CHALMERS
UNIVERSITY OF TECHNOLOGY

How Different Is The Female Neck From Male?

Downloaded from: https://research.chalmers.se, 2026-05-31 05:46 UTC

Citation for the original published paper (version of record):
Fichera, C., Svensson, M., John, J. (2026). How Different Is The Female Neck From Male?. [Source Title missing]

N.B. When citing this work, cite the original published paper.

research.chalmers.se offers the possibility of retrieving research publications produced at Chalmers University of Technology. It covers all kind of research output: articles, dissertations, conference papers, reports etc. since 2004. research.chalmers.se is administrated and maintained by Chalmers Library

(article starts on next page)

HOW DIFFERENT IS THE FEMALE NECK FROM MALE?

Chiara Fichera, Mats Svensson, Jobin John

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

Paper Number ESV26-044

ABSTRACT

Neck is a commonly injured body region in all crash severities. Impairments from neck injuries are often seen to affect women more than men in vehicle crashes. In this paper, we study the sex-differences in neck morphology using publicly available anthropometry database. The differences in neck circumference and neck length between men and women are quantified using Bayesian linear regression. Posterior predictive distributions of the neck anthropometries for males and females of 5th, 50th, and 95th percentiles sizes were used to evaluate sex-differences. The neck length variations can be attributed to stature. However, the neck circumference was considerably different between men and women. The 95th female neck circumference was seen to be smaller than 5th male neck circumference. These findings highlight distinct morphological patterns between women and men, underscoring the need for sex-specific representations in injury assessment.

Keywords: sex-differences, ANSUR II, neck circumference, neck length, Bayesian regression, anthropometry, Human Body Modeling (HBM), HBM geometric validation

INTRODUCTION

Improvements of advanced driver assistance systems (ADAS) capabilities and the ongoing development of automated driving systems are likely to lead to a decrease in crash severities in the future [1].
Although lower crash severities are associated with a reduced risk of fatality, mitigating occupant injuries in these low-severity collisions remains a significant challenge [2]**.** As low-severity crashes are expected to account for an increasing proportion of traffic accidents, their societal and economic burden due to medical treatment costs, and potential long-term impairment remain challenge [3, 4]. Among the spectrum of injuries sustained in motor vehicle crashes, neck injuries—and particularly whiplash-associated disorders (WAD)—remain prevalent across all crash severities, including lower severity [5, 6]. These injuries still remain challenging not only for their high incidence but also for their potential to result in permanent medical impairment [7].

Studies have shown that females have a higher risk of experiencing WAD compared to men [8]. This sex disparity from epidemiology highlights the importance of investigating sex-specific anatomical and biomechanical differences of the neck, both at the cervical spine level and the surrounding tissues [9]. While several studies have characterized structural differences in cervical vertebrae and soft tissue anatomy between males and females, few have examined sex differences in neck musculature [10–12]. Yet, neck muscles play a critical role in both passive and active stabilization of the head and neck during pre-crash and crash loading conditions, especially at lower-speed impacts [13]. A detailed understanding of neck anthropometry—that intrinsically describes the neck muscles morphology—across sexes and body sizes is therefore important for a better understanding of the sex-differences in neck biomechanics.

The aim of the study is to quantify sex-specific differences in neck anthropometry, specifically for neck circumference and neck length, for the 5th, 50th, and 95th percentile adult male and female populations.

METHODS

Length and circumference of the human neck were analyzed for sex-differences using Bayesian linear regression. In this study we used the Anthropometric Survey of U.S. Army Personnel (ANSUR-II) data, which consists of 93 anthropometric measurements from 6,068 from U.S. Army personnel (4,082 men; 1,986 women) [14]. The neck length (described as neck link in ANSUR-II) and circumference were regressed on sex, stature, and body mass index (BMI), following the approach previously described in Fichera et al [15].

Let i index for single individuals and $j \in$ {male, female} denote sex, the likelihood and the model were built as follows:

$$y = \mu + \varepsilon$$

$$\varepsilon \sim \text{Normal}(0, \sigma)$$

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

where H_i and BMI_i were mean-centered by their sample averages H_{mean} and BMI_{mean}. The intercept α_j represented the expected value of the anthropometric measure for sex j at average stature and BMI; β_j and γ_j captured sex-specific associations with stature and BMI, respectively.

In the models, weakly informative priors were used to regularize the estimates: α~Normal(mean,10), β~Normal(0,1), γ~Normal(0,1), σ~Uniform(0,10). The prior for α was centered on the average neck circumference or length across the full dataset. Posterior inference employed the No-U-Turn Sampler (NUTS). For each model we ran four chains with 2,000 iterations per chain (1,000 warm-up and 1,000 sampling), yielding 4,000 posterior draws used for summaries and derived quantities. The models were implemented in PyMC 5.1.2. Each of the Bayesian regression model returned a distribution for the neck circumference and length, called posterior distribution.

From the posterior distribution, we generated a synthetic population of posterior predictive draws by repeatedly sampling parameter space. The posterior predictive draws were generated from individuals corresponding to the 5^{th}, 50^{th}, 95^{th} female and male percentiles [16]. The percentiles for the stature are reported in Table 1, whereas the BMI was held constant at 25 kg/m^2 across all three categories.

Table 1: Stature 5, 50, 95^{th} percentiles according to Jelenkovic et al. 2016 [16].

	Female Stature (cm)	Male Stature (cm)
5^{th} Percentile	151	163
50^{th} Percentile	165	178
95^{th} Percentile	179	194

RESULTS

The neck length showed an increasing trend with stature of the human body, irrespective of the sex (Figure 1: Posterior predictive distributions of neck length for males (in blue) and females (in red), shown for the 5th, 50th, and 95th percentilesFigure 1). Posterior predictive distributions overlapped for the neck length, indicating no sex-related differences. In contrast, the neck circumference was considerably different between females and males, and increased progressively from 5^{th} to 95^{th} percentile (Figure 2) within each sex. The mean neck circumference for a 95^{th} female (34cm) was seen to be smaller than that of a 5^{th} male (37.5 cm), as shown in Table 2. The High-density intervals (HDI) of the posterior predictive distributions further underscored this pattern: while HDIs (Table 2) overlapped for neck length, those for neck circumference showed clear dofferences between men and women.

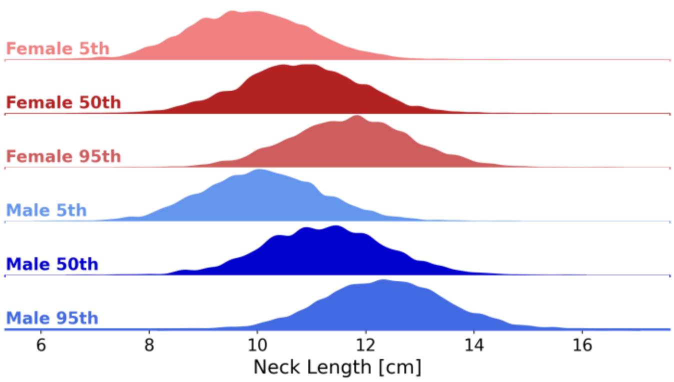

Figure 1: Posterior predictive distributions of neck length for males (in blue) and females (in red), shown for the 5th, 50th, and 95th percentiles.

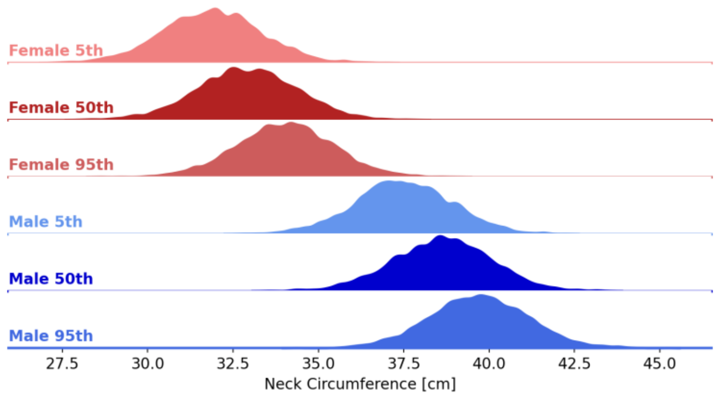

Figure 2: Posterior predictive distributions of neck circumference for males (in blue) and females (in red), shown for the 5th, 50th, and 95th percentiles.

Table 2: Averages and 95% HDI intervals for the neck length and neck circumference for 5th, 50th, 95th percentile female and male.

	Neck Length (cm)		Neck Circumference (cm)	
	Average	95% HDI	Average	95% HDI
Female 5th	9.8	[7.8; 12.0]	31.8	[29.1; 34.5]
Female 50th	10.8	[8.5; 12.8]	32.9	[30.2; 35.8]
Female 95th	11.7	[9.6; 13.9]	34.0	[31.3; 36.8]
Male 5th	10.1	[8.0; 12.2]	37.5	[34.9; 40.4]
Male 50th	11.2	[9.1; 13.5]	38.7	[35.8; 41.4]
Male 95th	12.4	[10.3; 14.6]	39.7	[36.8; 42.3]

DISCUSSION

The goal of this study was to investigate sex differences in neck anthropometry. Results showed sexual dimorphism for neck circumference, but not for neck length. In this study, we compared three percentile groups – that reflect population specific distribution of different stature and mass - variables that are known to differ between males and females, since men on average are taller and thus heavier than women. Prior work reported a size-matched comparison between the sexes, by controlling for stature and BMI [15]. Even when these key anthropometric variables were controlled for, the neck circumference still differed between males and females. Thus, these findings of percentile comparisons together with the size-matched comparisons strengthen the conclusion that neck morphological differences between females and males are intrinsic rather than resulting from stature or BMI differences. These findings were earlier reported by Vasavada et al. with limited number of sized matched volunteers [11].

Currently, percentiles of the population are widely used in evaluating risk and crash scenarios for occupant safety. The current standard relies on the use the average male or small female representations of the human body as a proxy to represent a larger proportion of the population. Our finding indicates that the female neck cannot be regarded as a scaled-down version of the male neck in size, particularly when evaluating neck-related injuries which are prevalent even in low-speed crashes.

LIMITATIONS

A limitation of this study lies in the composition of the anthropometric dataset, which was collected from individuals in military service, and therefore reflects a younger adult population and may represent a selected population in terms of fitness and health status. Although greater variability can be expected with inclusion of an older and more general population sample, the inferences remain valid as height and mass are used as predictor variables in the regression models.

CONCLUSIONS

The morphology of neck structure shows distinct patterns between women and men, indicating the need for sex-specific representations in injury evaluations. This study provides the geometric reference values for female models recently developed and currently under development, especially to define anthropometry and develop injury criteria.

ACKNOWLEDGMENTS

The project was funded by Chalmers Area of Advance Transport project Human Body FE-modeling for multidisciplinary prediction of whiplash injury.

REFERENCES

[1] Schoner, Jessica, Rebecca Sanders, and Tara Goddard, "Effects of Advanced Driver Assistance Systems on Impact Velocity and Injury Severity: An Exploration of Data from the Crash Investigation Sampling System," *Transportation Research Record: Journal of the Transportation Research Board* 2678 no. 5, (2024): 451–462, doi:10.1177/03611981231189740.

[2] Horsch, John D., "Evaluation of Occupant Protection from Responses Measured In Laboratory Tests," Paper presented at SAE International Congress and Exposition February 23, 1987, doi:10.4271/870222.

[3] Östling, Martin, Hanna Jeppsson, Jolyon Carroll, et al., "Injury Frequencies and Injury Risks in Frontal Car Crashes for AIS2+ and AIS1 Injuries that may lead to Long-Term Impairment – a GIDAS investigation," Paper presented at IRCOBI 2025.

[4] Östling, Martin, Hanna Jeppsson, and Jason Forman, "Injury Observations in High-exposure, Low-severity Frontal Car Crashes - a GIDAS Investigation," Paper presented at IRCOBI 2024.

[5] Jakobsson, Lotta, Hans Norin, and Mats Y. Svensson, "Parameters Influencing AIS 1 Neck Injury Outcome in Frontal Impacts," *Traffic Injury Prevention* 5 no. 2, (2004): 156–163, doi:10.1080/15389580490435989.

[6] Bunketorp, Olle, Lotta Jakobsson, and Hans Norin, "Comparison of Frontal and Rear-End Impacts for Car Occupants with Whiplash-associated Disorders: Symptoms and Clinical Findings," Paper presented at IRCOBI 2004.

[7] Stigson, Helena, Maria Boström, and Anders Kullgren, "Health status and quality of life among road users with permanent medical impairment several years after the crash," *Traffic Injury Prevention* 0 no. 0, (2020): 1–6, doi:10.1080/15389588.2020.1817416.

[8] Carlsson, Anna, *Addressing Female Whiplash Injury Protection: A Step Towards 50th Percentile Female Rear Impact Occupant Models*, PhD, Chalmers University of Technology, 2012.

[9] Stemper, Brian D., and Brian D. Corner, "Whiplash-Associated Disorders: Occupant Kinematics and Neck Morphology," *Journal of Orthopaedic & Sports Physical Therapy* 46 no. 10, (2016): 834–844, doi:10.2519/jospt.2016.6846.

[10] Stemper, Brian D., Narayan Yoganandan, Frank A. Pintar, et al., "Anatomical Gender Differences in Cervical Vertebrae of Size-Matched Volunteers:," *Spine* 33 no. 2, (2008): E44–E49, doi:10.1097/BRS.0b013e318160462a.

[11] Vasavada, Anita N., Jonathan Danaraj, and Gunter P. Siegmund, "Head and neck anthropometry, vertebral geometry and neck strength in height-matched men and women," *Journal of Biomechanics* 41 no. 1, (2008): 114–121, doi:10.1016/j.jbiomech.2007.07.007.

[12] John, Jobin D., I. Putu A. Putra, and Johan Iraeus, "Finite Element Human Body Models to study Sex-differences in Whiplash Injury: Validation of VIVA+ passive response in rear-impact," Paper presented at 2022, https://www.ircobi.org/wordpress/downloads/irc22/pdf-files/2236.pdf.

[13] Siegmund, Gunter P., John R. Brault, and Dennis D. Chimich, "Do Cervical Muscles Play a Role in Whiplash Injury?," *Journal of Whiplash & Related Disorders* 1 no. 1, (2002): 23–40, doi:10.3109/J180v01n01_03.

[14] Gordon, Claire C., Cynthia L. Blackwell, Bruce Bradtmiller, et al., *2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics*, NATICK/TR-15/007, Kansas St., Natick, MA, USA: U.S. Army Natick Soldier Research Development & Engineering Center, 2014, https://www.hsdl.org/?abstract&did=762624.

[15] Fichera, Chiara, Carol A. Flannagan, and Jobin D. John, "Quantifying Sex-differences in Anthropometry: a Bayesian approach," Paper presented at IRCOBI 2024.

[16] Jelenkovic, Aline, Yoon-Mi Hur, Reijo Sund, et al., "Genetic and environmental influences on adult human height across birth cohorts from 1886 to 1994," *eLife* 5, (2016): e20320, doi:10.7554/eLife.20320.