ICED13
INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

A COMPARISON OF DESIGN FOR HUMAN VARIABILITY STRATEGIES IN SEATING REQUIREMENTS OF ANTHROPOMETRICALLY DIVERSE POPULATIONS

Charlotte DEVRIES (1), Gregory ROACH (2), Matthew PARKINSON (1)
1: Pennsylvania State University, United States of America; 2: Brigham Young University - Idaho, United States of America

ABSTRACT
When considering the needs of global populations, variations in overall body size and shape create an interesting situation for designers: should products designed for global markets achieve accommodation through a single variant, or should multiple variants—each targeted at a different market—be considered? The present work demonstrates the range of variability that can be exhibited by three distinct populations (male civilians in India, Japan, and the United States) and the effect of different globalization strategies on design requirements. The work focuses on "fit" or spatial accommodation in seating, excluding comfort and other important aspects of seat design. Qualitative assessments of the strategies and how appropriate they might be for other Design for Human Variability (DfHV) problems are provided.

Keywords: inclusive design, user centred design, design for X, ergonomics, global populations

Contact:
Prof. Matt Parkinson
Pennsylvania State University
Engineering Design
University Park
16802
United States of America
parkinson@psu.edu

1 INTRODUCTION

Design for human variability is a *DfX* activity in which artifacts, tasks, and environments are designed to be robust to the variability of their users. This variability can include body size and shape, capability, preference, and other user attributes. Variations in overall body size and shape, when considering the needs of global populations, create an interesting situation for designers: should products designed for global markets achieve accommodation through a single variant, or should multiple variants—each targeted at a different market—be considered? The present work demonstrates the range of variability that can be exhibited by three distinct populations (male civilians in India, Japan, and the United States) and the effect of three globalization strategies on design requirements. Assessments of the strategies are also provided.

Seating is the example used throughout the present work. It is an illustrative example because it is common, relevant across a number of industries and cultures, and inherently multivariate. It is simple enough that it may tempt designers into using univariate design approaches, but complex in appropriate ways—demonstrating the hazards of simplifying a problem too much. It also rewards multivariate analyses due to the interaction of the design variables (e.g., width of seat, depth of seat). In other words, for most users, being disaccommodated on a seat that is too narrow, for example, should be penalized at a different rate than being disaccommodated on a seat that is too wide. Seating design is a complex task involving both quantitative (e.g., spatial fit) and qualitative (e.g., comfort) factors. Only spatial accommodation is considered here.

Due to differences in *anthropometry* (body size and shape), some users will be more likely to be accommodated by a design than others. The probability of accommodation may be affected by local demographics such as gender, race, or age (Annis, 1996; Cardoso, 2012), or, as in the context of this paper, global populations (Yang et al., 2007). If a design were to require users to be taller than a specified height in order to be accommodated, the taller population would be better accommodated than the shorter population. Although it may not be possible to have exactly the same accommodation level for two separate populations, it is important that the accommodation rates of each population are at a suitable level.

2 BACKGROUND

Background is provided for three principle areas: the design task at hand, multivariate analyses, and synthesizing data.

2.1 Design Task

This study is focused on seat design, a simple multivariate problem applicable for many safety and comfort requirements. Seats are common to a number of designed artifacts and environments including tractors, automobiles, airplanes, office environments, etc. Seating can also affect a number of safety and performance issues (Goossens, 2011; Mehta, 2008). There are also standards governing some industries, such as the Business and Institutional Furniture Manufacturers' Association (BIFMA). When standards are not available, proprietary and/or published recommendations are often used. For example, Mehta (2008) conducted an anthropometric survey of agricultural workers in India and made recommendations on tractor seat design based on the results. Manjrekar (2008) compared the effects of different market segments within the US on vehicle seat design requirements.

Seat design practice usually identifies a target user population (e.g., civilians in the United States) and some desired level of accommodation (e.g., 95%), the percentage of users able to interact with the design in the intended manner. Ideally, desired accommodation levels are high and the designer is unconstrained in design choices such that these high levels of accommodation are achieved. Unfortunately, constraints such as cost, manufacturability, and spatial requirements can limit design freedom and the universality of a design. For example, a very wide seat may be necessary for some members of the US civilian population, but the increased cost or limited space may make very wide seats impractical.

For the problem at hand, three seat design parameters were identified as critical: *seat pan width*, *seat pan depth*, and *seat height*. These correspond to the body dimensions *seated hip breadth*, *buttock-popliteal length*, and *popliteal height* (Figure 1). Individuals are considered spatially accommodated (i.e., they "fit") if their hip breadth is narrower than the seat width and buttock-popliteal length is greater than the seat depth. For fixed-height seats, the popliteal height must be taller than the seat height. For the present work, the seat is considered to be adjustable, so the popliteal height must be greater than the minimum seat height and less than the maximum. Although armrests are not shown in the figure, their presence or other material on the sides (e.g., consoles in a vehicle) are the typical maximum-width constraint. The seat pan width is a good indicator of those dimensions.

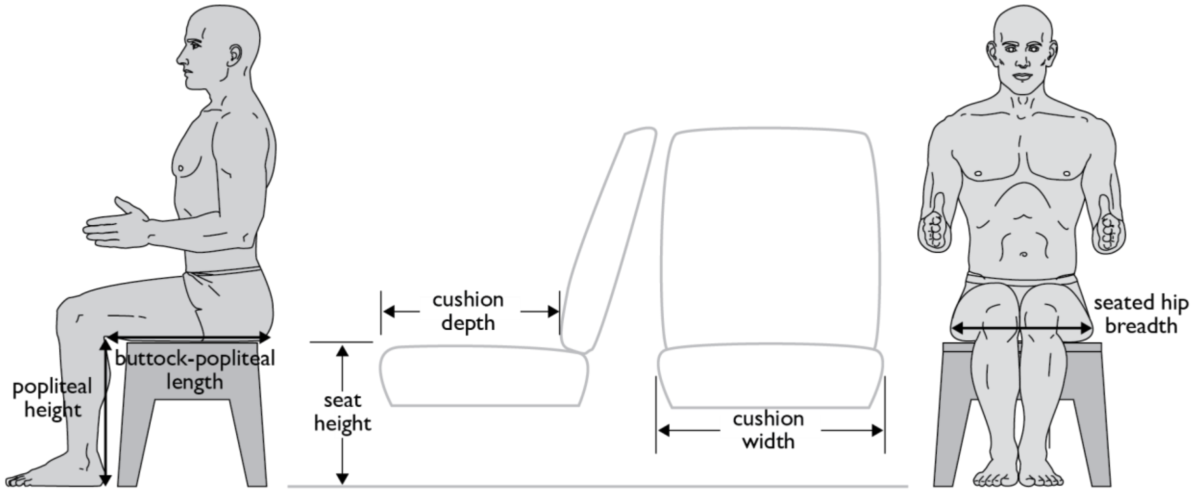

Figure 1 - The seat design parameters and their corresponding body dimensions.

The seat design problem has been simplified to one of “fit” for this presentation. When conducting a real seat design, important factors such as clearance margins, material compression, and user preference must be considered. Broader concerns related to cost, manufacturability, and market opportunities would also be part of the concept development and refinement.

2.2 Multivariate Analyses

A design’s success is influenced by the percentage of users that can interact with it safely and comfortably. The number of accommodated users can be increased through sizing and adjustability. Although these methods are effective, they can add to the cost of a design. Since accommodating 100% of users can be prohibitively expensive and even impossible, more realistic design targets (e.g., 90% or 95% of the target population) are usually used, and the design is created to minimize costs for that level. Designing around the correct anthropometry of the target population can increase the accommodation while limiting costs. Nadadur and Parkinson (2012) proposed a multivariate anthropometry synthesis method in order to design for global populations. By properly sizing designs for different populations, the materials are properly allocated, which minimizes waste.

In univariate design, the requirements for each design variable are assessed separately. When this one-at-a-time approach is utilized, accommodation levels are usually overestimated. For instance, if a design accommodates 90% of users on one metric, and 90% of users on another, the correlation between the two measurements would not be taken into account. There is an underlying assumption that the 10% of users disaccommodated on one metric are the same as the 10% on the other. While some body dimensions (e.g., shoulder height and stature) are strongly correlated, many are not (e.g., leg length and hip breadth). As a result the actual accommodation level in this example could be as low as 80%.

In a multivariate design approach, the measures are considered simultaneously. This requires that the relationships between the measures are known. Since these are typically not available in published tables, it is usually more helpful to have data representing each individual within a population of virtual users. Once a candidate design is specified, a virtual fit trial (VFT) is conducted to determine accommodation on each of the measures for each individual. The percentage of accommodated virtual users is the estimate of overall multivariate accommodation for the design.

2.3 Synthesizing Anthropometry

Obtaining accurate estimates of the body size and shape of a design’s target user population is critical to design for human variability. These anthropometric data provide quantitative guidance on the spatial optimization of the designed artifact.

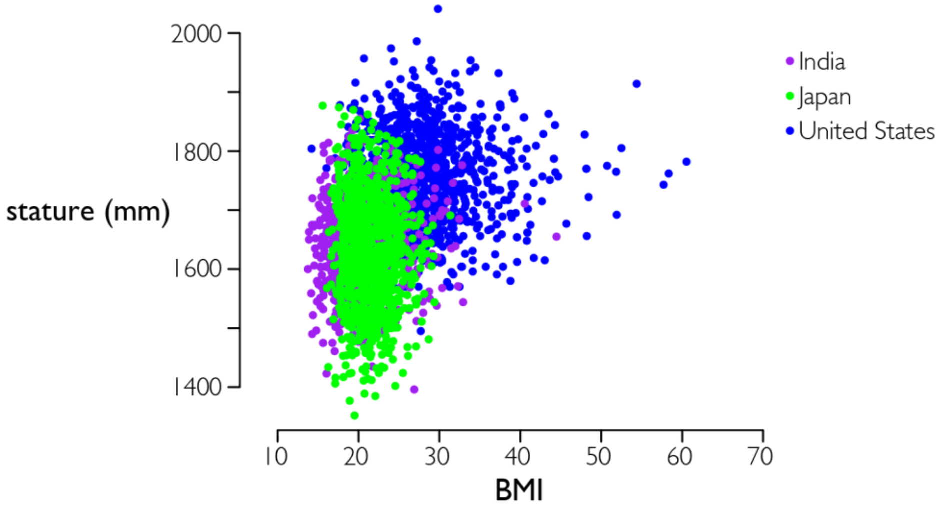

Figure 2 - The stature and body mass index (BMI, a measure of weight-for-stature) for the three virtual user populations considered in this paper.

This work considers three dissimilar populations: adult male civilians in India, Japan, and the United States. They were selected both for the interesting similarities and differences in anthropometry and because of their relevance to the automotive industry. Figure 2 shows the stature (height) and body mass index (BMI, a measure of weight-for-stature) for the three populations. These summary statistics demonstrate the large difference in overall body size and shape across the three target user populations. There are other differences within the populations, notably in the relative lengths of body segments—sometimes called "proportionality constants". A proportionality constant is the average ratio of one body measure with respect to another. For example, the average ratio of leg length to stature within the ANSUR US military population (Gordon et al., 1989) is 0.529. These constants are used to estimate body dimensions critical to design tasks. Since civilians in the US, India, and Japan have different racial and ethnic compositions, the ratios of measures within the populations are also different (Tilley et al., 2002). In other words, people in the US are not just scaled versions of individuals in India or Japan and vice versa. This has important ramifications for design practice, including the methods used for estimating the multivariate anthropometry of the target user population. Accurate anthropometric data may be expensive to obtain experimentally, so for many design scenarios it is necessary to estimate the data using statistical models. This data synthesis may be accomplished using proportionality constants (Drillis and Contini, 1966), boundary manikins (Bittner, 2000), linear regression (Garneau and Parkinson, 2010), or principal components analysis (PCA; Parkinson and Reed, 2009), among others. While these methods differ in terms of accuracy and complexity, they all require predictor data (e.g., stature and BMI) for the population of interest, along with a detailed database of related anthropometry for the creation of the prediction models.

The data for India and the US used stature and BMI as the predictors for anthropometry synthesis. Using the approach outlined in Parkinson and Reed (2009), PCA was used to create virtual user populations, each consisting of 1000 individuals. The Indian anthropometry was synthesized using a sample of stature and BMI data and a prediction model created from information in Chakrabarti (1997). The predictors for the US virtual population are an unweighted sample of stature and BMI based on NHANES (U.S. Center for Disease Control and Prevention, 2008), a database of the current US civilian stature and health. The model to predict anthropometric measurements was created using the data from CAESAR (Blackell et al., 2008), a detailed study of North American and European civilians that, unweighted, does not represent a specific target population.

In contrast to the populations in India and the US where detailed anthropometry were synthesized, detailed anthropometry for Japan were already publicly available (Research Institute of Human Engineering for Quality Life, 1997). The data are from a comprehensive study conducted in the late 1990s and are available for download online. Approximately 80% of the study participants were between 20 and 30 years of age, so the data are skewed towards younger individuals.

3 SEAT DESIGN

Two candidate designs were considered. The first is based on the typical, univariate approach in which the 5th- and 95th-percentile values for the relevant measures determine the seat parameters. The second design is informed by the failure of the first: the 1st- and 99th-percentile values are used, anticipating that the increased accommodation on an individual measure will be necessary to achieve the 95% target. These designs were generated for three populations: India, Japan, US, and India+Japan+US.

Virtual fitting trials were conducted for each of the individuals in each of the three target user populations. The designs described above were assessed for overall multivariate accommodation. An additional approach in which a design based on one population but utilized for another was also considered.

3.1 India

Percentile values of interest for the target users in India are shown in Table 1. These are calculated from the synthesized population of 1000 virtual users, representative of the target user population. In addition to overall descriptors stature, mass, and BMI, the three relevant design measures are also provided. A naïve designer might establish an accommodation target such as 95%, then identify the appropriate 5th- and 95th-percentile values to establish the seat design parameters. This univariate design approach grossly overestimates accommodation levels. For example, the values in Table 1 would indicate seat pan width = 391mm, seat pan depth = 411mm, and an adjustability range of 373mm through 444mm.

Table 1 - Percentile values (mm) of interest for the target user population of civilian males in India.

	1st	5th	50th	95th	99th
stature	1485	1531	1645	1752	1800
mass	36.5	41.0	53.0	74.5	87.7
BMI	14.6	15.8	19.6	26.6	30.8
hip breadth, seated	257	274	322	391	424
popliteal height	361	373	408	444	465
buttock-popliteal length	395	411	458	507	530

Figure 3 shows the results of this design approach for the virtual users. The 1000 individuals in the synthesized population are plotted by hip breadth and buttock-popliteal length. Individuals that will “fit” and those that are disaccommodated are coded separately. When seat height is excluded from consideration, approximately 5% of the population is disaccommodated on each of the two measures for an overall accommodation of 90.1% (Table 2). When including disaccommodation due to seat height, overall accommodation drops to 82.8%. Note the lack of correlation between the three measures: individuals disaccommodated on one measure are, for the most part, distinct from those disaccommodated on another.

Table 2 - Accommodation levels (%) for country-specific populations when only data from India are used.

method		India	Japan	US
5th and 95th guidelines	seat pan only	90.1	90.1	56.9
	seat pan + adj. seat height	82.8	75.1	43.0
1st and 99th guidelines	seat pan only	98.0	98.8	83.2
	seat pan + adj. seat height	96.6	91.7	75.8

Since the three relevant body dimensions are not perfectly correlated, higher levels of accommodation can only be achieved by designing to more extreme values. For example, the 1st- and 99th-percentile values might be appropriate. For the population within India this will result in an overall accommodation level of 96.6%, much closer to the desired target of 95%. However, this increased accommodation may come at significantly increased costs.

Of particular interest are global design strategies. One is to design for the local population, then use that same design globally. For example, a seat designed for India could be exported to the US. Using the 5th- and 95th-percentile design limits from India, the US population would achieve an accommodation level of only 43.0%. If the 1st- and 99th-percentile design limits are used, the expected level for US male civilians using seats designed for a population in India would be 75.8%. This indicates that extreme care is required when considering the design of product for release in global markets where results such as these may not be clearly understood or anticipated.

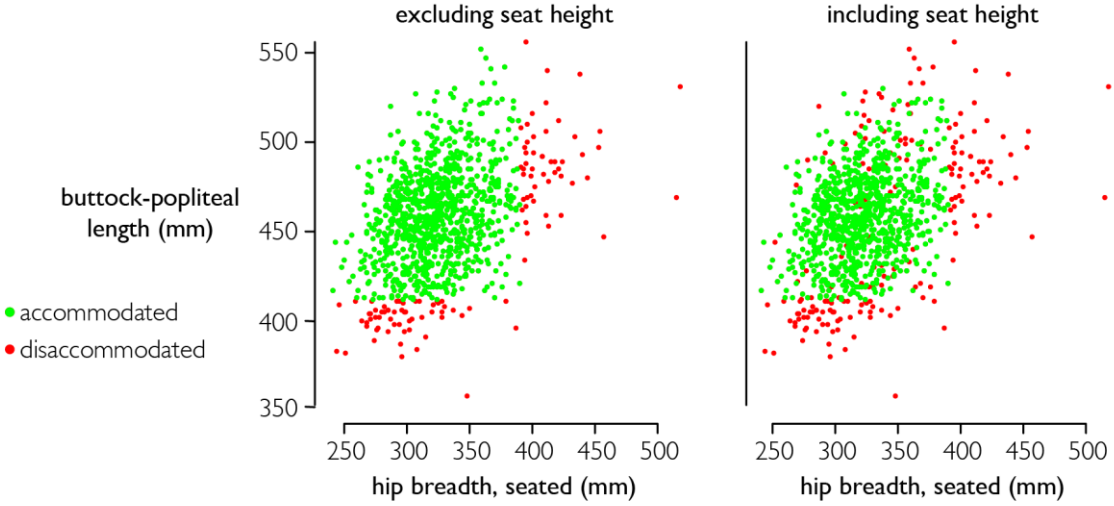

Figure 3 - The combinations of buttock-popliteal length and seated hip breadth for the 1000 members of the target user population in India. Accommodated and disaccommodated individuals for the two conditions are shown.

3.2 Japan

Overall, the people in the Japanese data are slightly shorter than those in India and much more so than those in the US (Table 3). As with individuals in India, their BMI is much lower than that of those in the US. The three measures of interest are all much smaller than their US counterparts. In contrast, there is no consistent trend when comparing with the data from India. This is likely a reflection of the different relative lengths of leg segments and sitting heights across the two populations.

Table 3 - Percentile values (mm) of interest for the target user population of a Japanese civilian male population.

	1st	5th	50th	95th	99th
stature	1418	1465	1627	1789	1845
mass	41.2	44.9	56.4	72.8	85.0
BMI	17.0	18.0	21.3	26.0	29.0
hip breadth, seated	306	318	350	384	400
popliteal height	339	356	397	443	459
buttock-popliteal length	394	406	447	491	511

Table 4 - Accommodation levels (%) for country-specific populations when only data from Japan are used.

method		India	Japan	US
5th and 95th guidelines	seat pan only	89.6	90.1	50.0
	seat pan + adj. seat height	84.9	83.4	38.2
1st and 99th guidelines	seat pan only	95.7	98.0	65.8
	seat pan + adj. seat height	94.6	95.7	58.5

As Table 4 shows, using the 1st and 99th percentile values as guidelines is an effective strategy for achieving the desired 95% accommodation within the Japanese population as well. Note that the similarities in the Japanese and Indian data mean that the seat designed for Japan would be effective in India as well. In contrast, accommodation levels in the US range from 38.2% to 65.8%, depending on the scenarios.

3.3 United States

Individuals within the US are much larger on all measures than their counterparts in India or Japan (Tables 1 and 3 vs. Table 5). The 50th-percentile stature in the US target population (1755mm) is approximately the same as the 95th-percentile stature of target users in India. Mass and BMI have even greater disparity—1st-percentile mass for US is greater than the 50th-percentile mass in the Indian design population. The differences are only somewhat smaller when contrasting with the Japanese population.

Table 5 - Percentile values (mm) of interest for the target user population of civilian males in the United States.

	1st	5th	50th	95th	99th
stature	1580	1622	1755	1882	1936
mass	54.2	60.7	85.3	124	151
BMI	18.5	20.5	27.9	38.9	48.2
hip breadth, seated	308	325	384	455	514
popliteal height	373	385	426	475	494
buttock-popliteal length	443	455	499	548	577

Seat dimensions were specified using three strategies in the example above: 1) 5th and 95th, 2) 1st and 99th, and 3) using a seat designed for one population as the product for another. These were repeated here using data from the US population (Table 6).

Table 6 - Accommodation levels (%) for country-specific populations when only data from the US are used.

method		India	Japan	US
5th and 95th guidelines	seat pan only	55.4	39.9	90.1
	seat pan + adj. seat height	53.9	39.3	82.5
1st and 99th guidelines	seat pan only	70.6	57.5	98.1
	seat pan + adj. seat height	70.1	56.5	96.3

A seat designed based on the 5th- and 95th-percentile limits will result in an overall accommodation of 82.5%. When that seat designed for the US population is exported to India or Japan, the accommodation level for those populations is only 53.9% and 39.3%, respectively. When the design is expanded to utilize 1st- and 99th-percentile values, accommodation increases to 96.3% (US), 70.1% (India), and 56.5% (Japan).

3.4 India + Japan + United States

Rather than designing using a product designed for one population to satisfy the spatial requirements of another, the needs of the populations can be considered simultaneously. In this strategy, the data from the three populations are combined. The percentile values are calculated on these combined data (Table 8). Note that the percentile values lie, as expected, between those for the design populations of the three countries.

Table 7 - Percentile values (mm) of interest for the combined target user populations of civilian males in India, Japan, and the United States.

	1st	5th	50th	95th	99th
stature	1449	1522	1676	1843	1900
mass	39.3	44.2	60.9	107	132
BMI	15.4	17.0	22.1	33.6	40.9
hip breadth, seated	269	290	351	429	478
popliteal height	349	367	411	459	481
buttock-popliteal length	398	413	467	531	559

By considering the spatial requirements of all of the populations simultaneously, a single product can be designed that meets their collective requirements. The overall accommodation levels for the "1st and 99th" strategy for the combined population are appropriately high at 96.1% (Table 9). However, note that each of the subpopulations are accommodated at different levels. Figure 4 shows the disproportionate disaccommodation across the three user populations for the combined 5th and 95th seat pan only solution.

Table 8 - Accommodation levels (%) for combined and country-specific populations when considering all the population data simultaneously.

method		combined	India	Japan	US
5th and 95th guidelines	seat pan only	90.3	92.8	92.3	86.0
	seat pan + adj. seat height	83.2	90.4	84.2	75.1
1st and 99th guidelines	seat pan only	97.9	98.3	98.2	97.2
	seat pan + adj. seat height	96.1	98.2	95.7	94.3

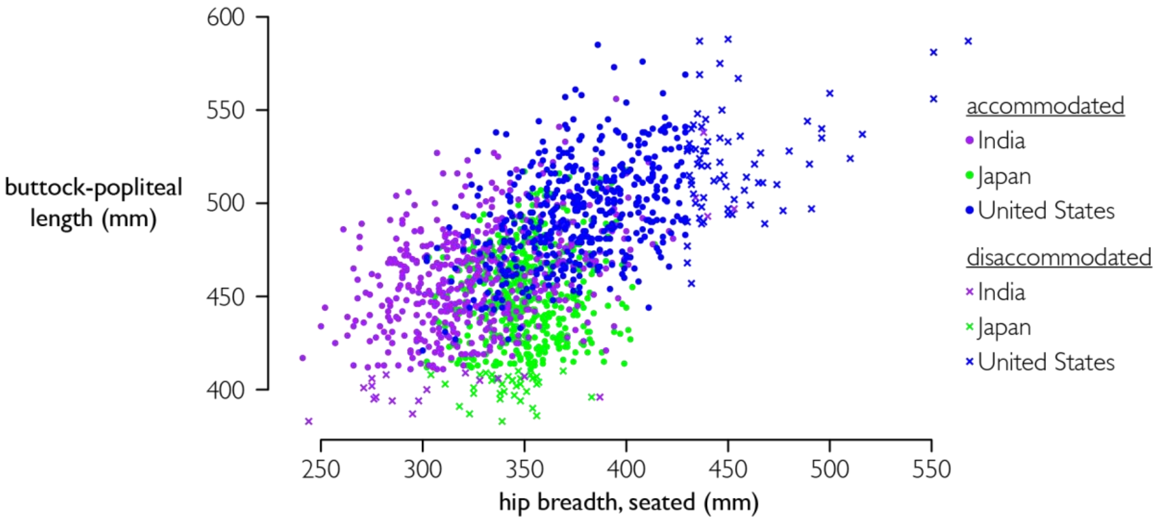

Figure 4 - Accommodation and disaccommodation for the three populations.

When considering the effect of vertical adjustability, the differences in anthropometry (in this case, popliteal height) are pronounced. The data from Japan are more tightly distributed and are approximately bounded by those from India. As a result, individuals disaccommodated on vertical seat adjustment are predominantly from the India and the US.

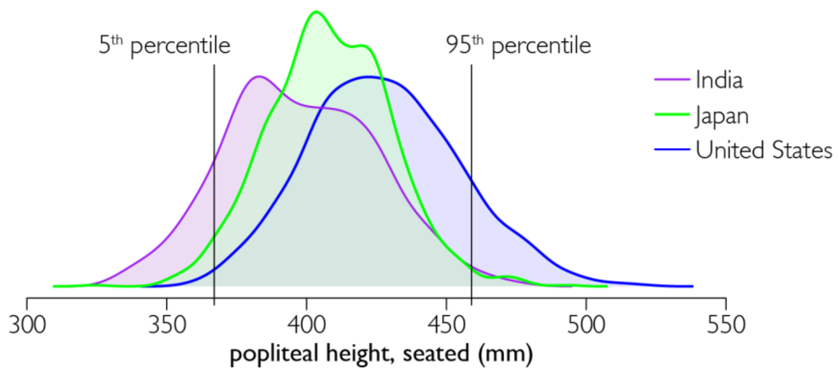

Figure 5 - Probability density of popliteal height for populations from India, Japan, and US. The 5th and 95th percentile values for the combined population are marked.

4 DISCUSSION

The previous sections demonstrated three strategies for global product development in design for human variability. In the first, distinct products are created for each market. Using that approach, with appropriate design practice (i.e., using 1st- and 99th-percentile values instead of 5th and 95th), the target accommodation of 95% can be achieved within the "home" population.

In the second strategy, a single product is designed using data from one population, then exported for use by all. When this occurs, accommodation levels drop significantly. When the 5th/95th strategy is used, accommodation drops from ~81% to either 42% (people in India using a seat designed for individuals in the US) or 52% (individuals in the US using a seat designed for the population in India). The seat designed for 1st/99th performs much better across populations, dropping from ~95% in the home population to ~76% and ~69%. In fact, the improvement in accommodation levels for the "foreign" population exceeds that in the home with the change in design strategies. That is due to the sparsely populated tails of the distribution within the home population.

The final strategy creates a single product based on the consideration of design requirements from all three populations simultaneously. High levels of performance can be achieved for all three populations, but this comes at a cost. For example, when using the 5th/95th strategy, the seat is 429mm-391mm=38mm (10%) wider and requires an additional 92mm-71mm=21mm (30%) of vertical adjustability than the seat designed exclusive for India. When using the 1st/99th strategy, the demand on seat width increases by 54mm. If these increases are acceptable, this can be an effective strategy for increasing accommodation in multiple markets. The three populations considered here are very distinct—it is anticipated that most populations would have body size and shape somewhere between these two extremes. As such, this presents a potentially extreme view of the within-gender differences a designer might anticipate across countries. When both males and female users are considered, the costs associated with the one-size-fits-all approach might be even greater.

5 CONCLUSION

This work has explored the range of variability between three populations (India, Japan, and the US) and the implications as applied to three global design strategies. Analysis has shown that univariate analysis for any of the three populations based on the 5th and 95th percentile limits can result in high levels of disaccommodation, falling significantly short (~83% accommodation) of the desired accommodation target of 95%. It was shown that if the 1st and 99th percentile values are used, the target was achieved (e.g., 95.9% accommodation). However, as stated, this increased accommodation may add significant cost to the design or violate manufacturability or spatial constraints.

This issue is further compounded when considering the design of global products for diverse populations. The results demonstrated that a product designed for one population then exported for use by all could also produce far greater unintended consequences of disaccommodation, with levels of fit dipping to 38% (seat designed for the Japanese sold in the US).

When considering global design, an appealing strategy is the creation of a single product addressing the design requirements for all populations simultaneously. This approach, in the application to seat design, yielded improved percentages of accommodation, but comes at the cost of increased adjustability, materials costs, etc. The work serves to emphasize the necessity to understand the target populations of end-users for products designed to apply to global markets and consumers. Specific to seat design, the work is limited by the exclusion of qualitative assessments such as comfort. Additionally, to simplify the analyses, women were not considered in the sample, which limits the practical utility of the specific numbers here.

ACKNOWLEDGMENTS

This research was partially funded by the National Science Foundation under Award No. 1131467. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. Prof. Parkinson has also received funding from Siemens and Dassault to conduct work in modeling the size and shape of populations.

REFERENCES

Annis, J.F. (1996) Aging effects on anthropometric dimensions important to workplace design. *International Journal of Industrial Ergonomics,* Vol. 18, No. 5-6, pp. 381–388.

BIFMA (2002) *Ergonomics guideline for VDT (visual display terminal) furniture used in office work spaces.*

Bittner, A.C. (2000) A-CADRE: Advanced family of manikins for workstation design, *Human Factors and Ergonomics Society Annual Meeting,* Long Beach, CA, 30 July–4 August, Santa Monica, CA: Sage Publications, pp. 774–777.

Blackell, S., Brill, T., Boehmer, M., Fleming, S., Kelly, S., Hoeferlin, D. and Robinette, K. (2008) CAESAR survey measurement and landmark descriptions. *Air Force Research Laboratory,* Wright-Patterson AFB, OH.
Cardoso, C, and Clarkson, P.J. (2012) Simulation in user-centred design: helping designers to empathise with atypical users. *Journal of Engineering Design*, Vol. 23, No. 1, pp. 1–22.
Chakrabarti, D. (1997) *Indian Anthropometric Dimensions for Ergonomic Design Practice,* National Institute of Design.
Drillis, R. and Contini, R. (1966) *Body Segment Parameters,* New York, Office of Vocational Rehabilitation Engineering & Science.
Garneau, C.J. and Parkinson, M.B. (2010) A comparison of methodologies for designing for human variability. *Journal of Engineering Design*, Vol. 22, No. 7, pp. 505-521.
Gordon, C.C., T Churchill, C.E., Clauser, B., Bradtmiller, J.T., McConville, I., Tebbetts, and Walker, R.A. (1989) 1988 Anthropometric survey of U.S. army personnel: methods and summary statistics final report. Tech. Rep. NATICK/TR-89/027. U.S. Army Natick Research, Development and Engineering Center. Natick, MA.
Goossens, R.H.M., Snijders, C.J., and Fransen, T. (2000) Biomechanical analysis of the dimensions of pilot seats in civil aircraft. *Applied Ergonomics,* Vol. 31, No. 1, pp. 9–14.
Manjrekar, K. and Parkinson, M.B. (2011) Considering race and gender distributions of the target user population in the multivariate design of vehicle seating. *International Journal of Vehicle Design*, Vol. 55, No. 2-4, pp. 174-188.
Meta, C.R., Gite, L.P., Pharade, S.C., Majumder, J., and Pandy, M.M. (2008) Review of anthropometric considerations for tractor seat design. *International Journal of Industrial Ergonomics,* Vol. 38, No. 5-6, pp. 546-554.
Nadadur, G. and Parkinson, M.B. (2012) Designing for multiple global user populations: increasing resource efficiency for greater sustainability. *Work: A Journal of Prevention, Assessment and Rehabilitation,* Vol. 41, No. 1, pp. 6031-6038.
Parkinson, M.B. and Reed, M.P. (2009) Creating virtual user populations by analysis of anthropometric data. *International Journal of Industrial Ergonomics,* Vol. 40, No. 1, pp. 106-111.
Research Institute of Human Engineering for Quality Life (1997) *Japanese Body Size 1992–1994* [online], http://www.dh.aist.go.jp/bodyDB/s/s-01-e.html (5 September 2012).
Tiley, A.R. and Henry Dreyfuss Associates. (2002) *The Measure of Man and Woman: Human Factors in Design*, New York, John Wiley and Sons.
U.S. Center for Disease Control and Prevention. (2008) National Health and Nutrition Examination Survey. *National Center for Health Statistics.* [online], http://www.cdc.gov/nchs/nhanes.htm. (10 January 2013).
Yang, L, Shen, H. and Wu, G. (2007) Racial differences in respirator fit testing: A pilot study of whether American fit panels are representative of Chinese faces. *Annals of Occupational Hygiene,* Vol. 51, No. 4, pp. 415–421.