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Professor Jaeggli

Bioengineering Measurement, Engineering, and Statistics - Section 03

15 November 2024

Project 1: Statistical Testing of Human Anthropometry

Part 1 - Bioengineering Topic of Interest

For this project, I chose to study how average height and weight affects airplane seat design. This topic is easily applicable to everyday life, as the changing seat designs in commercial aircrafts affects consumer satisfaction and these changes are something that the average person witnesses and experiences any time they are on a plane. Additionally, this topic is interesting due to varying the motivations behind commercial and military airplane seat design.

Part 3 - Normal Distribution Generation

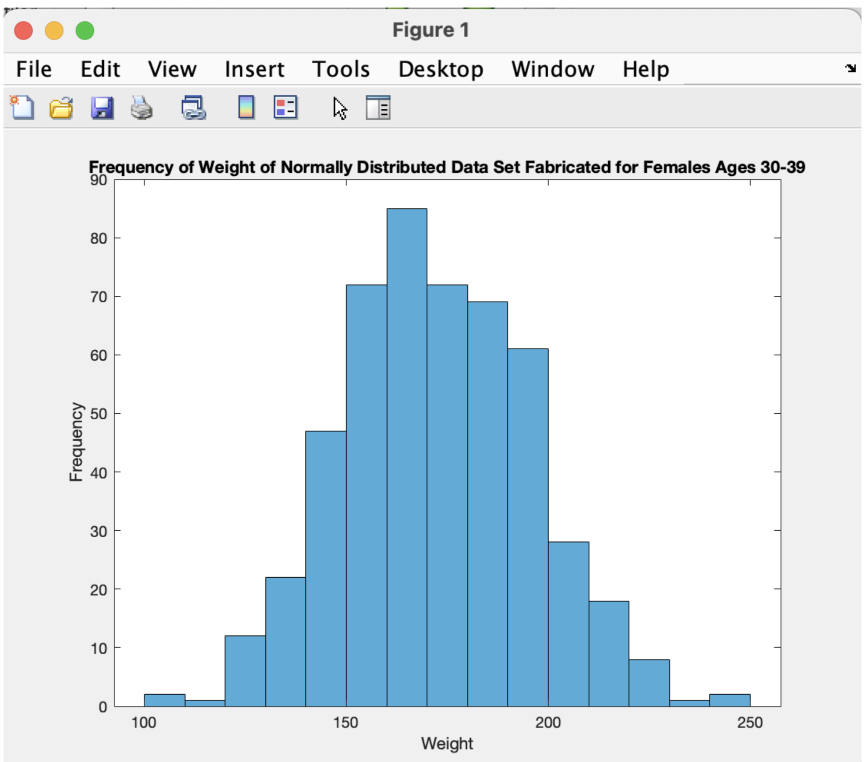

Figure 1: *Histogram of the Normal Distribution Data Generated for the Females Aged 30-39 Weight NHANES Statistics.*

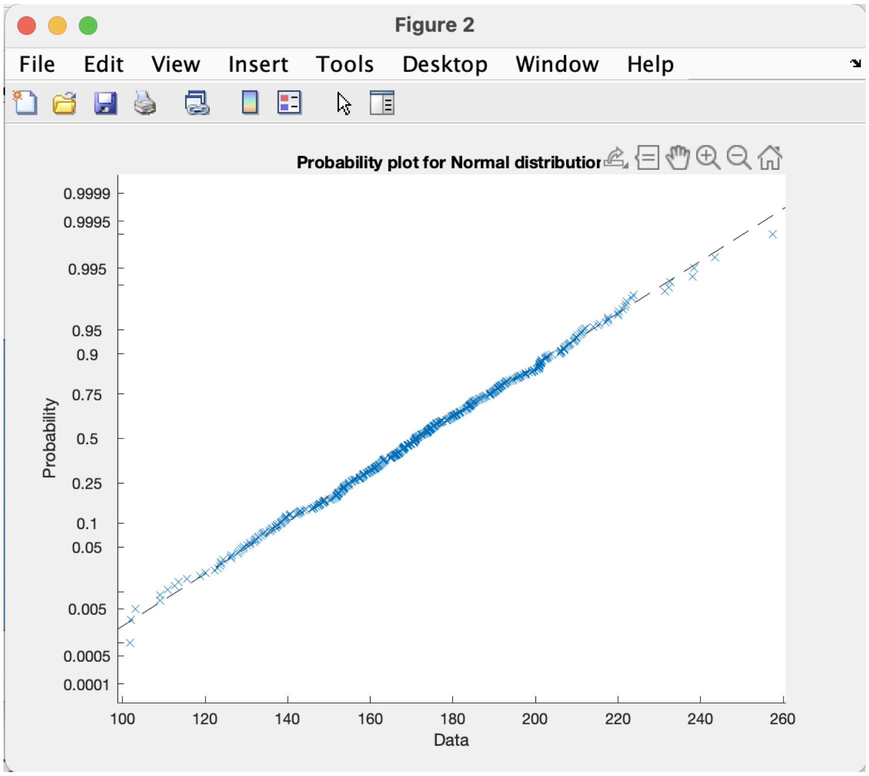

Figure 2: *Normal Probability Plot of the Normal Distribution Data Generated for the Females Aged 30-39 Weight NHANES Statistics.*

Based on the generated figures, the data is normally distributed. This is because the histogram generally follows the shape of a normal distribution. Additionally, in the probability plot, the data points fit closely and are distributed evenly along the line of normal distribution Therefore, it can be concluded the data set (Normal Distribution Data Generated for the Females Aged 30-39 Weight NHANES Statistics) is normally distributed.

Part 4 - Graphical Analysis of ANSUR and NHANES Data

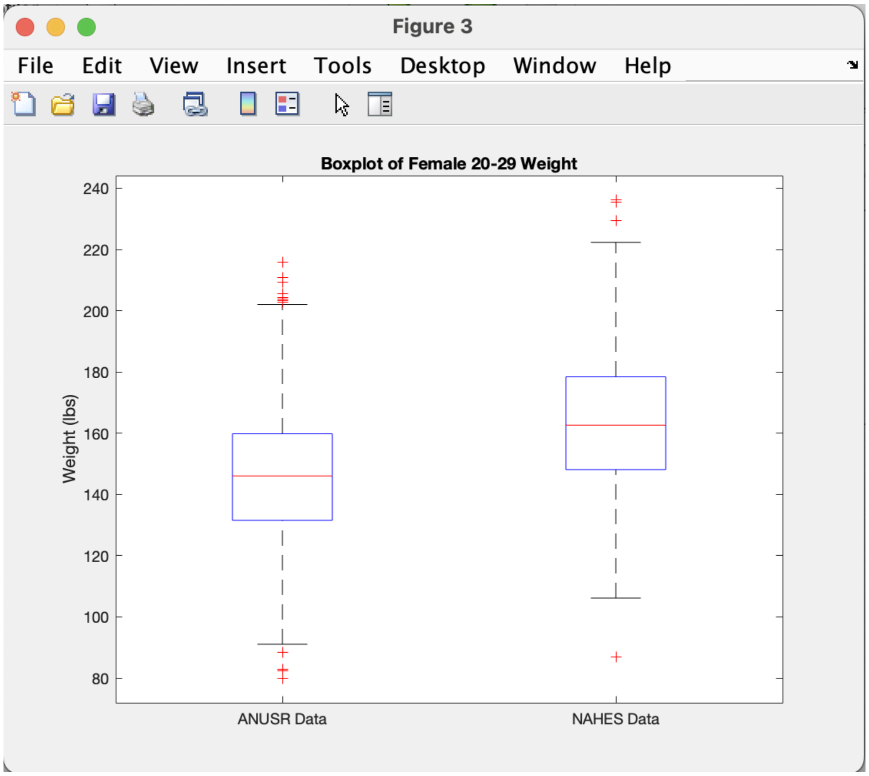

Figure 3: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Weight Data for Female Aged 20-29.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the NHANES data yields a higher weight as the interquartile range and median line are above that of the ANSUR data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are not extreme. Additionally, it appears that the ANSUR data has a larger variance than the NHANES data, as there are more outliers in the ANSUR data not included in the whiskers, representative of data points more than 1.5 times the standard deviation of the data set from the median.

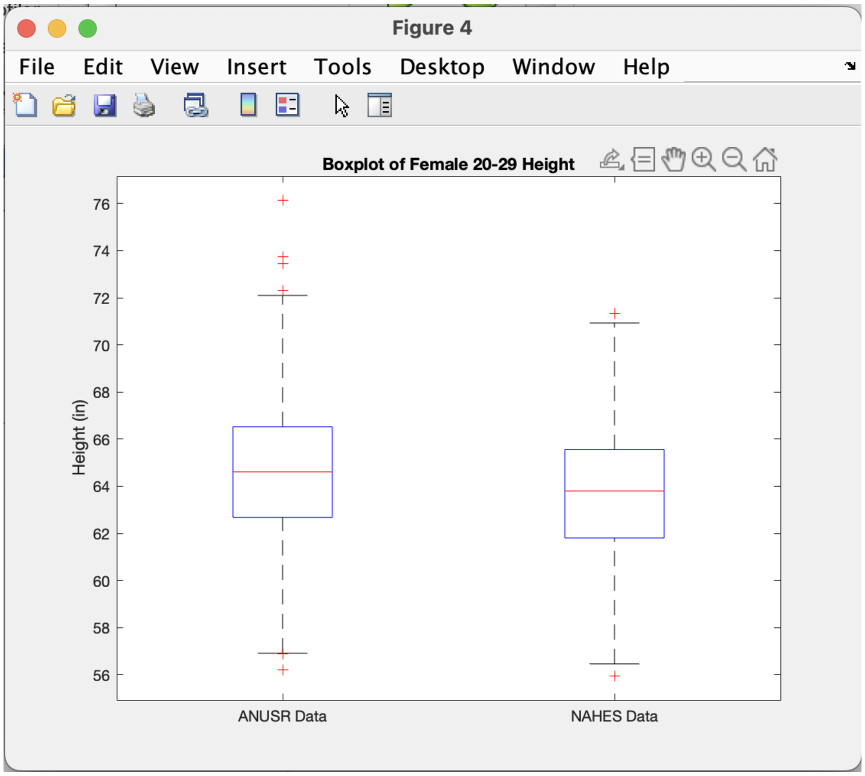

Figure 4: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Height Data for Female Aged 20-29.*

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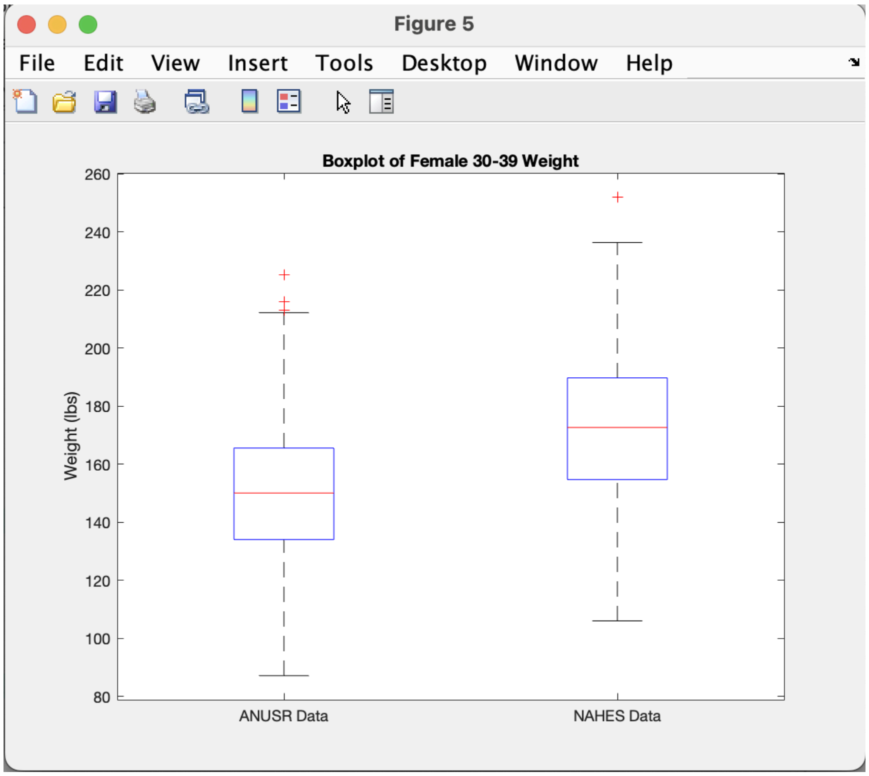

Figure 5: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Weight Data for Female Aged 30-39.*

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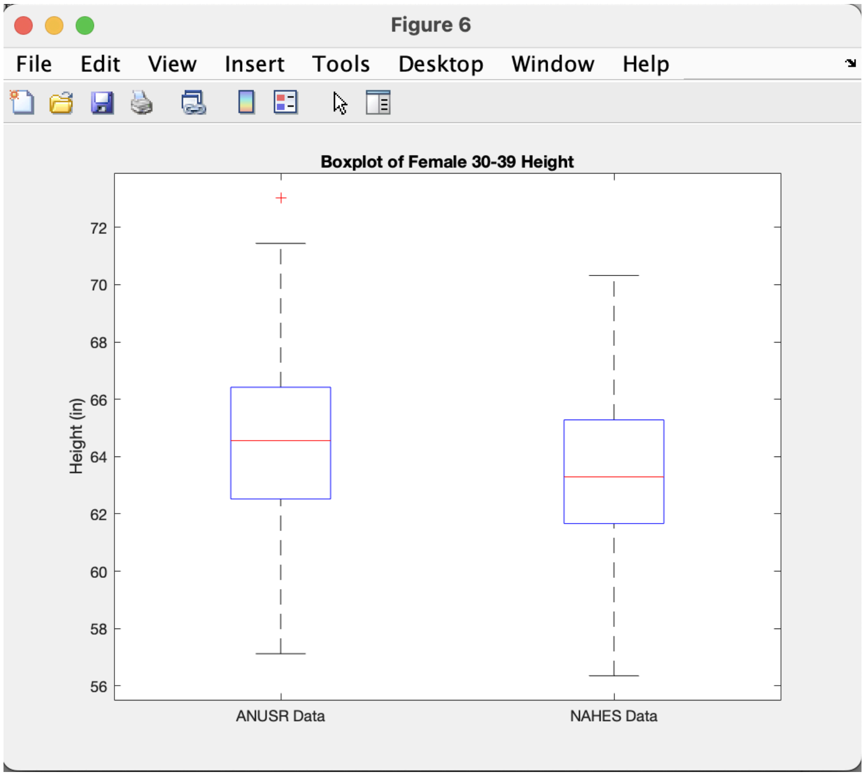

Figure 6: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Height Data for Female Aged 30-39.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the ANSUR data yields a slightly higher height as the interquartile range and median line are above that of the NHANES data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are slight. Additionally, it appears that the variances of both the ANSUR and NHANES are approximately equal as there are about the same number of outliers.

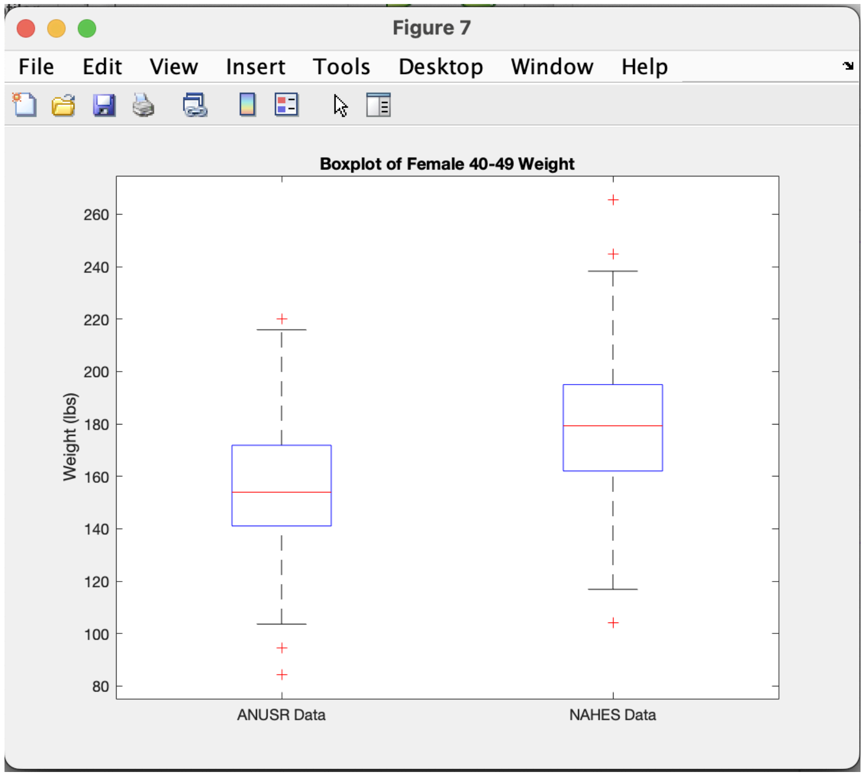

Figure 7: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Weight Data for Female Aged 40-49.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the NHANES data yields a higher weight as the interquartile range and median line are above that of the ANSUR data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are not extreme. Additionally, it appears that the variances of both the ANSUR and NHANES are approximately equal as there are about the same number of outliers.

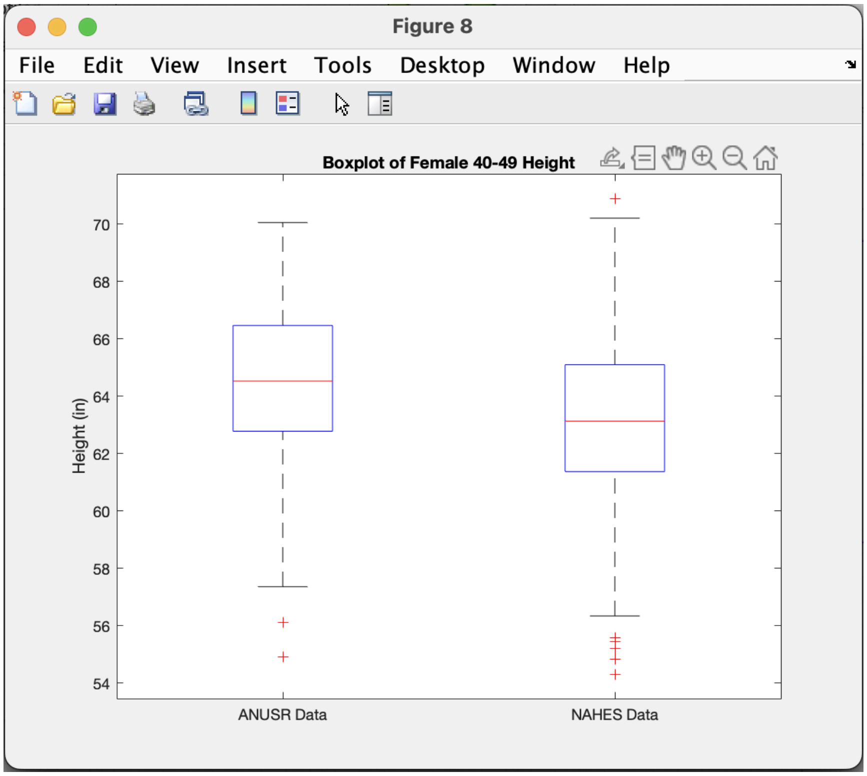

Figure 8: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Height Data for Female Aged 40-49.*

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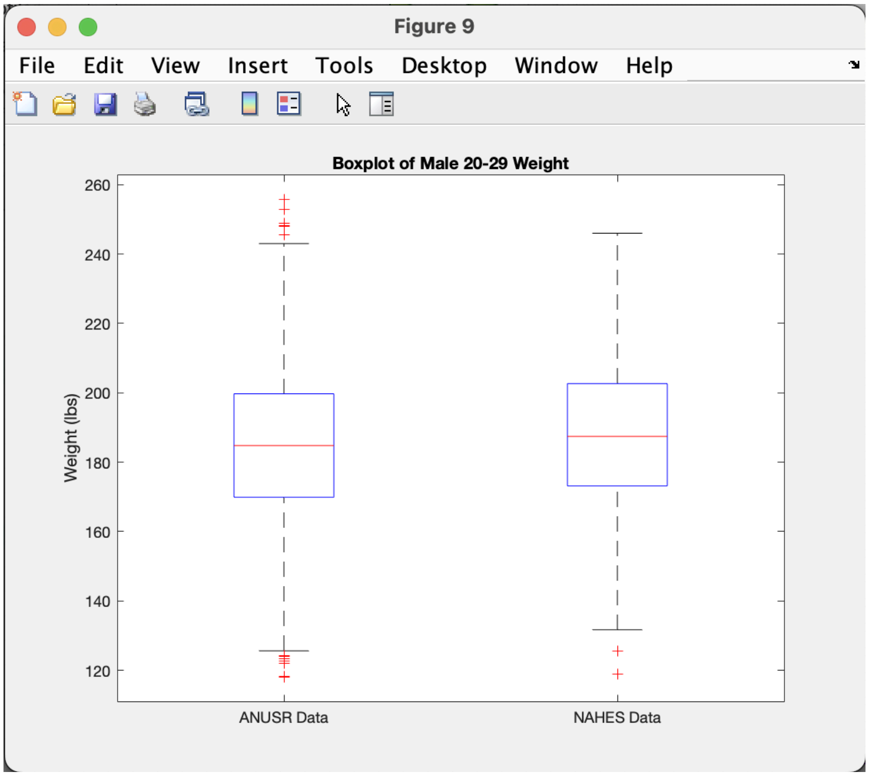


Figure 9 *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Weight Data for Males Aged 20-29.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the NHANES data yields a slightly higher weight as the interquartile range and median line are above that of the ANSUR data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are very slight. Additionally, it appears that the ANSUR data has a larger variance than the NHANES data, as there are more outliers in the ANSUR data.

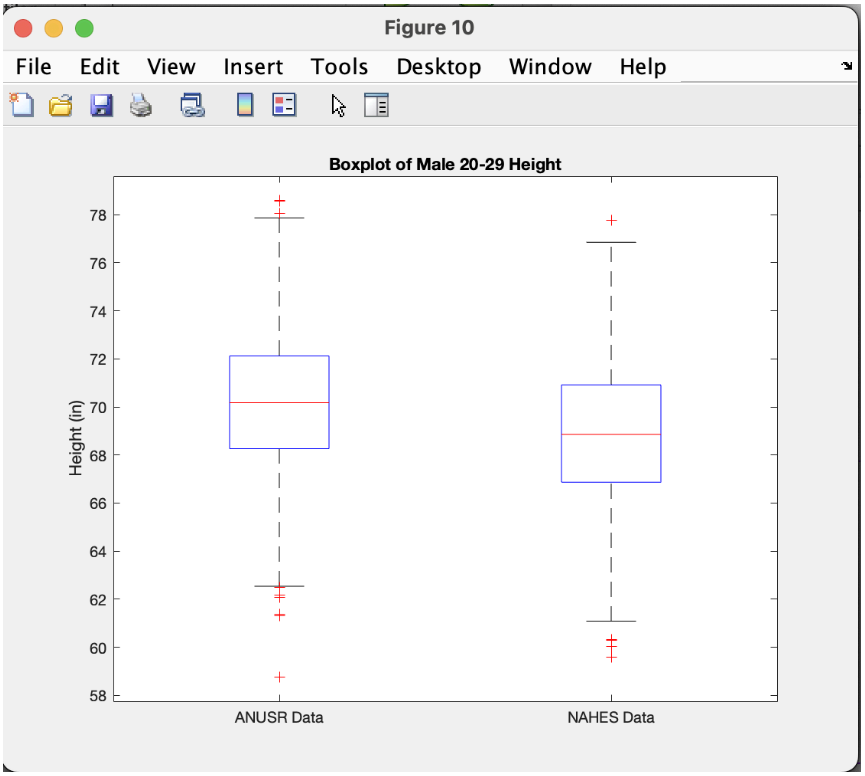


Figure 10: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Height Data for Males Aged 20-29.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the ANSUR data yields a slightly higher height as the interquartile range and median line are above that of the NHANES data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are very slight. Additionally, it appears that the ANSUR data has a larger variance than the NHANES data, as there are more outliers in the ANSUR data.

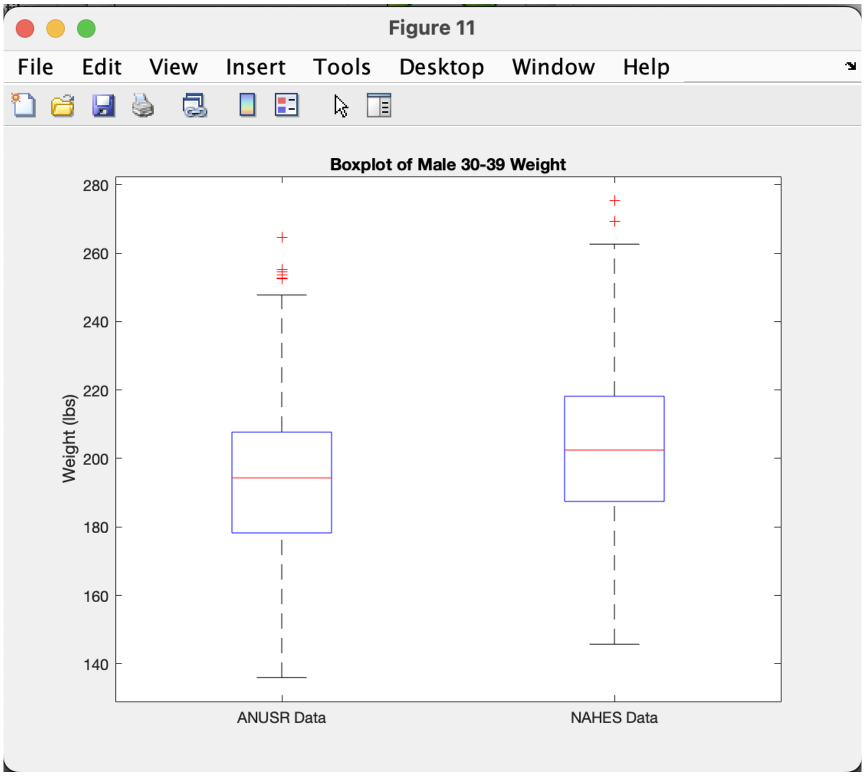


Figure 11: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Weight Data for Males Aged 30-39.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the NHANES data yields a slightly higher weight as the interquartile range and median line are above that of the ANSUR data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are very slight. Additionally, it appears that the variances of both the ANSUR and NHANES are approximately equal as there are about the same number of outliers.

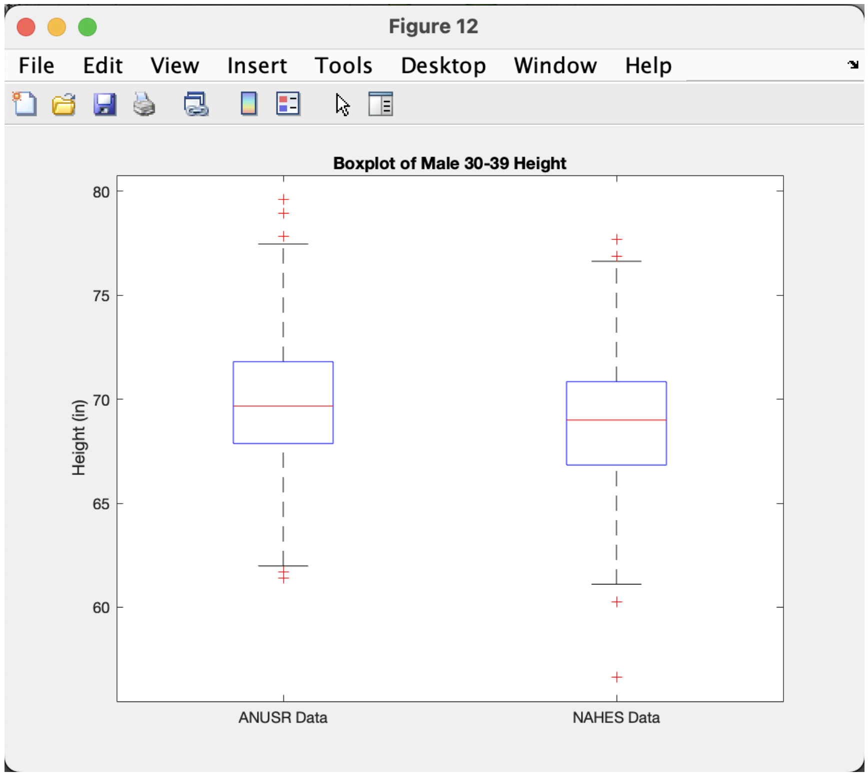


Figure 12: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Height Data for Males Aged 30-39.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the ANSUR data yields a slightly higher height as the interquartile range and median line are above that of the NHANES data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are very slight. Additionally, it appears that the variances of both the ANSUR and NHANES are approximately equal as there are about the same number of outliers.

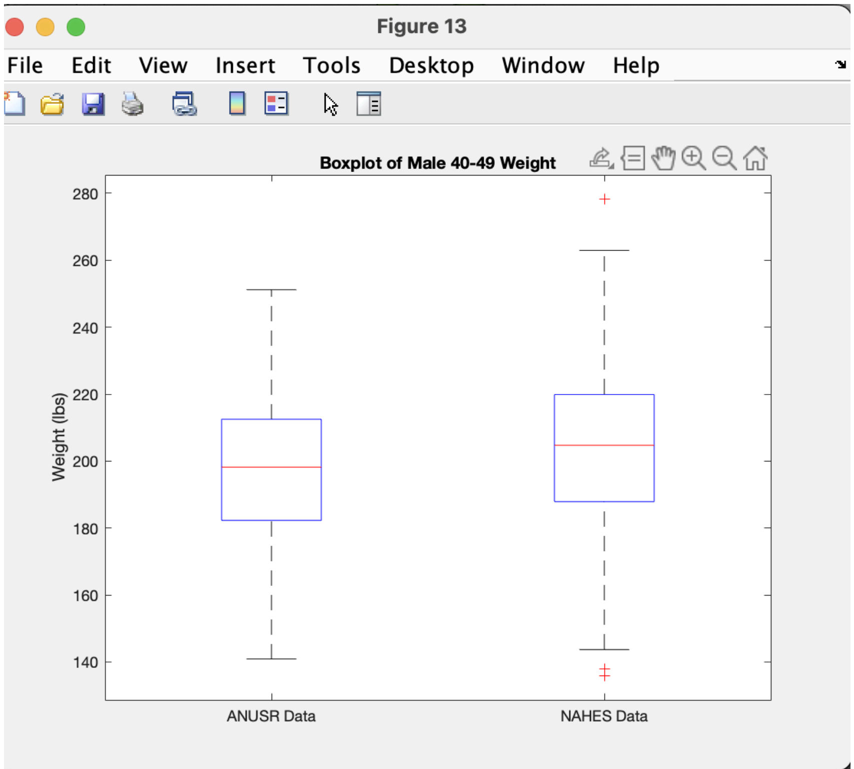


Figure 13: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Weight Data for Males Aged 40-49.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the NHANES data yields a slightly higher weight as the interquartile range and median line are above that of the ANSUR data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are very slight. Additionally, it appears that the variances of both the ANSUR and NHANES are approximately equal as there are about the same number of outliers.

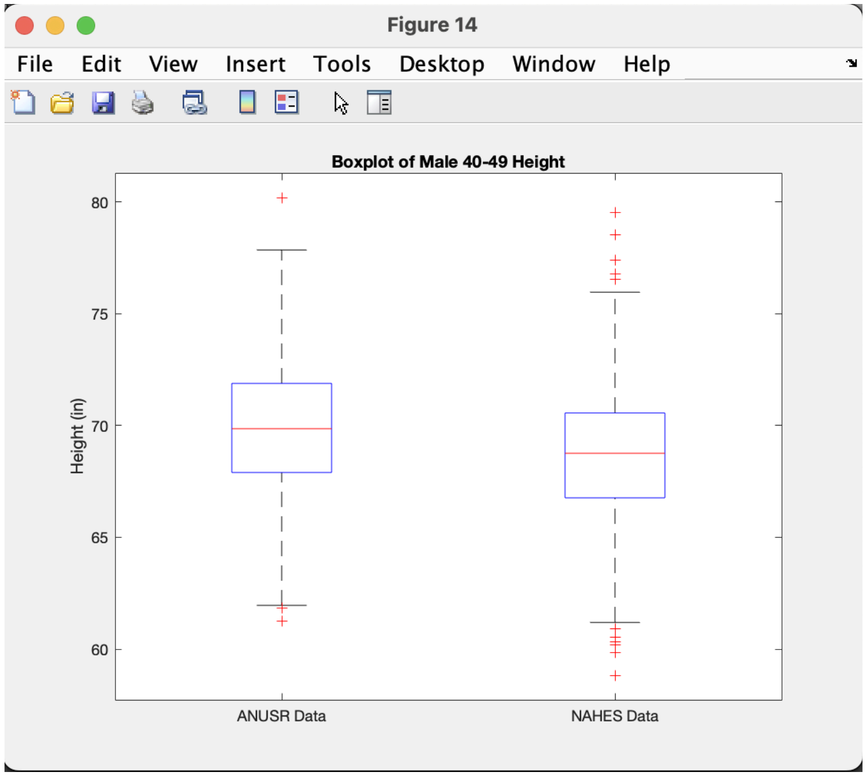


Figure 14: *Boxplots to compare the median, distribution, and variance of ANSUR and NHANES Height Data for Males Aged 40-49.*

When comparing the ANSUR and NHANES data for this group and measuring graphically, it appears that the ANSUR data yields a slightly higher height as the interquartile range and median line are above that of the NHANES data. However, it is possible this difference is due to chance rather than statistically significant difference, as the visual graphical differences are very slight. Additionally, it appears that the NHANES data has a larger variance than the ANSUR data, as there are more outliers in the NHANES data.

In general, throughout the Female Height and Weight data, based on graphical comparison it appears that NHANES generally had higher weight values, while ANSUR had higher height values. However, the difference between ANSUR and NHANES data in measures of height were smaller than the differences in measures of weight, indicating a higher likelihood that the observed differences are due to chance rather than statistically significant differences across the data sets. The Male Height and Weight data followed a similar pattern of higher weight values in the NHANES data and higher height values in the ANSUR data. However, these differences were even smaller and harder to distinguish visually than the female data, indicating that it is possible many of these observed differences were due to chance. Additionally, due to overlap throughout all of the comparison figures, it is impossible to conclude with confidence which comparisons showed significant differences of increased or decreased height and weight. Therefore, further statistical analysis is required.

Additionally, in general there were more outliers and thus a greater variance in the ANSUR data compared to the NHANES data. This is logical because the ANSUR datasets used were sourced from real measurements of active-duty army service members and on the other hand, the NHANES data was fabricated to follow a normal distribution and the statistics (mean, standard deviation, and sample size) given. Therefore, the data coming from a real life source (ANSUR data) is more likely to have inconsistent outliers and not follow a distribution perfectly. However, there was one group and measure comparison, Males aged 40-49 height in which the NHANES data had significantly more variance than the ANSUR data.

Part 5 - Statistical Analysis Using a T-Test

For this analysis, I chose to use a Two Sample T-Test for all comparisons that exemplified equal variances, and a Welch's T-Test for those that did not show equal variances. In order to ensure a T-Test is an appropriate test statistic, the data sets must be independent of each other, follow a normal distribution, and have a large sample size (generally over 30 data points). In order to most accurately compare the data, I ran individual statistical analyses comparing the data from each group and measure, ie. comparing NHANES Female 20-29 Weight to ANSUR Female 20-29 Weight and so on.

Using the metric of this comparison, it is clear that the assumption of independence is met as each set of data used came from a separate source. The ANSUR data was sourced from a database of US Army records of active-duty army service members' age, sex, height, and weight. Meanwhile, the NHANES data was fabricated based on statistics of height, weight, and sex by the USA Center for Disease Control. Since these two datasets were separate measurements by separate organizations, they have no influence on each other and can be assumed to be independent.

Next, the assumption of large sample size is met. For one, each group and measure of the ANSUR data had a sample size ranging from 271 data points to 2088 data points. This is well over the general rule of 30 data points and therefore, the ANSUR data can be assumed to be sufficiently large of a sample size. Additionally, in the generation of the NHANES normal distribution data sets (in part 3), I used a data set size of 500, an arbitrary value that produced a sufficiently normal histogram and probability plot. However, this value is also well over the general rule of 30 data points, and therefore the NHANES data also meets the assumption of large sample size.

Lastly, the assumption of normal distribution is met. The NHANES data clearly demonstrates a normal distribution as it was fabricated to follow that distribution. This is also further demonstrated in

Figure 1 and 2, in which the random group and measure chosen follows a normally distributed probability plot and histogram. In order to ensure the ANSUR data also followed a normal distribution, normal probability plots were created for each age group and measure (Appendix 1). Based on these probability plots, each of the ANSUR groups follows a normal distribution and thus the assumption can be met.

The final assumption that applies uniquely to a Two Sample T-Test is equality of variances. However, there are other T-Tests that compare two samples, but do not require the assumption of variance equality, notably Welch's T-Test. Therefore, for each group and measure compared, the equality of variances was tested using Levene's Absolute test, which returns a p value greater than alpha (0.05 used for the purposes of this project) if the two data sets have equal variance, and returns a value less than alpha if the variances are unequal. This test was performed for each comparison of ANSUR to NHANES groups. If the variances were found equal, the Two Sample T-Test was performed, and if not Welch's T-Test was performed.

Group	P-Value	H Value	Test Used	Confidence Interval
Female 20-29 Weight	$1.225 * 10^{-48}$	1	Two-Sample T-Test	[-20.688, -15.9514]
Female 20-29 Height	$1.710 * 10^{-13}$	1	Two-Sample T-Test	[0.8231, 1.41298]
Female 30-39 Weight	$3.037 * 10^{-41}$	1	Two-Sample T-Test	[-24.724, -18.6924]
Female 30-39 Height	$9.362 * 10^{-8}$	1	Two-Sample T-Test	[0.6054, 1.30055]
Female 40-49 Weight	$2.771 * 10^{-35}$	1	Two-Sample T-Test	[-25.199, -18.6075]
Female 40-49 Height	$5.568 * 10^{-11}$	1	Two-Sample T-Test	[0.9240, 1.69797]
Male 20-29 Weight	0.03401	1	Two-Sample T-Test	[-4.515, -0.1771]
Male 20-29 Height	$1.139 * 10^{-13}$	1	Two-Sample T-Test	[0.7845, 1.3436]
Male 30-39 Weight	$2.789 * 10^{-14}$	1	Two-Sample T-Test	[-11.521, -6.8334]
Male 30-39 Height	$4.594 * 10^{-7}$	1	Two-Sample T-Test	[0.4872, 1.1032]
Male 40-49 Weight	0	1	Welch's T-Test	[-150.7666, -141.7901]
Male 40-49 Height	$1.515 * 10^{-10}$	1	Two-Sample T-Test	[0.8132, 1.5218]

Table 1*: Results of Statistical Analysis displayed by group including p-value, h-value, which test was used and the confidence interval*

Based on the results of statistical testing (Table 1 above), every comparison showed a statistically significant difference between the groups. This is seen by each test resulting in p values less than alpha (which had a value of 0.05). From an anthropometry stand point, this indicates that the military population will have statistically significantly different heights and weights compared to that of the civilian population.

On some level this is logical. Looking at the measurement of weight, the military population on average exercises and is more physically fit than the average American and this behavioral difference causes differences in physical statistics including BMI, muscle mass, and notably in this study weight. Therefore, it is logical that the weight statistics vary between military and civilian populations.

On the other hand, height is generally a random genetically determined physiological feature, and thus it is not necessarily logical that the civilian and military populations would be statistically different on this metric. However, the differences detected from statistical analysis could be attributed to which civilian populations are more likely to be recruited to the military in the first place. As previously discussed, the military wants and needs people who are physically fit, with some level of athleticism, and able to withstand the physical strains of combat. Coincidentally, these general requirements tend to fit better with individuals who happen to be taller, since genetically height is on some level associated with athleticism, especially in men. There are clear and common exceptions to this generalization, however the tendency for athletic people to be taller and more athletic people to also be more likely to join the military gives some ground for the statistical difference in height between the military and civilian populations.

The magnitude of confidence intervals for the height comparisons are generally much smaller than the confidence intervals for the weight comparisons. Thus indicating that there is less statistically significant difference in height comparisons than there is in weight comparisons. This is logical given the previously discussed reasons behind these differences, as the reason for differences in weight is much more direct than the reasoning behind height differences.

Part 6 - How do these differences impact Airplane seat design?

The differences detected between the ANSUR (military population) and NHANES (civilian population) data sets affect the manufacturing and production of commercial and military aircraft. According to a research article from Penn State, aircraft manufacturing companies utilize body measurement data, like that of the NHANES data sets to find the most accurate averages to base their seat designs off (Chavanic). In order to appease airlines, whose main concern is making the biggest profit on each flight, commercial aircraft manufacturers have to find the balance of which dimensions of an airplane seat will accommodate the greatest percentage of people while maintaining a sufficient number seats on each plane to ensure the airlines make profit. For example, in order to appease absolutely everyone, manufacturers could use the upper limits of these data sets, using the tallest and heaviest individuals as the basis of seat design. However, this would result in significantly less seats fitting on each plane, thus driving profits down as less tickets can be sold. This would also make air travel harder for consumers as competition for tickets would increase with less available seats on each plane. Therefore, the aircraft manufacturers must utilize data, such as that in the NHANES, to find the most ideal measurements and seat designs to accommodate the average passenger.

Similarly, military aircraft manufacturers must find the balance for military populations to sit comfortably on their aircrafts, while also ensuring there is sufficient room for the equipment that needs to be stored on military aircrafts. Their motivations are less concerned with comfort, as their passengers are not customers and there's no profit concern in military aircraft production. Additionally, military aircraft manufacturers are concerned with space efficiency as many military aircrafts either aim to be as small as possible for energy conservation (ie. fighter jets and other combat aircrafts) or need to hold equipment that takes up significant space within the aircraft (ie. transportation aircrafts). In contrast to commercial aircraft manufacturers, military aircraft production is more concerned with the most efficient seat designs while ensuring the safety of their passengers as military aircrafts generally have more dangerous flight paths than commercial aircrafts.

Based on the respective requirements and motivations of military and commercial aircraft manufacturers, it is not logical to use the data sets of the opposite population. As shown above, the average American has statistically significantly different heights and weights than the average military personnel. Therefore, it doesn’t make sense to cater commercial airlines to military populations or cater military airplanes to civilian populations. If the statistical testing proved there was not a significant difference between the populations, I think it would be reasonable for military airplane manufacturers to use civilian data as it is a better representation given its larger population referenced. However, I still don't think it is logical to cater commercial airlines to military population data, as the military population is a smaller data set.

Part 7 - Repeat Statistical Testing

Group	Original Run	Re-run 1	Re-run 2	Re-run 3	Re-run 4	Re-run 5	Re-run 6	Re-run 7	Re-run 8	Re-run 9
Female 20-29 Weight	1	1	1	1	1	1	1	1	1	1
Female 20-29 Height	1	1	1	1	1	1	1	1	1	1
Female 30-39 Weight	1	1	1	1	1	1	1	1	1	1
Female 30-39 Height	1	1	1	1	1	1	1	1	1	1
Female 40-49 Weight	1	1	1	1	1	1	1	1	1	1
Female 40-49 Height	1	1	1	1	1	1	1	1	1	1
Male 20-29 Weight	1	1	1	0	1	0	0	1	1	0
Male 20-29 Height	1	1	1	1	1	1	1	1	1	1
Male 30-39 Weight	1	1	1	1	1	1	1	1	1	1
Male 30-39 Height	1	1	1	1	1	1	1	1	1	1
Male 40-49 Weight	1	1	1	1	1	1	1	1	1	1
Male 40-49 Height	1	1	1	1	1	1	1	1	1	1

Table 2: *H-Values of Statistical Re-testing sorted by group*

Based on the results of the repeated statistical testing in part 7 (Table 2 above), in general the results were consistent. This can be concluded, as the h-values calculated were for the most part returned as 1, indicating a statistical difference. However, the expectation to this generalization was the Male 20-29 Weight data group, in which the statistical testing of some generated distributions showed significant difference (h-value of 1) and some did not (h-value of 0). This group, even in the original statistical testing, had the largest p-value by multiple orders of magnitude. This in combination with the varying results in retesting indicates that this age group specifically, can not be concluded with confidence. This group was the largest sample size of the ANSUR by almost 1000 data points. Additionally, from the visual graphical analysis, the boxplots of this group were the most difficult to distinguish a difference between. Therefore, it is not surprising that this group of all of them is the data set most difficult to conclude whether or not there is a statistical difference. Based on these results, further testing is needed to more confidently determine whether there is statistical difference in this age group and measure. However, in the other groups, further testing is not necessarily required as the results of statistical testing remained unchanged throughout all re-tests.

References

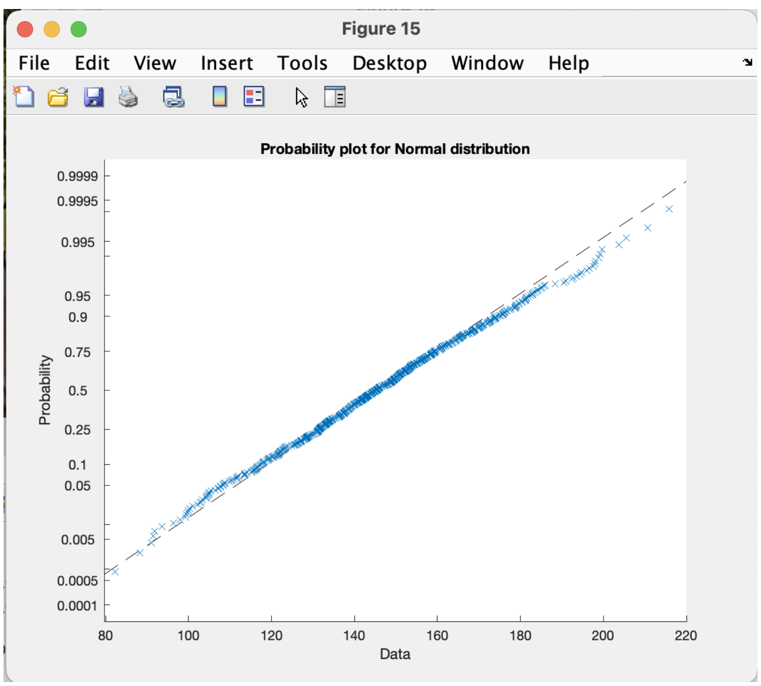
Chavanic, Samantha. “Measuring flying comfort: Researchers investigate airplane seat accommodation.” *Penn State*, 22 May 2019, https://www.psu.edu/news/research/story/measuring-flying-comfort-researchers-investigate-airplane-seat-accommodation.

Gordon, Claire C., et al. “2012 ANTHROPOMETRIC SURVEY OF U.S. ARMY PERSONNEL: METHODS AND SUMMARY STATISTICS.” *U.S. Army Natick Soldier Research, Development and Engineering Center Natick, Massachusetts 01760-2642*, 2014.

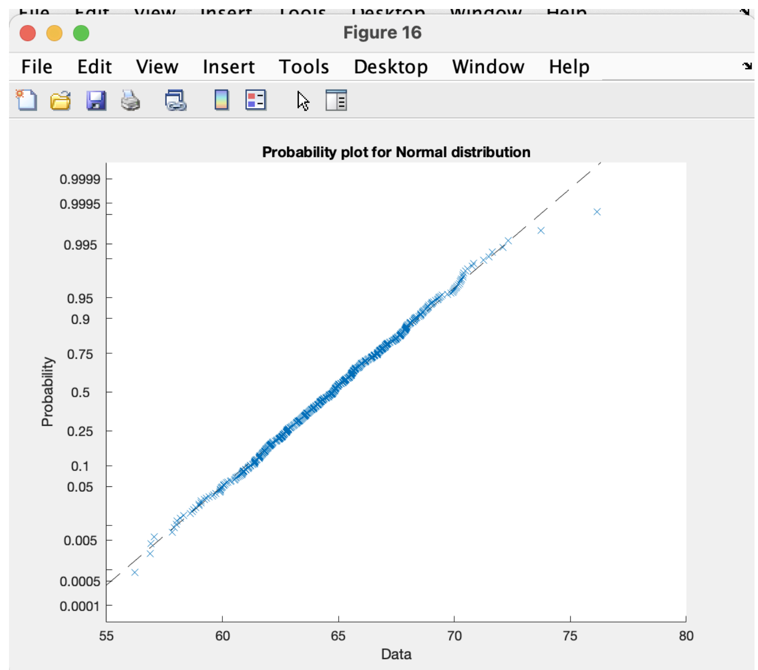
NATIONAL CENTER FOR HEALTH STATISTICS. “Anthropometric Reference Data for Children and Adults: United States, 2015–2018.” *Analytical and Epidemiological Studies*, 2021.

Appendices

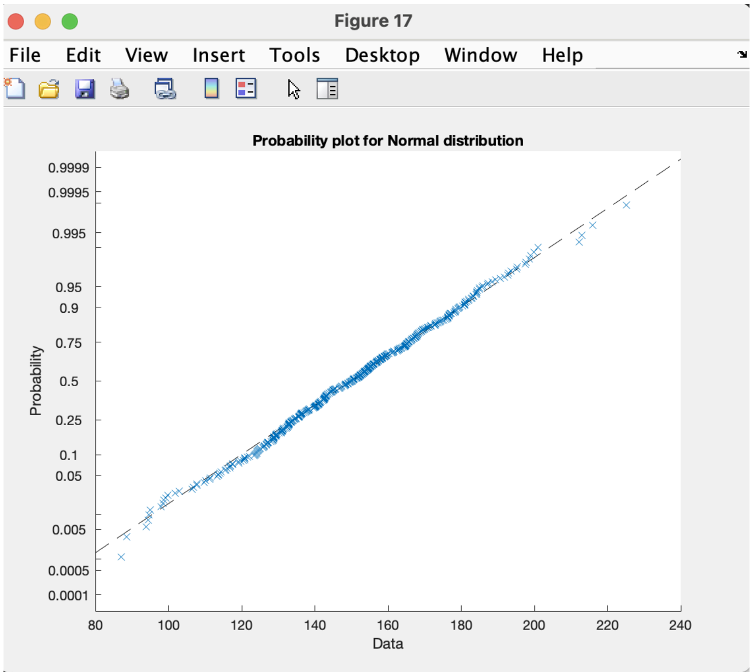
Appendix 1: Normal Probability Plots of each ANSUR data group and measure:



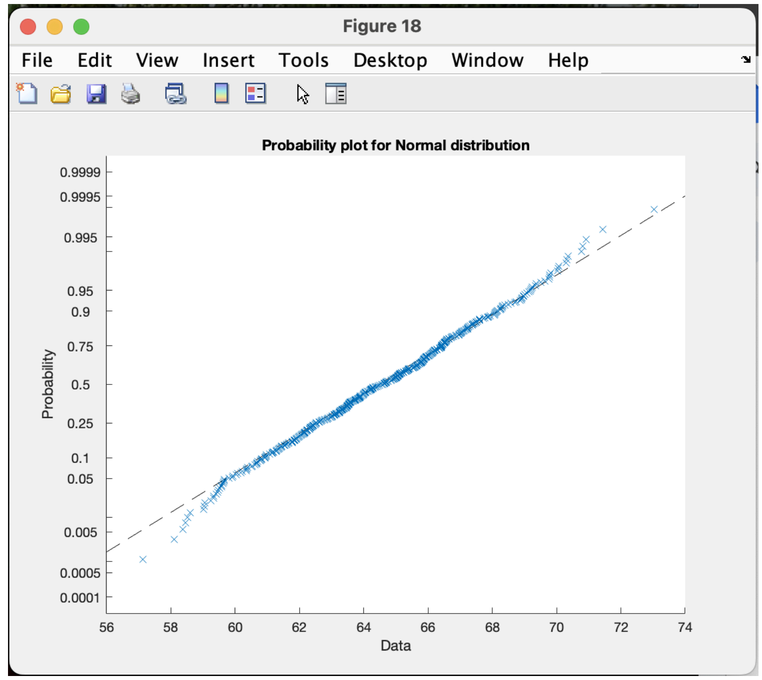
Appendix 1a: *Normal Probability Plot for Female 20-29 Weight Data*



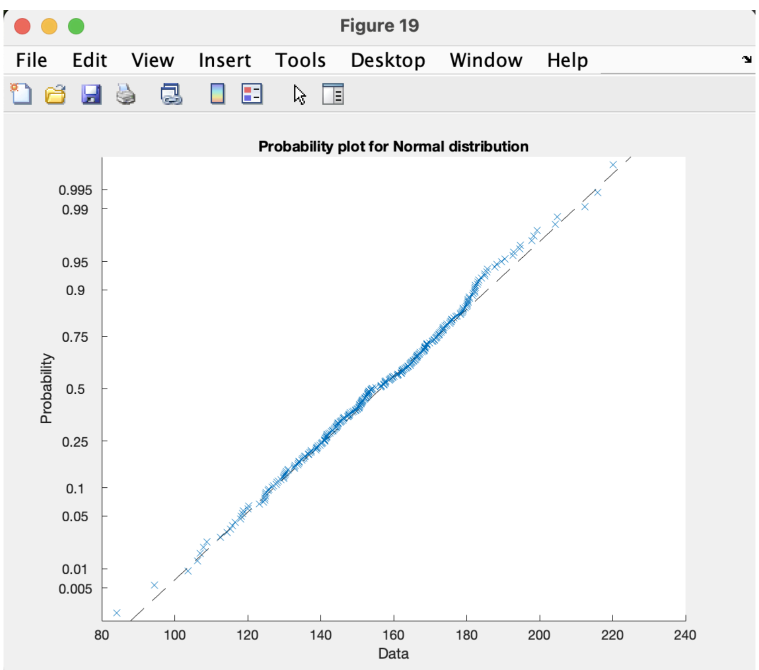
Appendix 1b: *Normal Probability Plot for Female 20-29 Height Data*



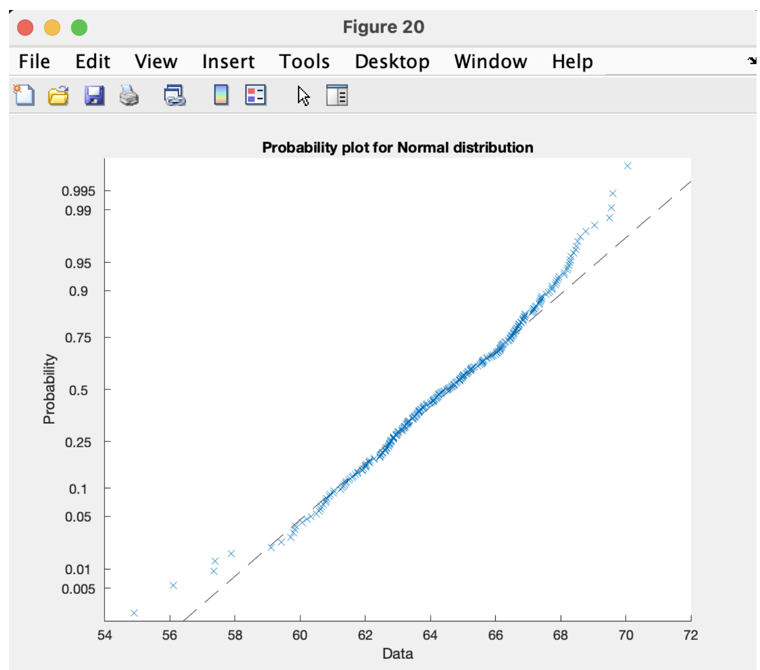
Appendix 1c: *Normal Probability Plot for Female 30-39 Weight Data*



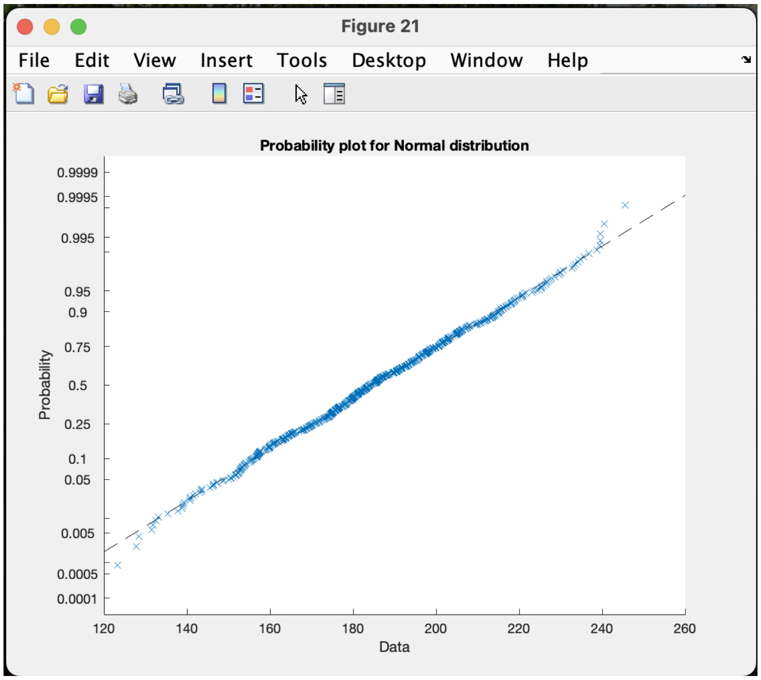
Appendix 1d: *Normal Probability Plot for Female 30-39 Height Data*



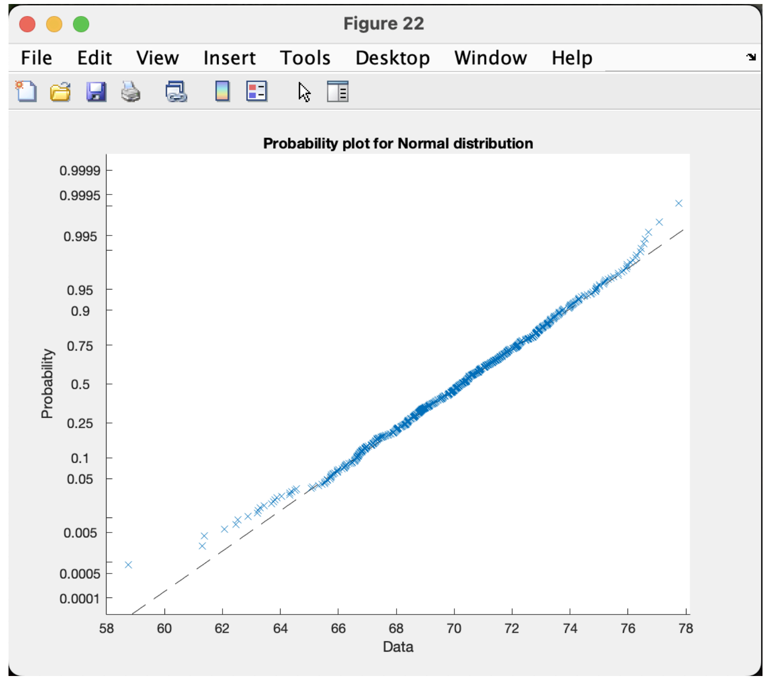
Appendix 1e: *Normal Probability Plot for Female 40-49 Weight Data*



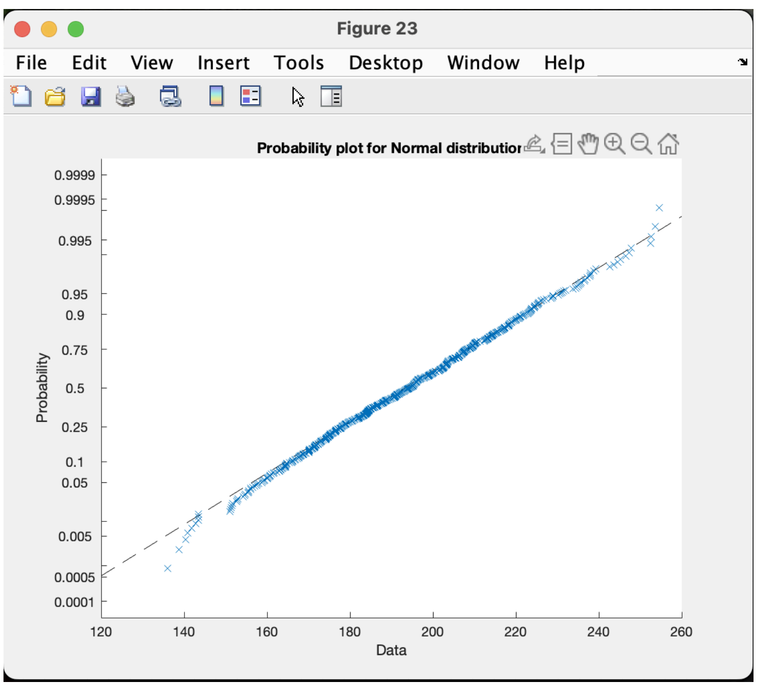
Appendix 1f: *Normal Probability Plot for Female 40-49 Height Data*



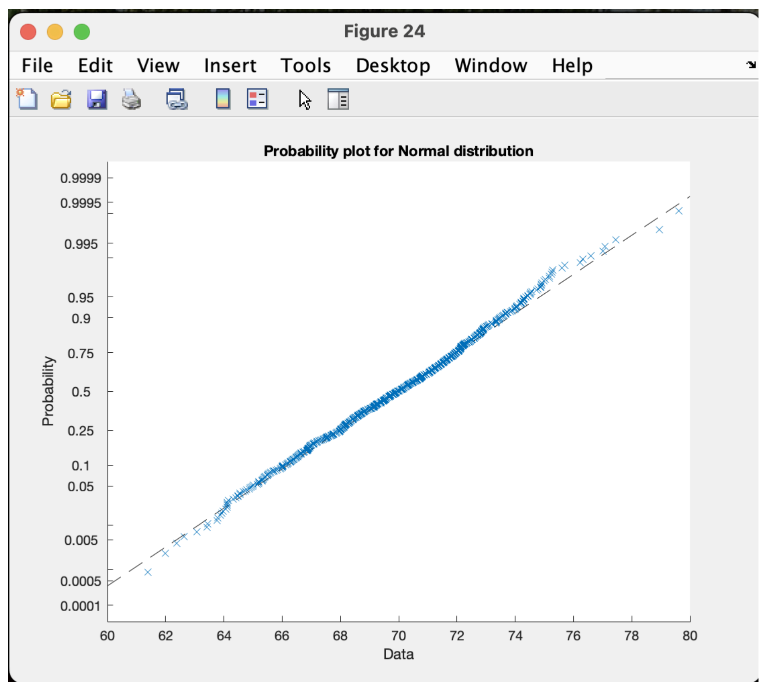
Appendix 1g: *Normal Probability Plot for Male 20-29 Weight Data*



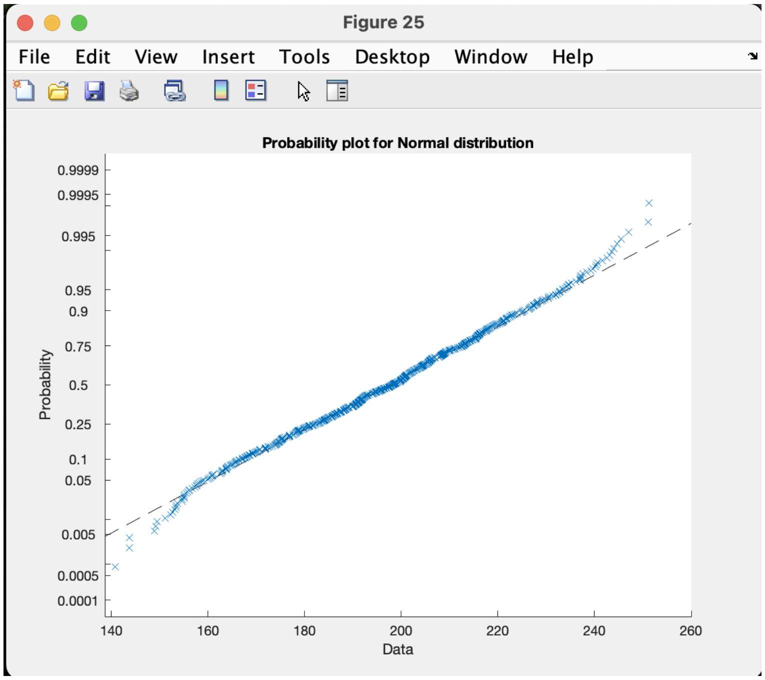
Appendix 1h: *Normal Probability Plot for Male 20-29 Height Data*



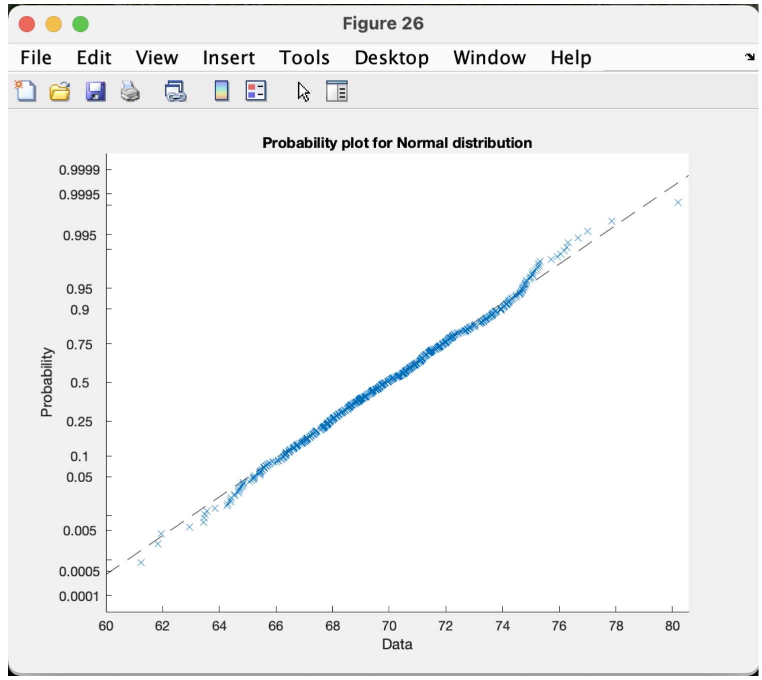
Appendix 1i: *Normal Probability Plot for Male 30-39 Weight Data*



Appendix 1j: *Normal Probability Plot for Male 30-39 Height Data*



Appendix 1k: *Normal Probability Plot for Male 40-49 Weight Data*



Appendix 1l: *Normal Probability Plot for Male 40-49 Height Data*