problems, for which the misapplication of univariate anthropometric data may yield appreciably lower estimates of accommodation than intended (Moroney and Smith 1972; Lockett, et al. 2005). This misapplication of the data results in inadequate user fit that diminishes aggregate comfort and safety due to lower levels of population accommodation. Due to improper training in the application of appropriate, robust methods for designing for human variability, such nonoptimal solutions are commonplace. For instance, univariate methods are misapplied in recent literature—workstation design in (Das 1996) and tractor seat design in (Mehta 2008).

A chief aim of the authors' research is to investigate the qualities of interactive tools for exploring anthropometric data that will encourage effective design for all classes of designers, from students to industrial ergonomists at large corporations. Such tools are to foster commonsense solution of customarily abstract design problems involving anthropometry and other forms of human variability. The outcome of the research may be used to guide digital manikin selection in subsequent design activities.

The current work describes preliminary efforts in evaluating dynamic tools for making design decisions involving user anthropometry. The pilot study described herein presents two types of design tools for investigating anthropometry—a static univariate tabular representation and a dynamic multivariate web-based representation. The intent is to assess the ability of designers to understand user accommodation as a function of anthropometry and the suitability of different kinds of tools for making decisions about accommodation. Specifically, effectiveness, efficiency, and satisfaction are measured for each type of tool.

The intended outcome of the study is to guide development of intuitive tools for making decisions when *designing for human variability*. Objective performance metrics indicate that estimates of accommodation improved with the interactive tool. Subjective performance metrics showed the results of the interactive tool to be more likely to influence non-expert decision makers, better aid their understanding of the characteristics of accommodated data, and provide more compelling evidence for decision-making, compared with the tables.

2. Materials and Methods

2.1. Study overview

To compare user performance with two kinds of design tools for investigating anthropometry, a within-subjects, web-based study was devised. Forty participants with varying experience using anthropometry for design solved two problems using two types of tools: (1) a traditional tool consisting of tables of percentile values for relevant anthropometry (i.e., 1st, 2nd, 5th, 10th, 25th, 50th, 75th, 90th, 95th, 98th, and 99th percentile values for each measure), and (2) the dynamic, web-based interface depicted in Figure 1. ANSUR data (Gordon, et al. 1989) were used to create both representations.

The web-based interface allows a user to pick anthropometric dimensions of interest from a list box, select desired ranges of data using sliders, and plot the data with color coding that indicates accommodation (accommodated points are blue and disaccommodated points are red). Percent accommodation on all measures is also indicated. A "symmetry" check box enables the option of ensuring symmetry of the selected range about the mean value for the dimension.

2.2. Experimental design

Each tool was used to solve each of two problems to facilitate direct comparison of the results, but with different numeric goals to avoid users simply copying answers. The first problem served as a practice problem to acquaint the user with the tools—it asked participants to calculate range in seated popliteal (knee) height and hip breadth necessary for 95% accommodation of the male population or 90% of the female population, depending on the tool. The second problem asked participants to calculate the range of shoulder widths and hip heights needed for 95% accommodation of the male population or 90% of the female population. Both problems and the requested design parameters for each are shown in Figures 2 and 3.

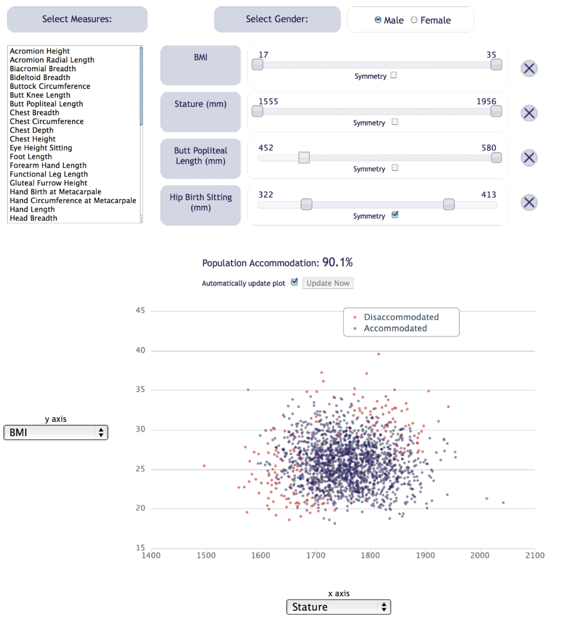

Figure 1: Interactive web interface used in the pilot study. The tool is available at *tools.dfhv.org/multivariate.php.*

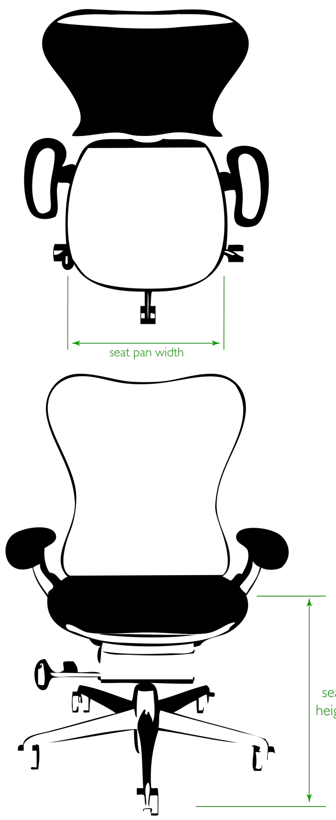

Figure 2: The first design problem. Associated anthropometry is seated popliteal (knee) height and hip breadth.

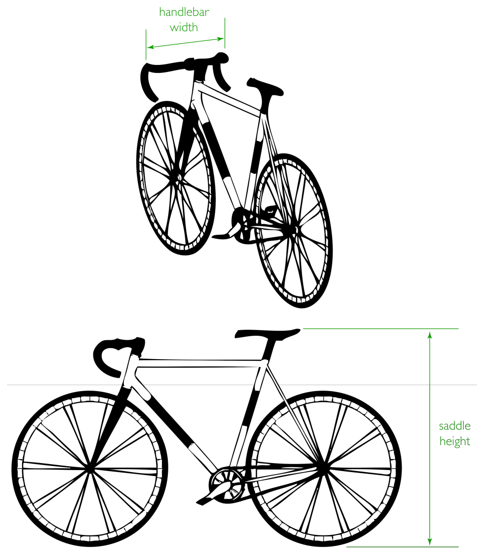

Figure 3: The second design problem. Associated anthropometry is hip height and biacromion breadth.

The participants were split into two groups—one group received the tables first and the other group received the web tool first—to avoid bias effects. Participants were drawn from two Penn State Industrial Engineering Courses (PSU-327 and PSU-547) and a small number of engineers from the Army Research Lab's Human Research and Engineering Directorate MANPRINT Methods and Analysis Branch (ARL). The study was approved by appropriately constituted internal review boards at both institutions. Note that the interface changed slightly as the study progressed—participants in the PSU-547 group received the interface shown whereas participants in the PSU-327 and ARL groups received an interface without the "symmetry" feature.

2.3. Performance metrics

Several measures were collected from participants, including background and demographic characteristics, their responses to the problems, the time required for completion of the problems, and a subjective assessment of the tools.

Simpson, et al. (2007) investigate response delay and training on user interfaces in engineering design and propose an evaluation scheme wherein *effectiveness* and *efficiency* are key metrics. These metrics are used in the present work, and subjective *satisfaction* is added as a third area of evaluation.

Effectiveness is expressed by determining the accuracy and accommodation percentage yielded by participants' responses. Accuracy is calculated by comparing participant answers (a and b) with a true answer predetermined by the experimenters (α and β), as in the following equation:

$$\text{accuracy} = 1 - \frac{1}{4}\left(\frac{|a_{\min} - \alpha_{\min}|}{\alpha_{\min}} + \frac{|a_{\max} - \alpha_{\max}|}{\alpha_{\max}} + \frac{|b_{\min} - \beta_{\min}|}{\beta_{\min}} + \frac{|b_{\max} - \beta_{\max}|}{\beta_{\max}} \right)$$

Accommodation is calculated by imposing the limits given by participant responses (*a* and *b*) on the set of anthropometry under investigation. If a particular anthropometric data point lies outside the limits given by *a* and *b*, that point is said to experience disaccommdoation. This is an application of the *virtual fit* methodology (Parkinson 2007).

Efficiency is evaluated by comparing time required to solve a problem with accuracy. In Section 3, efficiency is presented graphically by plotting the change in required time against change in the accuracy between the web tool and tables.

Satisfaction is evaluated by asking participants to judge their experiences with each tool. First, participants are asked to rate the confidence that they have correctly identified a correct result on a 10-point scale. Second, participants are asked to respond to the five questions featured in Figure 8 on a 5-point Likert scale.

3. Results

Figure 4 shows participant responses across the various groups for the web tool and tables for the second problem. Figure 5 evaluates efficiency for both problems. It compares accuracy and required time for the web tool versus the accuracy and required time for the tables. As such, positive values indicate that results from the web tool were more accurate or took longer to obtain than results for the tables. Figure 6 shows the change in accuracy between the second problem and the first problem. Positive values on the ordinate indicate greater accuracy for the second problem.

Figures 4 and 5 show that designers are better able to specify enough adjustability when using the web tool. The web tool generally increased participants' accuracy and estimates of accommodation, but required more time to solve the problem. Figure 5 shows an average increase in accuracy of about 5% and average increase in required time of about 100 sec for the web tool compared with the tables for the first problem; for the second problem, Figure 5 shows an average increase in accuracy of about 2% and average increase in required time of about 30 sec for the second problem. Figure 6 indicates that practice improves user performance—accuracy increased for almost all responses between the first and second problems.

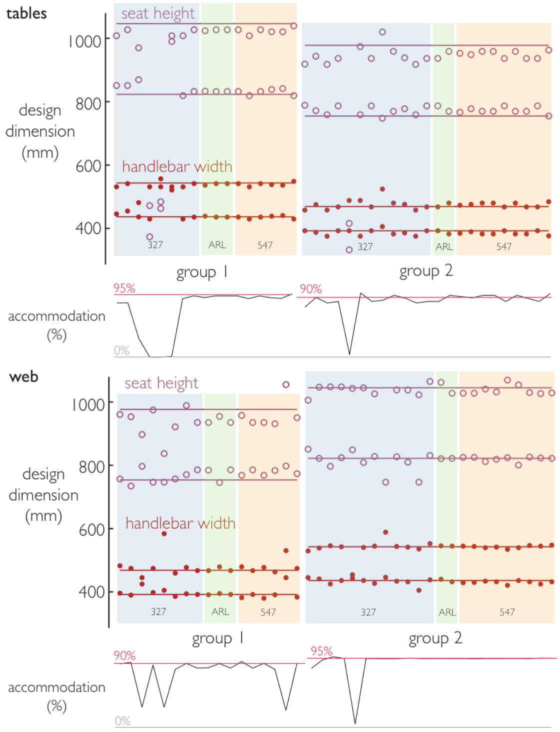

Figure 4: Participant responses for the tables (top) and web tool (bottom). Accommodation achieved by each response is indicted below the response.

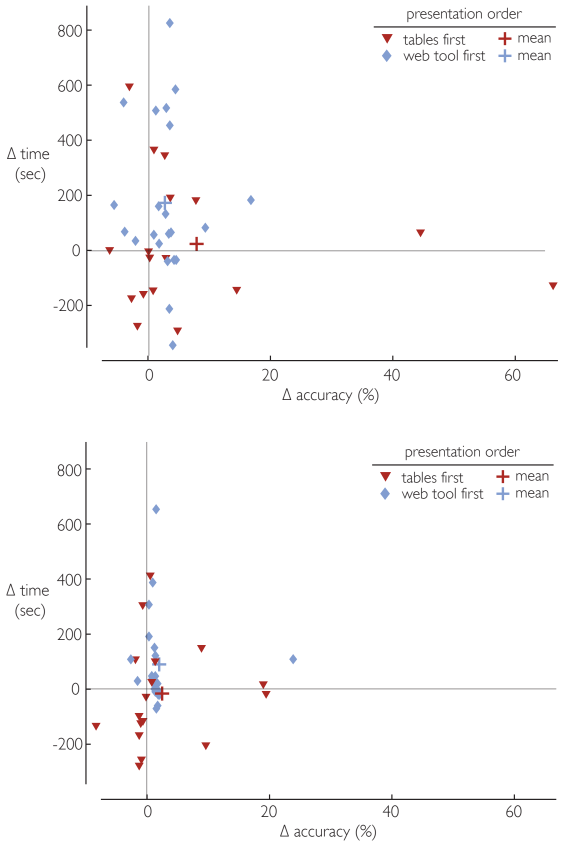

Figure 5: Change in accuracy and time between web tool and tables for problem 1 (top) and problem 2 (bottom).

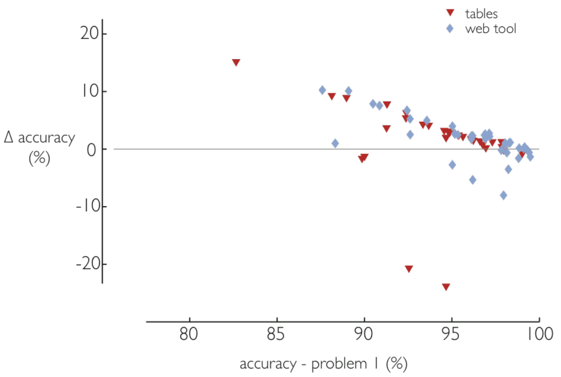

Figure 6: Change in accuracy between second and first problem for the web tool and tables. Positive values on the ordinate indicate better accuracy for problem 2.

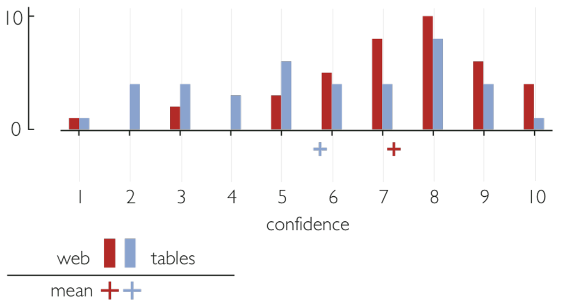

Figure 7: Subjective post-response assessment of confidence for both tools.

Figure 7 compares self-rated participant confidence on a 1-10 scale for the two tools. Figure 8 shows the distribution of responses for the five follow-up questions asked in the subjective portion of the assessment. The Wilcoxen Sign Test was applied to the subjective response data for each of the tools for both of the questions, and the results show that the differences for both were statistically significant to a confidence level of 99% for all but the first question.

Figure 7 shows participants to be significantly more confident in results produced by the web tool (mean 7.2/10) versus the tables (mean 5.8/10). Figure 8 is particularly promising—the results show that participants are more likely to view the web tool as easier to use and able to influence non-expert decision-makers, provide understanding about the problem and users accommodated by a design, and produce compelling evidence for decision-making.

4. Discussion

The results from the tables specify too little adjustability, indicated by Figure 4 (particularly for seat height). As mentioned in the Introduction, underaccommodation (i.e., too little adjustability) is to be expected when a univariate method, such as a table of anthropometry, is applied to a multivariate problem. This result has been proven for decades (i.e., Moroney and Smith 1972), but it is hypothesized that engineers today still are not aware of this limitation. While reported confidence was significantly higher for the web tool, 44% of participants reported a confidence in the results of the tables between 7 and 10, which would suggest a passable solution by convention.

Figure 8: Subjective post-response assessment of decision-making power for both tools.

In addition to the observations previously noted, this preliminary validation attempt yields an important result: participants in this study were more accurate and more confident using an interactive visualization tool than a traditional, static tabular tool. The second result is encouraging for further research; participants in this study performed better and were receptive to improved representations of anthropometry.

This first effort is fundamentally a pilot study—it is difficult to find conclusive evidence for specific recommendations due to drawbacks in both the data collection methods and content of the evaluation. Future iterations of the study will implement several improvements: (1) the data collection method will be improved by requiring participants to complete the study under observation in a controlled environment instead of allowing participants to complete it on the web anywhere, (2) an assessment of experience will be included to stratify results based on prior familiarity with the design task—experience will be determined based on answers to specific knowledge-based questions, and (3) accommodation will be used as the primary effectiveness metric—accommodation targets will be standardized at 95% to facilitate comparison. Further research will also investigate the practice effect apparent in Figure 6 to determine the extent to which improved responses are caused by experience with the tools.

The goal of further study is twofold—results will demonstrate the effectiveness of various representations of anthropometric data for making appropriate assumptions and design decisions, and results should recommend improvements or new representations for better understanding anthropometric data. The goal of the research is not to recommend a specific interface, such as the one depicted in Figure 1, but to establish features of tools or representations that are effective for making design decisions.

5. Conclusion

The results of the pilot study comparing two representations of anthropometric data show that responses exhibited better accuracy and estimates of population accommodation using the web tool compared with the tables. Subjective measures of performance indicate that participants judged the results of the web tool to be more likely to influence non-expert decision makers, better aid their understanding of the characteristics of accommodated data, and provide more compelling evidence for decision-making, compared with the tables.

The findings of the pilot study are encouraging for developing a more advanced framework for visualizing anthropometric data, understanding and making appropriate assumptions about data underlying digital human models, and making design decisions that result in accurate assessments of target population accommodation. The research described here augments findings in the area of Designing for Human Variability.

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