ANTHROPOMETRIC TARGETS FOR THE AVERAGE FEMALE: PRELIMINARY EVALUATIONS

Jobin John[1], Chiara Fichera[1], Tommy Pettersson[2], Mats Svensson[1], Astrid Linder [1, 2, 3]

[1] Chalmers University of Technology, Department of Mechanical Engineering, Vehicle Safety Division, Sweden

[2] Swedish National Road and Transport Research Institute, VTI, Sweden

[3] Monash University Accident Research Center, Melbourne, Australia

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ABSTRACT

Current anthropometric targets for crash test dummies (ATDs) largely stem from 1980s, which proposed four representative sizes: small female (F05), mid-sized female (F50), mid-sized male (M50), and large male (M95). Subsequent development, however, focused on M50, F05, and M95, leaving a gap for an average female surrogate. Recent efforts—such as EvaRID, BioRID-P50F, VIVA+ human body models (HBMs), and the Seat Evaluation Tool (SET)—have addressed this need, yet standardized anthropometric targets for an average female in a seated automotive posture remain unavailable.

This study aimed to establish anthropometric targets for a seated average female using the ANSUR II dataset of U.S. Army personnel. Bayesian linear regression modeled key seated dimensions (e.g., seated heights, hip breadth, buttock-knee length) as functions of sex, height, and weight. Posterior predictive distributions provided estimates for an average female (161 cm, 62 kg). Results indicate that SET 50F torso dimensions align closely with regression-based estimates, while extremities are shorter due to the use of adapted Hybrid III F05 components. Sex-related differences in static seat loading were also evaluated using SET 50F and 50M on a production vehicle seat. Seat cushion deformation was measured at nine locations under static loading. Profiles revealed distinct patterns: the rear cushion region deformed more for the average male size when compared to the average female even though both have a similar hip width, likely due to higher body mass.

The approach used in this study demonstrates the feasibility of deriving anthropometric targets for average female surrogates from existing datasets, providing both benchmarks and uncertainty bounds. Future work should expand measurements and include comparisons with average male targets to improve occupant safety assessments.

Keywords: Anthropometry, Crash Test Dummies, Average Female, Average Male, Bayesian Regression, Seat Interaction, Sex-differences

INTRODUCTION

Anthropometric targets for modern anthropometric test devices (ATDs), or crash test dummies, and human body models (HBMs) are mostly based on the study in the early 1980s by Schneider et al [1]. Schneider et al. recommended a set of four dummies whose height and weight would "form a rather evenly spaced progression from small to large in the U.S. population" – small female (F05), mid-sized female (F50), mid-sized male (M50), large male (M95). Subsequent development of detailed anthropometric specifications, however, considered only the M50, F05, M95 [2, 3]. The average male has since become the norm for injury assessment for vehicle occupant safety [4].

There have been various developments that sought to address the lack of an average female surrogate for crash testing. The finite element dummy model EvaRID and matching prototype BioRID P50F were developed for rear impact testing [5, 6]. Recent finite element human body model (HBM) developments have also begun to address this gap. Some examples include the open-source VIVA+ HBM [7] and GHBMC [8]. The Seat Evaluation Tool (SET) is a recent research dummy that represents both the average female and average male [9].

However, a challenge remains in that there are no anthropometric targets for these new average female surrogates similar to those that exist for other sizes. The objective of this study was to explore the use of existing anthropometry databases to develop anthropometric targets for a seated average female. In addition, to understand the influence of sex-differences in the static interaction with a vehicle seat, SET 50F and 50M were used to measure seat cushion deformation on a production car seat.

METHODS

Anthropometry Targets

Anthropometric data source This study used the Anthropometric Survey of U.S. Army Personnel (ANSUR II), conducted in 2012 by Gordon et al. [10]. The ANSUR II database represents one of the most comprehensive and recent anthropometric datasets available, containing measurements from 6,068 subjects (4,082 men and 1,986 women) serving in the U.S. Army. The database includes 93 anthropometric measurements per subject, covering linear dimensions, circumferences, surface distances, breadths, and depths relevant to human factors, engineering and equipment design. Anthropometric measures relevant to seated occupants were selected for this study (Figure 1), including seated heights (total seated height, cervicale height, acromial height), functional dimensions (functional grip reach, functional leg length), and body breadths and depths (seated hip breadth, buttock-knee length, seated knee height).

Anthropometry Regression Bayesian linear regression was used to model the anthropometric measurements as a function of sex, height, and body mass index (BMI). The mathematical framework, following the methodology described in Fichera et al. [11] as follows:

$$y = \mu + \varepsilon$$

$$\varepsilon \sim Normal(0, \sigma)$$

$$\mu_i = \alpha_j + \beta_j (H_i - H_{mean}) + \gamma_j (BMI_i - BMI_{mean})$$

where index j indicates sex (male or female) and i indexes individual subjects. The predictor variables (height H and BMI) are centered around their respective dataset means to improve model convergence and interpretability. The parameter α represents the baseline anthropometric measure for each sex at the mean height and BMI, β represents the rate of change with height, and γ represents the rate of change with BMI.

Prior distributions were specified as weakly informative priors that allow the data to primarily determine the posterior distributions while providing regularization:

$$\alpha \sim Normal(mean, 10)$$

$$\beta \sim Normal(0, 1)$$

$$\gamma \sim Normal(0, 1)$$

$$\sigma \sim Uniform(0, 10)$$

The prior for the intercept α was centered at the overall mean of each anthropometric measure in the full dataset, while the priors for the slope parameters β and γ were centered at zero with unit variance, representing minimal prior knowledge about the relationships. The residual standard deviation σ was given a uniform prior over a reasonable range.

Models were fitted using the No-U-Turn Sampler (NUTS). For each model, four chains were run with 2,000 iterations each (1,000 warmup, 1,000 sampling), yielding 4,000 posterior samples for inference. Python library for probabilistic programming, PyMC, was used for the Bayesian modeling. [12]

Sex-differences in Static Seat Interaction

The average female (50F) and average male (50M) of the SETs (v0.2) were used to evaluate the influence of sex-differences on static seat loading. A production vehicle seat, Toyota Auris model year 2010-2012, was used for this study. The seat deformation profile was measured under the static loading of the SETs. The deformation was measured using pins that were inserted through the cushion. The displacement of these pins was calculated by measuring the vertical movement of pin after the SETs were seated on the seat cushion. The deformation was measured at 9 points on the cushion as showed in Figure 2.

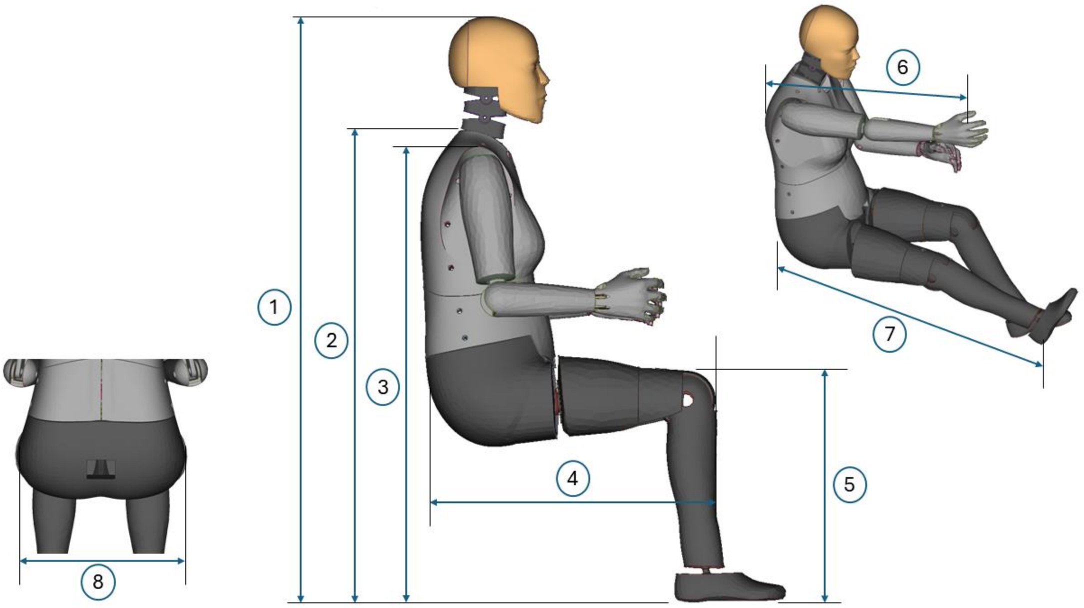

Figure 1: Anthropometric measurements considered in this study, illustrated using FE SET 50F geometry. 1. Total seated height. 2. Cervicale seated height. 3. Acromial seated height 4. Buttock-knee length. 5. Seated knee height. 6. Functional grip range. 7. Functional leg length 8. Seated hip breadth

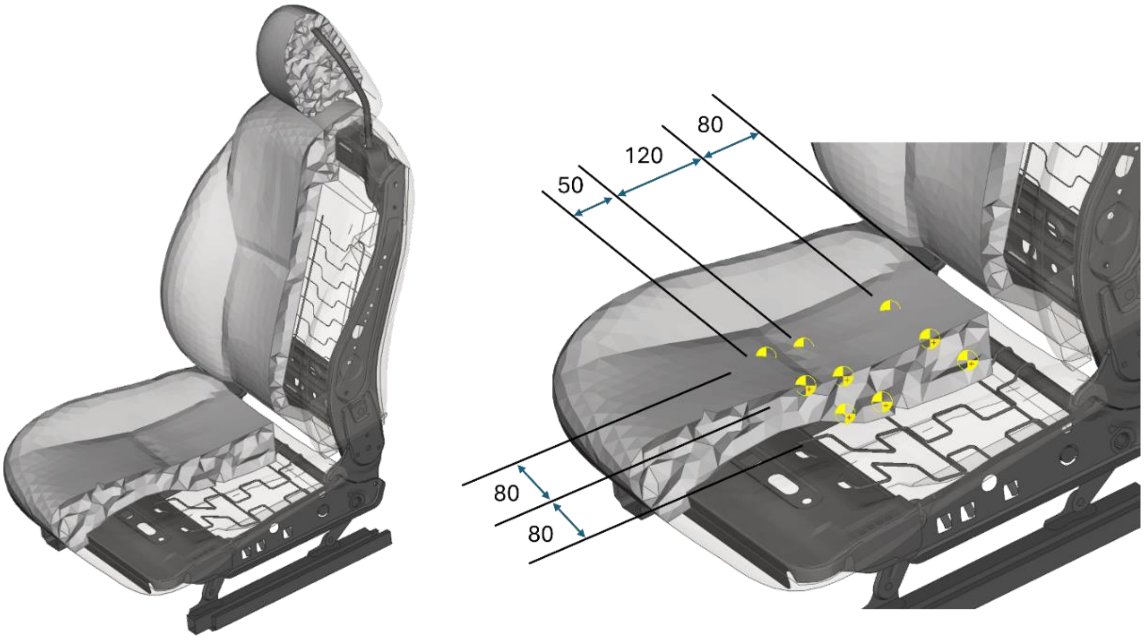

Figure 2: (Left) Production seat, Toyota Auris model year 2010-2012, used for seat static deformation evaluation. Visualization of the seat was created using the VIRTUAL open access finite element seat model [13]. Cut section shows the seat structures underneath the cushion (Right). Markers show the locations where the deformations were measured using pins through the cushion. Dimensions are shown in millimeters.

RESULTS

The predictions from the Bayesian regression for an average female size of height 161 cm and weight of 62 kg are given in Table 1. The measurements for the SET are also given in this table. For this study, these were measurements made on the FE SET [14], available as open source models on OpenVT [15].

Table 1: Average female anthropometric estimates from the linear regression, given by the median and High Density Intervals (HDI) of the posterior distributions, and compared below with SET 50F measurements.

Length measurement	Median (cm)	95% HDI (cm)	SET 50F (cm)
Total seated height	84.8	[80.6, 89]	85.3
Cervicale seated height	61.6	[57.8, 65.5]	58.8
Acromial seated height	55.9	[51.7, 60.1]	58.9
Functional grip reach	72.5	[66.6, 78.4]	65.5
Functional leg length	102.5	[96.8, 108.3]	90.9
Seated hip breadth	38.6	[35.6, 41.6]	36.7
Seated knee height	50.2	[47.8, 52.6]	46.0
Buttock-knee length	57.6	[54.5, 60.8]	57.0

The deformation profile of the seat cushion surface when statically loaded by the SET 50F and SET 50M is shown in Figure 3. The rear part of the seat cushion was deformed more by SET 50M than the SET 50F.

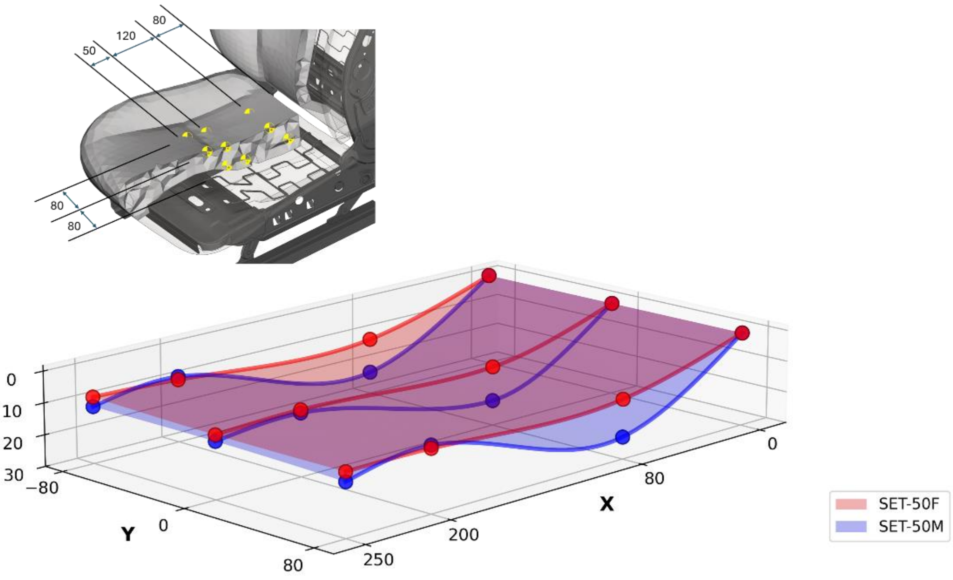

Figure 3: Deformation of the seat when statically loaded by the average female SET 50F and the average male SET 50M. The X-axis represents back-to-front direction, with the zero-point at the beginning of the seat cushion. The Y-axis represents the left-to-right direction with the zero-point at the middle of the seat.

DISCUSSION

Anthropometry can influence how vehicle occupants interact with vehicle interior and occupant restraint systems, which in turn determines the injury causing loading patterns on the human body during a crash event. Even though Schneider et al. were unanimous in their recommendation to not combine male-female variability in one dummy and instead proposed two mid-sized dummies (50F and 50M) [1], the current human surrogates for evaluating vehicle safety are predominantly average-male and may not be sufficient to represent the population in a safety assessment[4].

The comparison of SET 50F anthropometry to the estimates from the regression model showed that overall dimensions related to the torso compared well. These included the various seated heights and the hip breadth. The torso geometry of the SET was developed based on the outer geometry of the VIVA+ HBMs, which in turn was based on average statistical shape models developed at UMTRI. [7, 16]. The extremities, however, tend to be shorter than the estimates given by the regression models. This is because SET 50F uses modified extremities from the Hybrid III 5th percentile female dummy. [6, 9]

The deformation of the seat cushion shows that average male and female surrogates have distinct loading characteristics even under static loading. Although the hip breadth is not dissimilar between the average male and average female, the static loading of seat causes different deformation in the seat cushion. This can be attributed to the higher body mass of the male loading a similar area on the seat cushion as the female. This results in the rear portion of the seat cushion deforming downward more for the male compared to the female. These differences could lead to different seat interactions for men and women, potentially leading to distinct loading scenarios when it comes to injuries in the knee-thigh-hip complex.

LIMITATIONS

This study used anthropometric measurements from an army population. Because the dataset consists of a large number of data points and a regression-based method was used, it can be expected that the central tendencies of the distributions do not vary for a different sample. However, greater variation can be expected in the general population; therefore, the bounds of the high-density intervals of the posterior predictive distribution would likely be wider if non-army datasets are used for the regression.

CONCLUSIONS

This study explored an approach to obtain anthropometric measurement targets for an average female seated occupant from general anthropometric databases, given the lack of studies to quantify anthropometries in an automotive seated posture. The posterior predictive distributions, from the Bayesian regression, offers not only point estimates that can serve as targets for anthropometric specifications but also uncertainty ranges that can serve as bounds for the validation of human surrogates. This study is being expanded to include more anthropometric measurements and to also include comparisons with the average male size.

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