Design for Human Variability – Final Project (EDSGN / IE 547)

Virtual Reality Headset Design

Anthropometric Recommendations for Improved Accommodation

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15th December 2023

1. Introduction and Motivation

The advent of Virtual Reality (VR) technology has revolutionized how we interact with digital environments, yet a significant challenge persists in the universal design of VR headsets. The diversity in human head and facial dimensions presents a crucial ergonomic concern that current designs often overlook. This oversight not only affects comfort but also accessibility and usability for a wide range of users. Ensuring anthropometric accommodation in VR headsets is therefore not just a matter of user comfort, but a step towards inclusive and universal design. This is particularly critical in applications such as education, healthcare, and gaming, where VR's potential is immense. Incorporating comprehensive anthropometric data in the design process is essential to create VR headsets that are truly user-centric, promoting wider adoption and enhancing user experience across diverse demographic groups.

This final project presents an innovative approach to VR headset design, centering on the principle of improved anthropometric accommodation. Our goal is to develop a headset that excels in ergonomic inclusivity. This involves an approach to gathering and analyzing anthropometric data from diverse populations, ensuring our design meets a wide range of physical dimensions. We will concentrate on key metrices like head width, circumference, interpupillary distance, and nose bridge size. By doing so, it aspires to set a new standard in VR headset design, one that embraces diversity and ensures a universally enjoyable VR experience.

2. Literature Review

This review includes studies ranging from general head and facial measurements to specific dimensions such as nose width and head width, primarily within the US and Indian populations. The referenced works provide a comprehensive view of the physical diversity of potential VR headset users, which is critical for designing products that address a wide range of ergonomic needs and preferences.

Kalia et al. (2008) focuses on estimating stature through odontometry and skull anthropometry. It also highlights the correlation between various dental & skull measurements with overall stature, giving insights for understanding head size variations. Singh et al. (2013) provides insights into the variation in head sizes among Indians. This is significant for the development of virtual reality headsets that can accommodate a diverse range of users, ensuring comfort and fit for people of different ethnicities and age groups.

Mehta and Srivastava et al. (2017) address the issue of comfort and fitting around the nose area which is a common problem with current VR models. The study aims to create VR headsets that are more inclusive and comfortable for a diverse user base by understanding the range of nose sizes and shapes prevalent in the Indian population. This will enhance the overall user experience. Maseedupalli et al. (2023) focuses on head and facial anthropometry of the Indian population for the purpose of designing spectacles and head gear. The findings are valuable for understanding facial dimensions and the anthropometric measures relevant to VR headset design which are based on similar lines.

As part of this study, it was hypothesized that accommodations for the primary and secondary populations would vary, even across ethnicities and based on our analysis, we would be providing recommendations for the accommodation of 95% of primary and secondary populations, across ethnicities.

3. Methods

The aim of this study was to analyze US civilian and Indian civilian populations and provide recommendations for VR Headset design to accommodate 95% of both these populations. Further, we understood that the design recommendations could not only be a function of anthropometry, but a function of preference as well. As such, we took into account the measures of nose breadth, head width, head circumference, and Interpupillary Distance (IPD) for our analysis across both populations. Additionally, fit trials were conducted on a sample of 5 Graduate Students at the Pennsylvania State University, to get a better understanding of their preference of fit of VR Headsets. The VR headset used for the virtual fit trials was the Meta Quest 2.

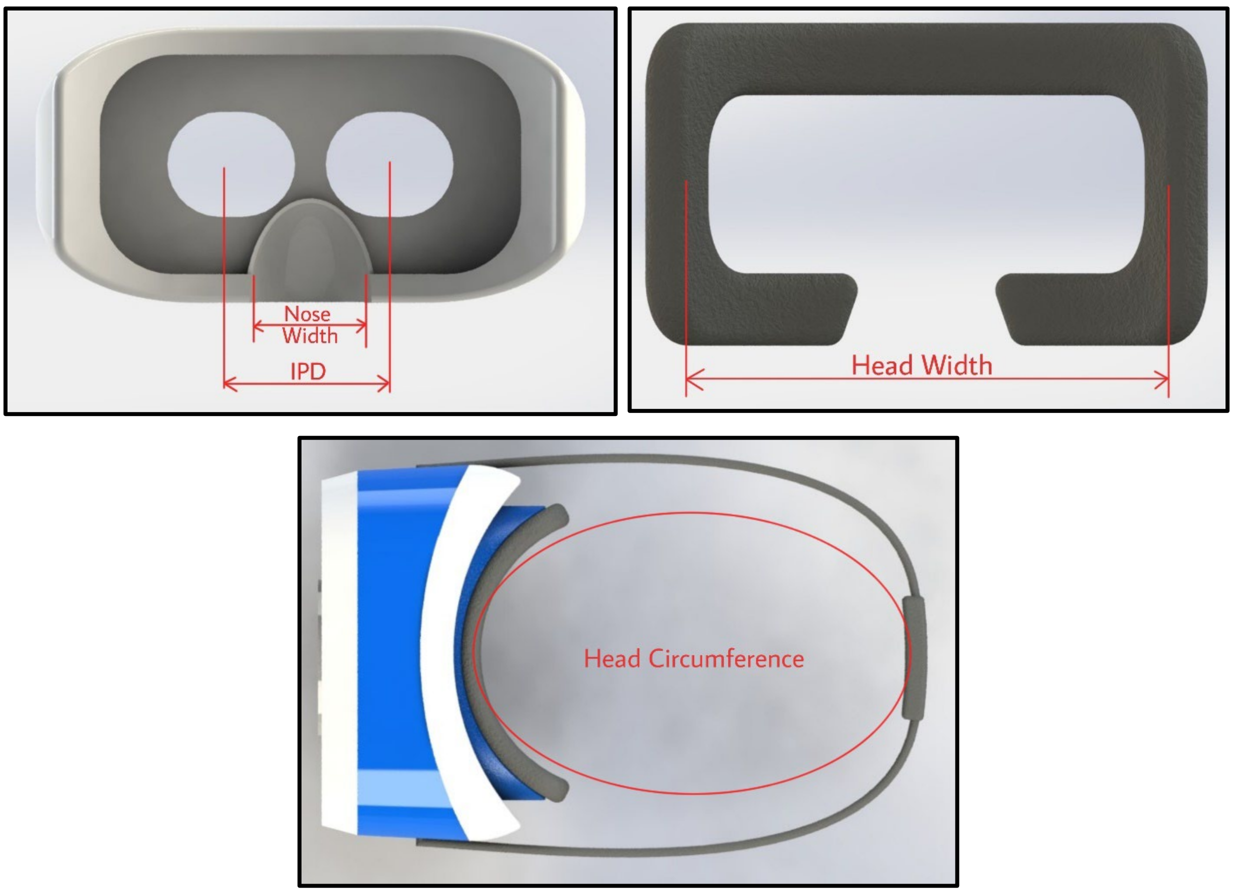

Figure 1: Anthropometric measures considered for a VR headset

Based on the results of our fit trial, we found out that all of the participants of the fit trials preferred the maximum strap extension length and would have preferred an even looser fit for long-term use of the VR Headset. The strap extension length correlates to the Head Circumference measure, and as a result, we decided to accommodate 10mm of additional adjustability (related to preference) in order to get the head circumference accommodation. Fig. 2 shows a participant undergoing the fit trials.

Figure 2: Trials on Meta Quest 2

In order to provide recommendations for our primary population (US Civilian Population), we analyzed the ANSUR I Headboard Data and NHANES 2013-2016 datasets. Further, in order to come up with the design recommendations for the secondary population (Indian Civilian Population), we utilized data published in existing studies such as Maseedupalli et al. (2023), Mehta and Srivastava et al. (2017), and Chakrabarti, D. (1997). Statistical techniques such as Data synthesis with Residual Variance, Quantile-based Synthesis, and Disproportionate Disaccommodation Analysis were utilized to come up with the recommendations, details of which are given in the following sections.

4. Data Analysis

For analysis of the primary population, ANSUR I Headboard data was utilized for the measure Nose Breadth, whereas the other three measures namely, head width head circumference, and IPD were taken from the regular ANSUR data. Data from ANSUR and ANSUR I Headboard was combined into a single data set for further analysis. Since our aim was to analyze US civilian data, we utilized the regression with residual variance technique to get the appropriate quantiles for our chosen measures in terms of the NHANES 2013-2016 data. This process involved the following steps:

i. Cleaning the data in NHANES (in terms of removing NAs) and choosing only relevant variables for our analysis (*Stature* - BMXHT, *BMI* - BMXBMI, *Race* - RIDRETH3, *Statistical Weights* - combinedWeight).

ii. Creating the linear regression model from the combined ANSUR I and ANSUR I Headboard data set. The response variables in this case were the four measures chosen by us and the predictor variables were chosen to be Stature and BMI, since they provided the maximum adj. R^2 values.

iii. Next, the model coefficients (of the predictor variables and the intercept) were added to the respective stature and BMI measures of the NHANES 2013-2016 data.

iv. Further, in order to perform regression with residual variance, a stochastic rnorm term was added.

v. Additionally, in the case of head circumference measures, an additional 10mm of variability was included to accommodate user preferences.

vi. Further, weighted quantiles (with reference to the combined weights) for the measure calculated using regression with residual variance was calculated and since the values would include a stochastic term, the code was repeated a number of times to ensure the values were in a reasonable range.

vii. Finally, the accommodation was calculated by checking different ranges of values for the measures. The entire process was repeated on all four measures and overall multi-variate accommodation was calculated.

For the analysis of the secondary population, since we only had access to summary statistics of the measures of interest from the different studies, we decided to conduct a quantile-based synthesis to come up with the required data for the measures for the Indian population. One of the key advantages of using the quantile-based synthesis method is that it re-engineers data from summary statistics, all the while preserving the relationships between the different measures. For our purpose, we acted on the assumption that the VR headsets would be used by populations balanced for gender and hence assumed an equal population split while using statistical weights for our analysis.

Based on the data for the Indian population re-engineered from quantile-based synthesis, we compared the Probability Density Functions (PDFs) for both male and female populations across the four different measures, to the data available for the US Civilian population (from the combined ANSUR I and ANSUR I Headboard data set). Below is the comparison of the PDFs across different measures:

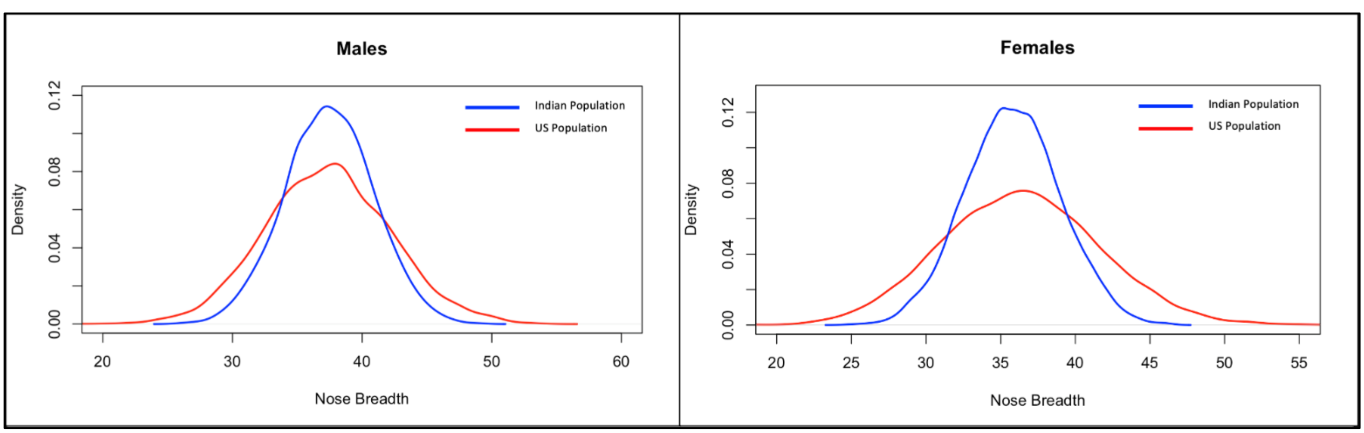

Fig.3: PDF comparison for Nose Breadth across males and females in both populations.

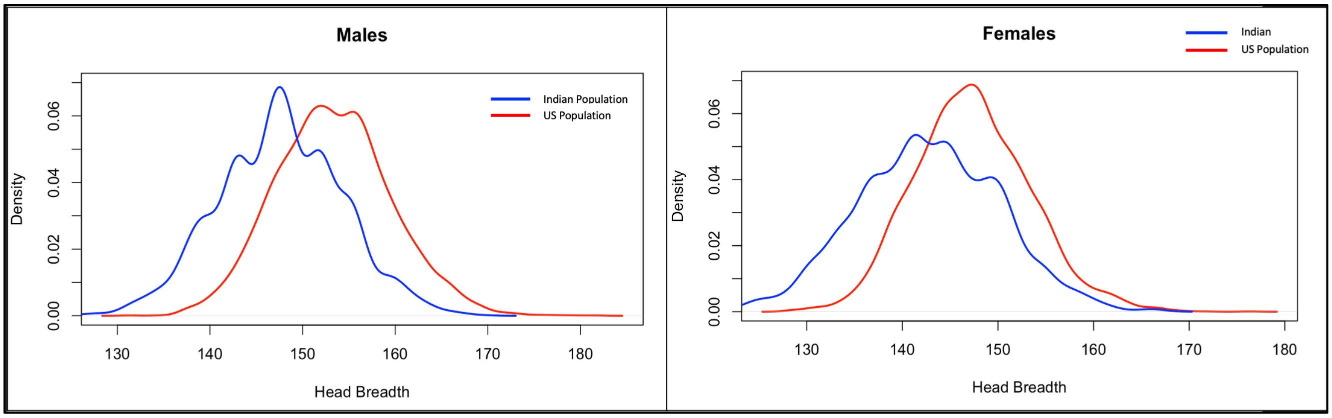

Fig.4: PDF comparison for Head Breadth across males and females in both populations.

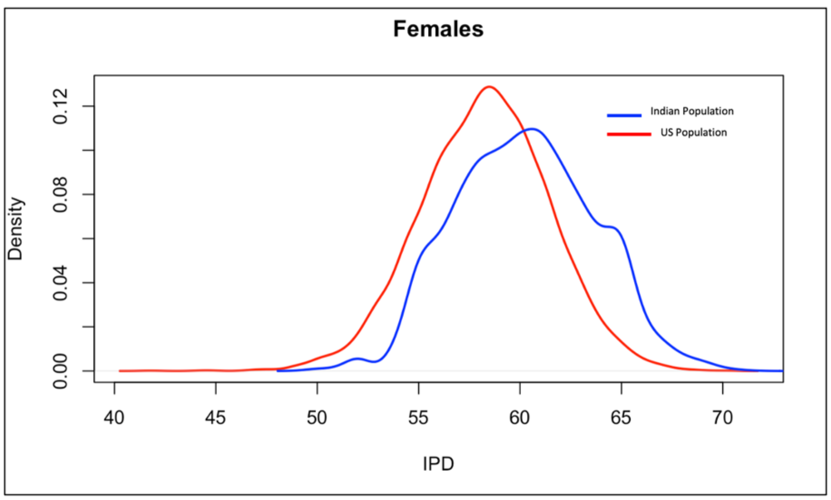

Fig.5: PDF comparison for IPD across females in both populations.

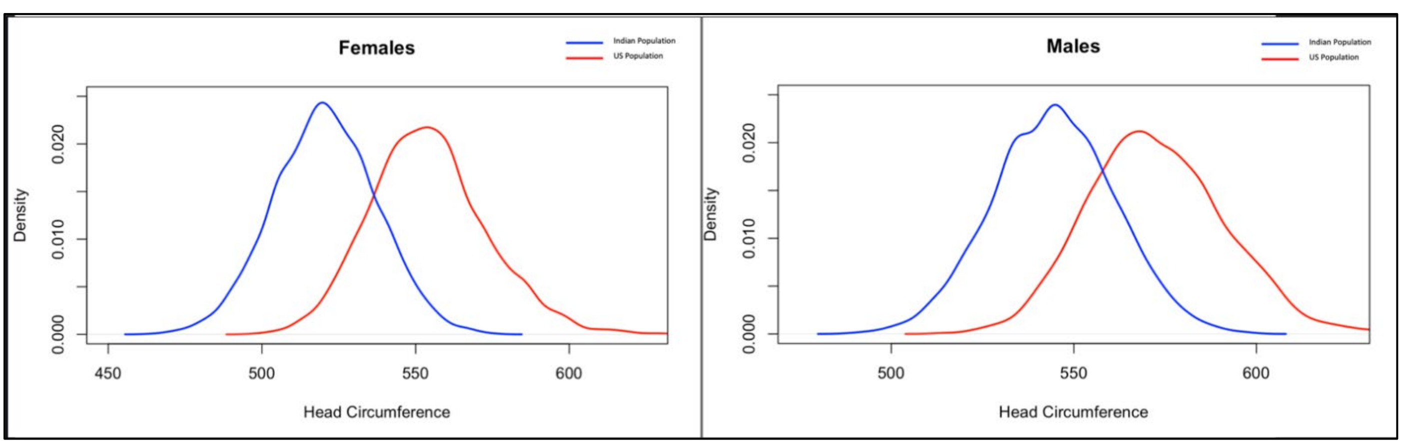

Fig.6: PDF comparison for Head Circumference across males and females in both populations.

As we can see from the comparison of the PDF plots in Fig.3, the distribution for nose breadth across both US and Indian populations seems to be centered around the mean however, the distribution of the Indian population is comparatively less spread out. From Fig. 4 we can observe that head breadths for the US population across both males and females seem to be wider and have a greater difference when compared to nose breadth measures. Fig. 5 showcases that IPD in females across both populations seems to have a similar distribution however, the IPD for the Indian female population is slightly larger. Further, Fig. 6 showcases the probability distributions for head circumference for both males and females across both populations. From this figure we can see that, the head circumference measure showcases the largest difference between the US and Indian populations amongst our selected measures. The head circumference for both US civilian males and females is greater than their Indian counterparts.

Additionally, a further analysis was conducted to understand the effects of disproportionate disaccomodation on the different races in the US Civilian population (based on the NHANES 2013-2016 data) for our design recommendations. As defined in the data set, the following races were taken under consideration: Mexican American and Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian, and Non-Hispanic others, including multi-racial. The accommodation rates were calculated for males and females and combined overall based on the data obtained from the regression with residual variance method. Details of our analyses from on disproportionate disaccomodation are given in the results section below.

5. Results

Based on our analysis of both our primary and secondary populations, Table 1 below provides our design recommendations for the selected 4 anthropometric measures. We have provided the maximum and minimum values for adjustability of those 4 metrics to accommodate over 95% of the population irrespective of race, ethnicity or gender.

Table 1: Design Recommendations for all Measures for 95% accommodation across both Populations

Measure	Min Value (mm)	Max Value (mm)	Adjustability (mm)	US Male Accom (%)	US Female Accom (%)	Overall US Accom (%)	Indian Male Accom (%)	Indian Female Accom (%)	Overall Indian Accom (%)
Nose Breadth	25	48	23	97.96	97.09	95.06	99.83	99.90	99.74
Head Width	129	166	37	96.75	99.15	95.91	99.26	96.92	96.18
Head Circumference	492	615	107	97.35	99.56	96.92	99.88	95.24	95.13
Inter Pupillary Distance (IPD)	47	70	23	97.95	99.68	97.64	96.22	99.77	95.99

For the levels of accommodation that we wanted to achieve, we decided to build a VR prototype following our design recommendations. This prototype is modelled in CAD and provides the adjustability mentioned in Table 1.

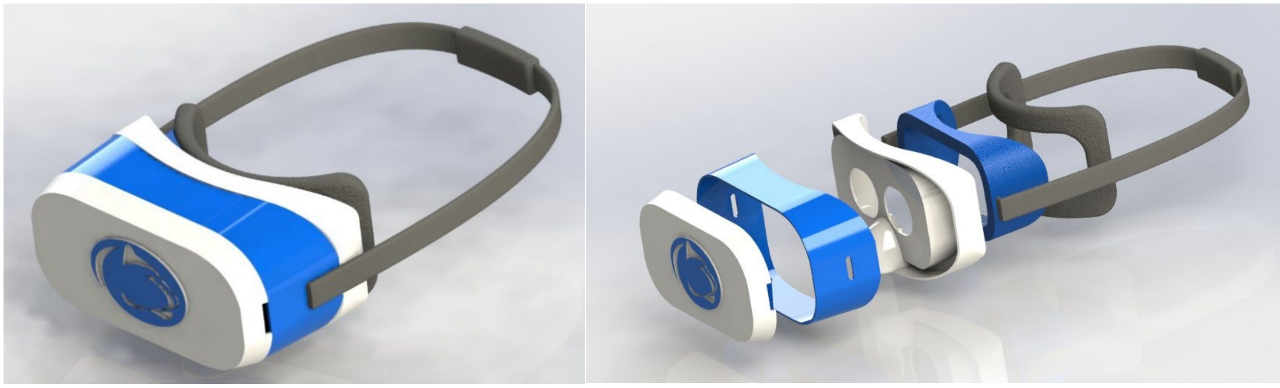

Figure 7: VR headset prototype

The design recommendation affects the accommodation of different races and genders differently. The tables below show a comparison between the levels of accommodation for the different races and genders from our primary dataset. Over 95% accommodation is achieved for every individual race ethnicity.

Table 2: Accommodation for the Non-Hispanic White population in the US

Measure	Non-Hispanic White – US Males Accom	Non-Hispanic White – US Females Accom	Non-Hispanic White – US Overall Accom
Nose Breadth	98.00	97.25	95.25
Head Width	97.23	99.73	96.96
Head Circumference*	97.93	99.68	97.61
Inter-Pupillary Distance (IPD)	99.93	99.85	99.79

Table 3: Accommodation for the Mexican American and Other Hispanic populations in the US

Measure	Mexican American and Other Hispanic – US Males Accom	Mexican American and Other Hispanic – US Females Accom	Mexican American and Other Hispanic – US Overall Accom
Nose Breadth	98.78	97.24	96.03
Head Width	97.92	99.79	97.72
Head Circumference*	98.16	99.76	97.93
Inter-Pupillary Distance (IPD)	100.00	100.00	100.00

Table 4: Accommodation for the Non-Hispanic Black population in the US

Measure	Non-Hispanic Black – US Males Accom	Non-Hispanic Black – US Females Accom	Non-Hispanic Black – US Overall Accom
Nose Breadth	97.35	96.85	94.20
Head Width	96.99	99.32	96.32
Head Circumference*	96.87	99.17	96.04
Inter-Pupillary Distance (IPD)	99.93	99.90	99.83

Table 5: Accommodation for the Non-Hispanic Asian population in the US

Measure	Non-Hispanic Asian – US Males Accom	Non-Hispanic Asian – US Females Accom	Non-Hispanic Asian – US Overall Accom
Nose Breadth	98.59	98.35	96.95
Head Width	100.00	99.84	99.84
Head Circumference*	99.81	100.00	99.81
Inter-Pupillary Distance (IPD)	100.00	99.82	99.82

Table 6: Accommodation for the Non-Hispanic other, including multi-racial population in the US

Measure	Non-Hispanic others, including multi-racial – US Males Accom	Non-Hispanic others, including multi-racial – US Females Accom	Non-Hispanic others, including multi-racial – US Overall Accom
Nose Breadth	95.33	97.20	92.54
Head Width	95.75	99.10	94.85
Head Circumference*	96.47	99.23	95.70
Inter-Pupillary Distance (IPD)	100.00	99.54	99.54

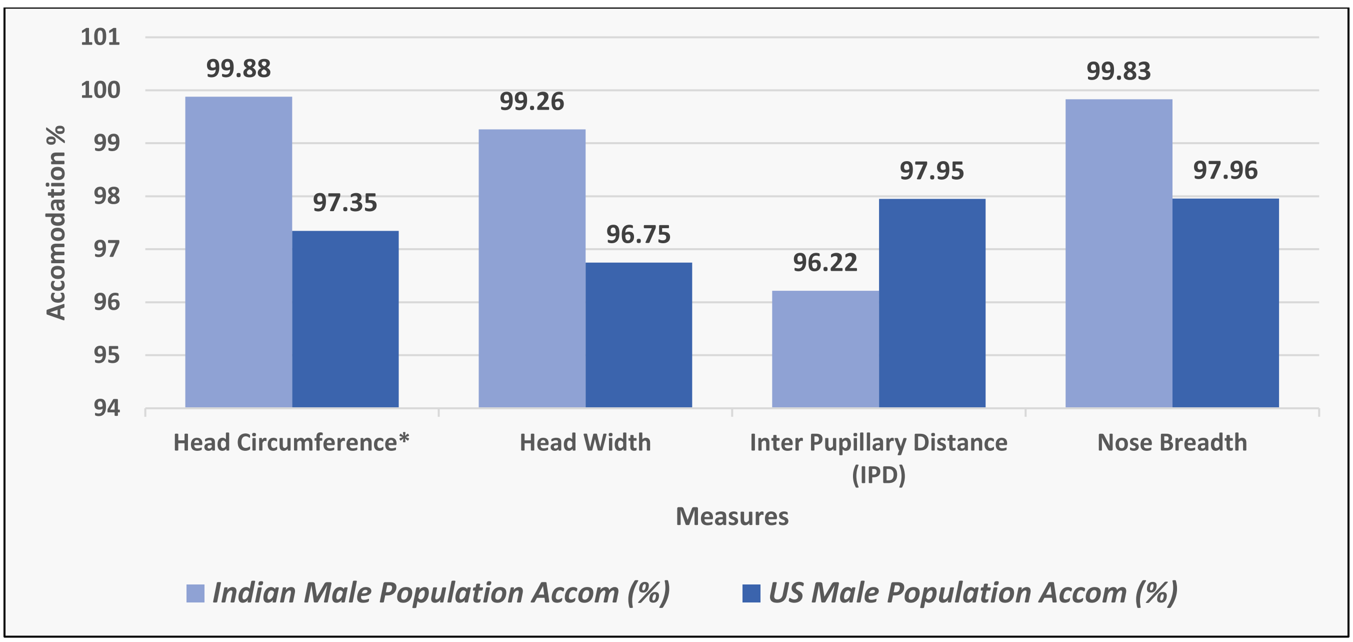

Figure 8: Comparison of Accommodation Percentages for Males between the Primary and Secondary Populations

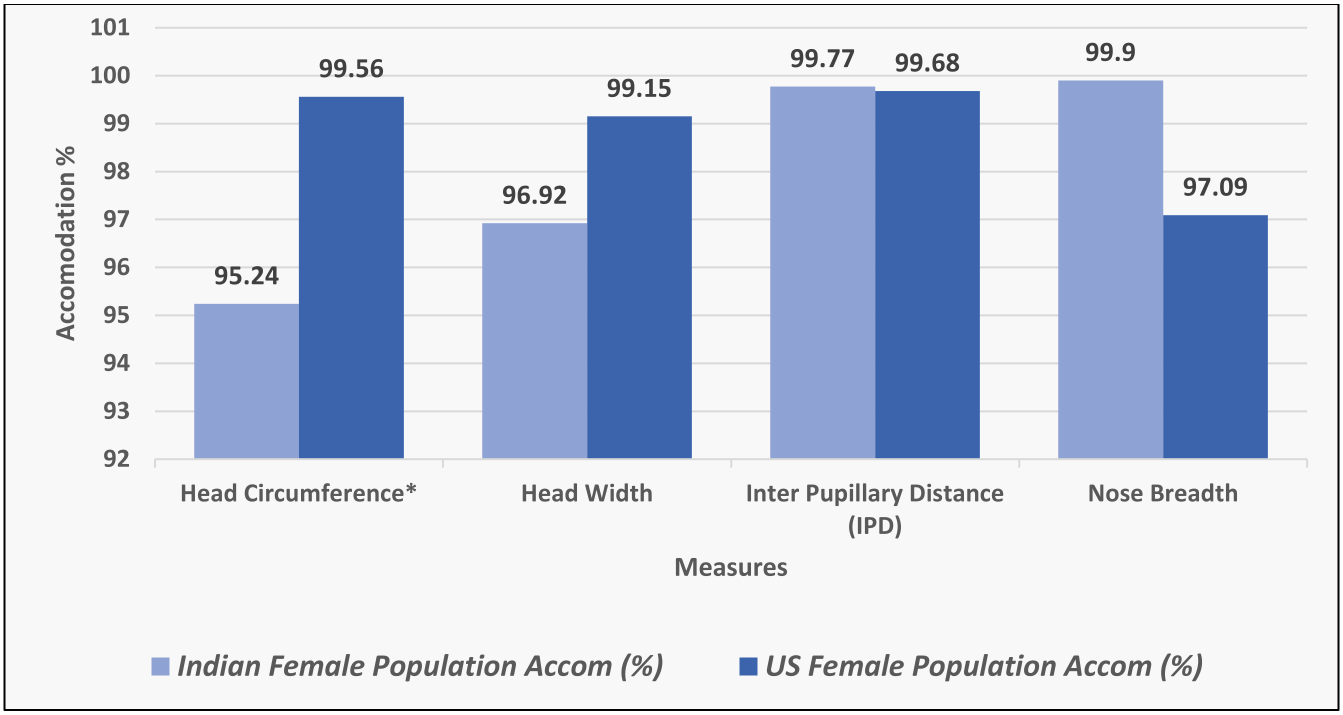

Figure 9: Comparison of Accommodation Percentages for Females between the Primary and Secondary Populations

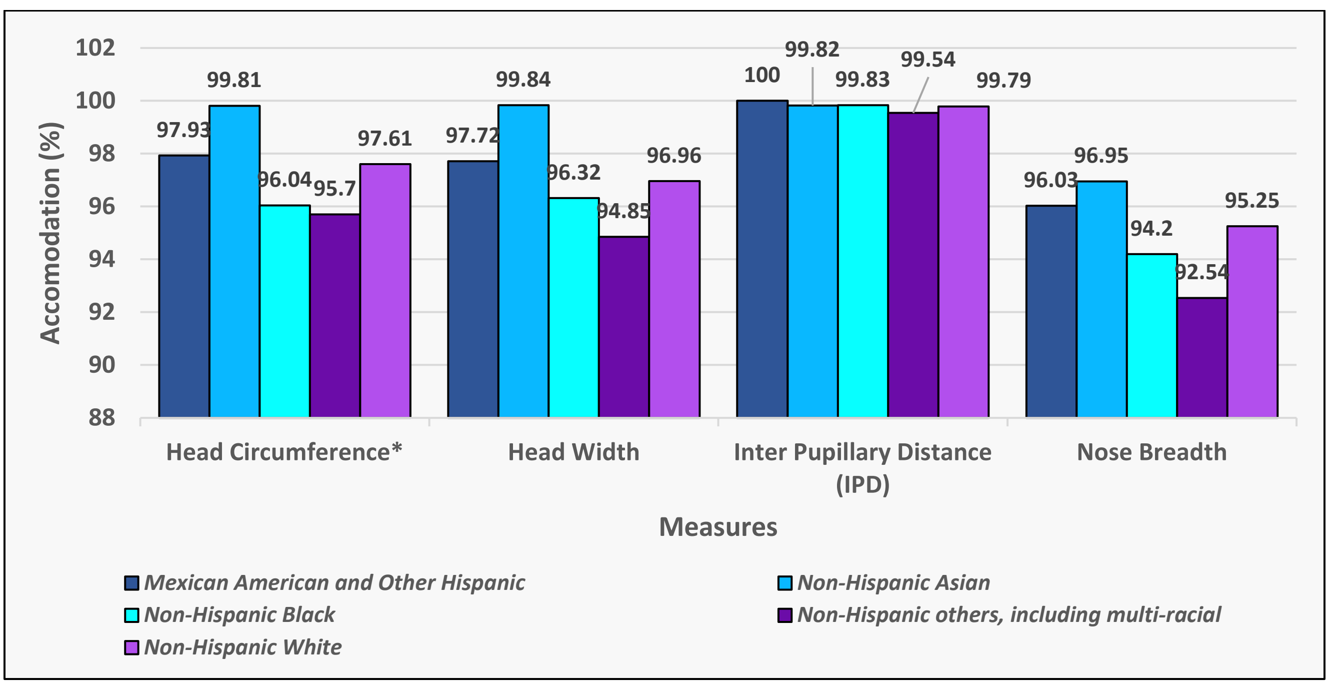

Figure 10: Comparison of overall accommodation between races in the US Population

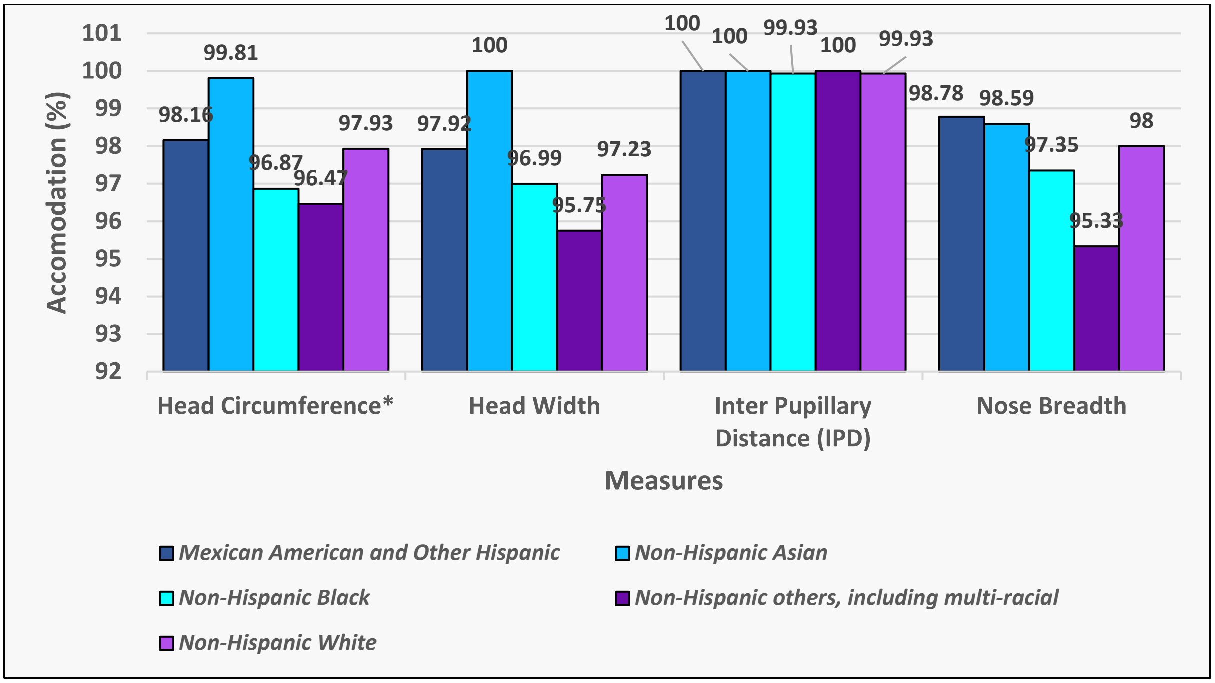

Figure 11: Comparison of accommodation for males between races in the US Population

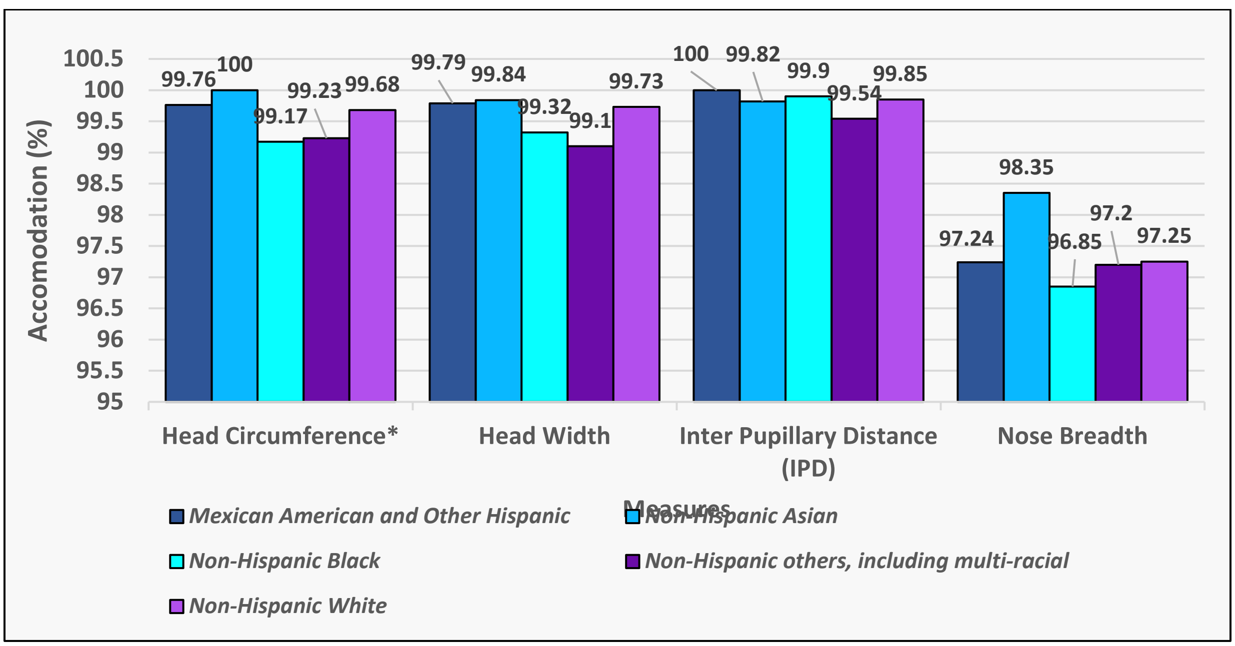

Figure 12: Comparison of accommodation for females between races in the US Population

The bar graph seen in Fig. 13 represents the multivariate analysis conducted on both the target populations and shows how overall accommodation is over 95% for both males and females of either demographic. The highest accommodated segment is that of US females at 96.46% and the lowest is of Indian men at 95.21%

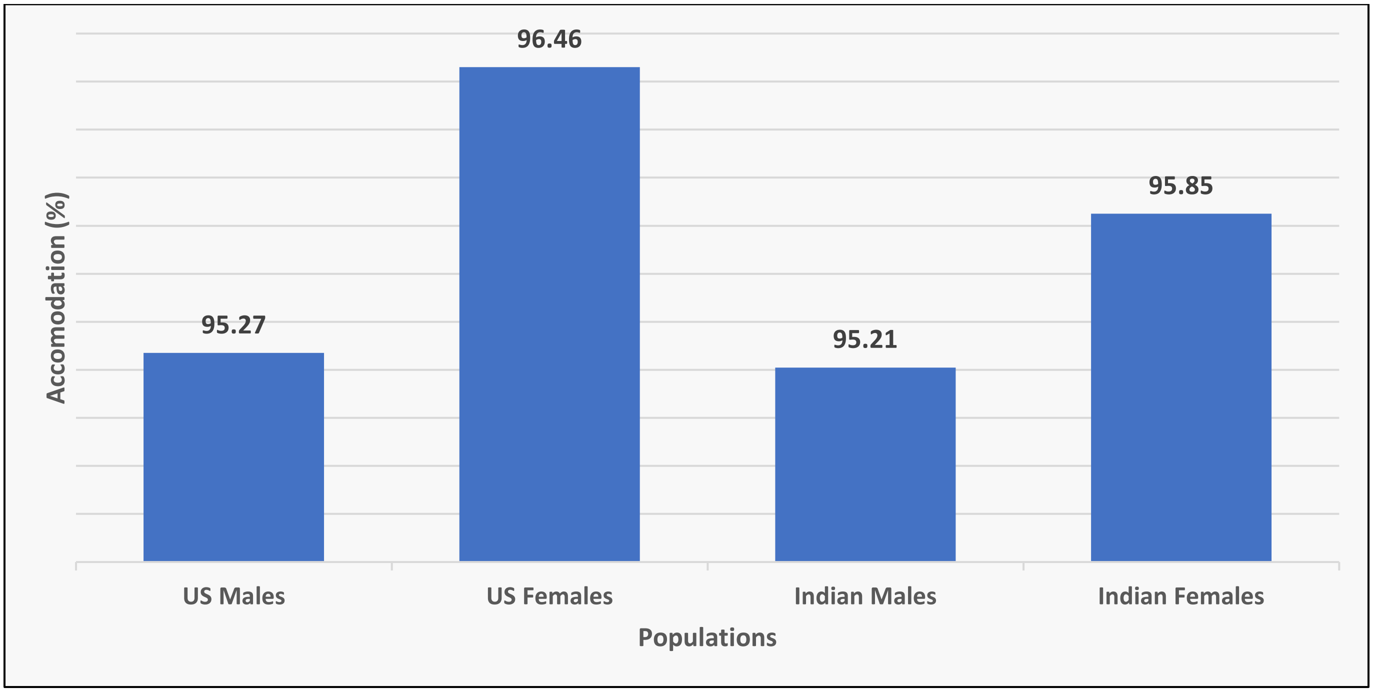

Figure 13: Multivariate accommodation for all measures in both populations

6. Discussion and Conclusion

This research has underscored the critical importance of integrating diverse anthropometric data into the design of VR headsets. The study aimed to accommodate 95% of both populations. Notably, for the U.S. population, the accommodation percentages for measures like nose breadth, head width, head circumference, and interpupillary distance (IPD) are 95.06%, 95.91%, 96.92%, and 97.64%, respectively. Similarly, for the Indian population, these percentages are 99.74%, 96.18%, 95.13%, and 95.99%. These findings highlight the disparities in head and facial dimensions across ethnicities, underscoring the necessity for adaptable VR headset designs.

This study's findings, while insightful, present certain limitations. The data on the Indian population was compiled from various sources with differing sample sizes, warranting caution before generalizing these results. Future research should aim for more uniform data collection to strengthen the validity of these findings. Additionally, an intriguing avenue for further investigation involves the cost of components. A detailed cost analysis could facilitate an optimization study, balancing the trade-off between optimal cost and the degree of anthropometric accommodation. This approach would not only enhance the design's inclusivity but also its economic feasibility.

The research emphasizes the importance of inclusive design in VR headsets. It specifically targets addressing diverse anthropometric needs, ensuring over 95% accommodation for crucial measures in U.S. and Indian populations. The study advocates for expanding this inclusive approach to other demographic groups and incorporating user feedback, aiming to make VR technology more accessible and comfortable for a wider range of users. This forward-looking perspective is essential for the advancement of VR headset design, prioritizing user comfort and inclusivity.

7. References

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