The Modern Vitruvian Man
Body Proportions

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In this article we look at the measurements of the body as a proportion of height. We compare the measurements gathered by students to the ideal proportions set out by the Roman architect Vitruvius. We also look at if females can fit within these proportions, and which measurements can be used in place of height to explain proportions

We find that the knee height, foot length, hand length, and arm span proportions all line up with the Vitruvian proportions. Male and female proportions do not differ greatly except for foot length. The hand length proportion can also explain much of the other proprtions.

Keywords: t-tests; proportions; data collection; correlation investigation

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1 Introduction

The Vitruvian Man was designed with certain proportions in mind. Vitruvius was a Roman architect and in his writings he describes the human body as a set of proportions of one's height. In this graphic we can see which of our measurements aligned with the Vitruvian proportions.

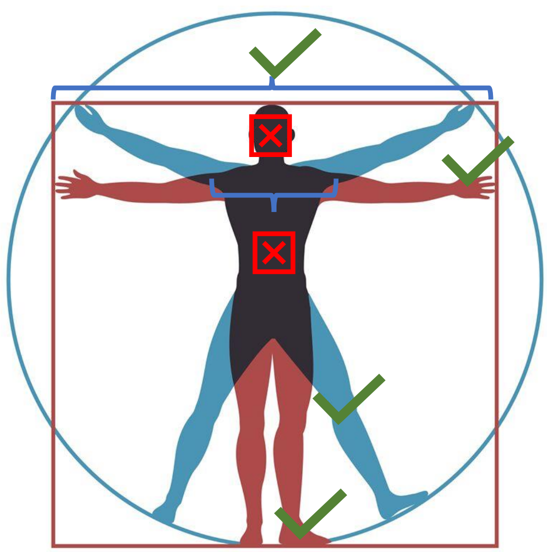


Figure 1: True Vitruvian Proportions

> "the open hand from the wrist to the tip of the middle finger is [a tenth part of the whole height]; the head from the chin to the crown is an eighth, ... The length of the foot is one sixth of the height of the body... and the breadth of the breast is also one fourth... outstretched arms... will be found to be the same as the height"

(Vitruvius 2006)

2 Research Question: Are the Vitruvian Man proportions realistic?

Below is the table with the proportions set out by Vitruvius that we can investigate with the data that we have. I am interested to see if these proportions are accurate by comparing them to the results that we have gathered.

Body length	Vitruvian Man proportions
Head height	0.125
Arm span	1.000
Hand length	0.100
Foot length	0.167
Knee height	0.250
Shoulder width	0.250

2.1 What measurement besides height explains the most body proportions for?

Height is one of the easiest measurements to relate the size of other body parts to. It would be interesting to know what other measurements we could use as a substitute. This way if we did not know someone's height we might be able to make some observations anyway.

2.2 Do body proportions differ significantly between males and females?

Vitruvius and DaVinci only considered the proportions of males when they constructed the ideal body proportions. I am interested if the proportions for females are the same as for males. If they are not, which ones differ the most.

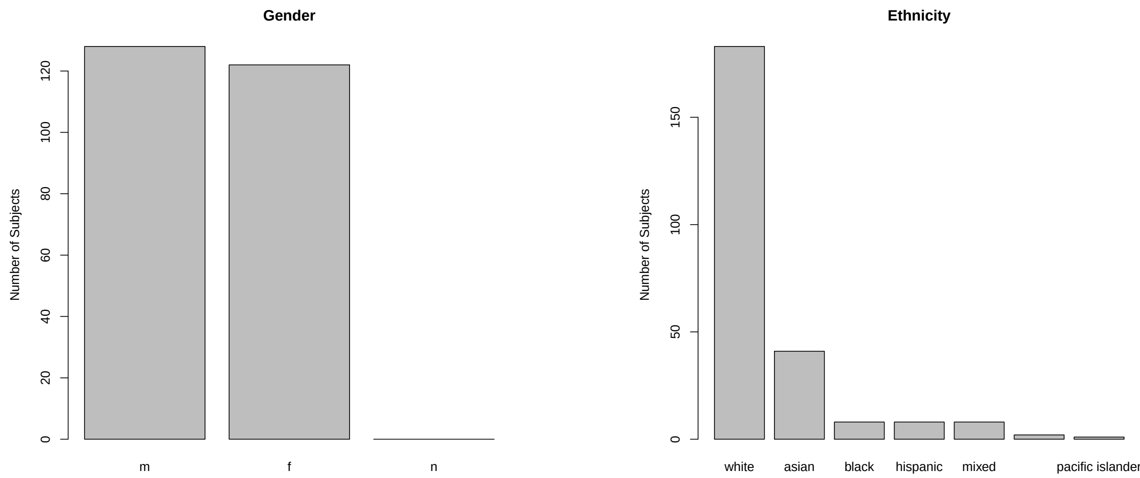
3 Data Description

The data was collected by approximately 30 students who are enrolled in STAT 419 at WSU. Students were supposed to gather measurements from at least ten people. The measurements gathered were: height, head height, head circumference, arm span, floor to navel, hand length, hand width, hand to elbow, elbow to armpit, arm reach, foot length, floor to knee-pit[1], floor to hip, and floor to armpit. The measurements were collected by having either the student or another measure the subject with a measuring tape such as the ones used by tailors. Students were also asked to record which side of the body the measurements came from. Some students chose to gather measurements from both sides for the sake of completeness.

The data from all students was then compiled into one dataset. The total dataset contains 263 rows of measurements. Covariates for each row were also collected. Each subject was instructed to identify their writing hand, swinging hand, dominant eye, eye color, age, gender, and ethnicity. The data collector then assigned a value (1-10) assessing the quality of the measurements taken, and recorded the amount of minutes that it took to complete the measurements.

3.1 Summary of Sample

The sample contained about equal parts male and female subjects. Subjects identifying as white made up about 70% of the dataset, the next largest ethnicity was Asian, which contained about 15% of subjects. The majority of those sampled were in their 20s. There were not many under 10 or over 70 sampled. Subjects who preferred their right-side made up about 80% of the sample. Most subjects had brown or blue eyes –46 and 31 percent respectively– with a a lesser number of hazel or green eyed persons. The quality of the data collected ranged mostly between 8-10 on a 10-point scale. Most data collectors took between 10-20 minutes to gather all measurements required.



(a) Gender Distribution **(b)** Ethnicity Distribution

Figure 2: Gender and Ethnicity Distributions

3.2 Summary Statistics of Data

By comparing tables below we can see that the average proportion for both male and female subjects are about the same. However, the standard deviations show that males vary more in arm span and shoulder width. To a lesser extent males vary more with hand length as well. Females have a more variable head.height proportion. Females also have a slightly more variable foot length and floor to knee-pit length.

Table 1: Descriptive Statistics and Correlation Analysis (FEMALE)

		M	SD	1	2	3	4	5
1	**head.height**	.133	.017	1				
2	**arm.span**	1.008	.050	-.04	1			
3	**hand.length**	.108	.007	.30**	.03	1		
4	**foot.length**	.145	.010	.22*	.18†	.48***	1	
5	**floor.kneepit**	.267	.019	.12	.06	.29**	.30**	1
6	**shoulder.width**	.186	.065	.01	.55***	-.06	-.04	-.10

Notes: Pearson pairwise correlations are reported;
a two-side test was performed to report correlation significance.

$^{\dagger}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

Table 2: Descriptive Statistics and Correlation Analysis (MALE)

		M	SD	1	2	3	4	5
1	**head.height**	.130	.013	1				
2	**arm.span**	1.011	.062	-.28**	1			
3	**hand.length**	.109	.008	.36***	-.09	1		
4	**foot.length**	.148	.009	.14	-.07	.52***	1	
5	**floor.kneepit**	.267	.018	.26**	-.20*	.05	.16†	1
6	**shoulder.width**	.203	.092	-.14	.55***	-.16	-.15	-.08

Notes: Pearson pairwise correlations are reported;
a two-side test was performed to report correlation significance.

$^{\dagger}p < .10$ $^{*}p < .05$ $^{**}p < .01$ $^{***}p < .001$

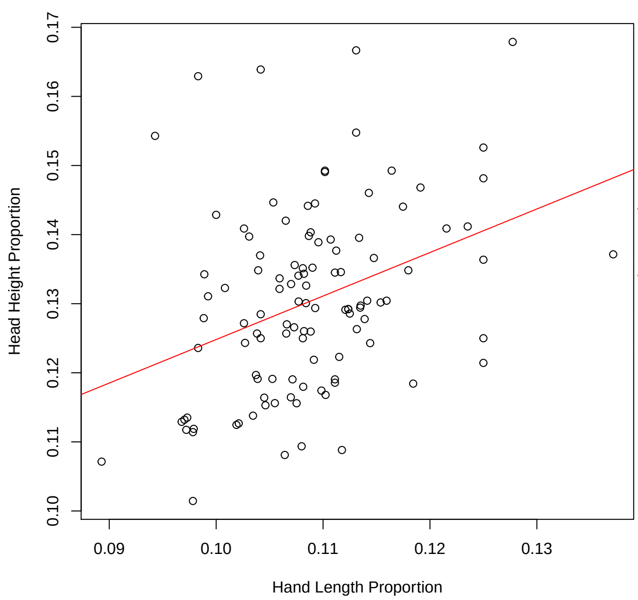
Male and female subjects have the significant positive correlations for hand length and head height, shoulder width and arm span, and foot length and hand length. This means that for any person if they have wider shoulders, then they are likely to have a bigger arm span. If a person has longer hands they are more likely to have a taller head and longer feet. For male subjects there is also a negative correlation between arm span and head height, meaning that those with bigger arm spans are likely to have shorter heads. However, there is a positive correlation for males between the height of the knee and the height of the head, meaning that a male with a higher knee (or longer legs?) is more likely to have a longer head. For female subjects there are significant positive correlations between the height of the knee, and both hand length and foot length. This suggests that females with longer legs may have longer feet and hands.

4 Key Findings

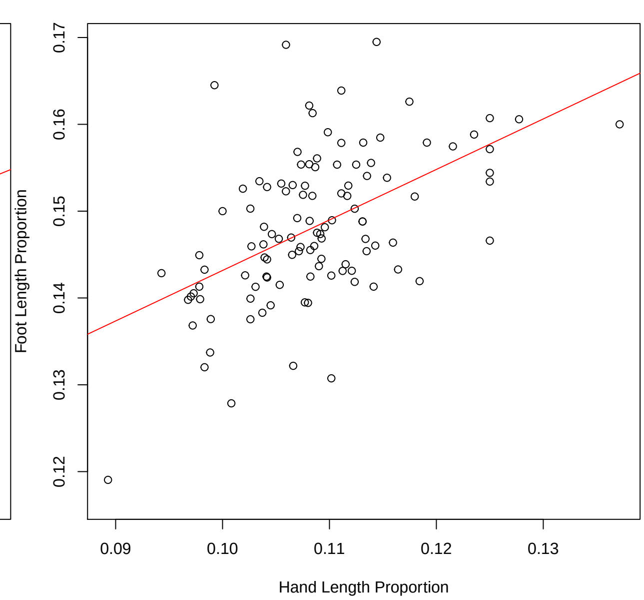
From running several t-tests on the male proportion data we can find which proportions align with the Vitruvian man. From the tests it seems that only arm span might be correct. The Vitruvian proportions for head height, hand length and knee height seem to be underestimated. In contrast the foot length and shoulder width data may have been overestimated. [2] Even though most of the Vitruvian proportions seem to disagree with where the true average might be, they are remarkably close to where the true average probably lies. In most cases, our measurements are not off by more than about 3% of the Vitruvian measurements. The two exceptions are shoulder width, and head height.

We have also found that the proportions for male and female subjects do not differ significantly for any of the variables except for foot length. For males the proportion of foot length to height is significantly larger than the same measurement for females. Testing the height of the knee especially shows that the male and female measurements are likely to be almost the same.

From the earlier calculations of the correlations we can determine that hand length is the best measurement for relating other measurements for either male or female subjects. For female subjects knee height also helps a lot to explain other proportions. For male subjects, the head height variable can also explain other proportions.



(a) Hand Length - Head Length Relationship



(b) Hand Length - Foot Length Relationship

Figure 3: Hand Length Relationships

5 Conclusion

From our findings in Section 4 we can conclude that arm span, hand length, foot length, and the knee height are all consistent with the Vitruvian measures. [3] The same cannot be said for head height which is larger than the Vitruvian proportions, and for shoulder width, which is smaller than the Vitruvian proportions.

In our investigation of male and female subjects we are able to conclude that in most respects the Vitruvian proportions hold for females as well as they do for males. The one notable exception being foot length, which is larger in males than in females.

Lastly, I have determined from Section 4 that the hand length proportion can be used in determining the other proportions of a human body. From Section 3.2 I have also determined that in the case of female subjects, the knee height proportion can help in determining other proportions. Likewise, for male subjects, the head height proportion can help in determining other proportions.

The conclusions here may not be able to be generalized widely due the the lack of ethnic diversity present in the sample as seen in Figure 2b. The range of ages for this dataset was also overwhelmingly of subjects in theirs 20s. Those wishing to improve the results of this study should seek to diversify the samples to be able to make more confident generalizations of body proportions.

6 APPENDICES

6.1 Data Provenance

As was listed in Section 3 the data collection was assigned to the STAT 419 class at WSU, which is around 30 people. This can lead to some discrepancies in the way that the data was collected. The data may not always have been measured by students, but by the people which their handouts were sent to. For the 10 people that I gathered measurements for I measured seven people personally, and then had three others send me their results by email. The number of data collectors involved can also lead to different interpretations of what each measurement means.

The data collector was given the option to pick which units they wished to measure in, and the subject was also asked to identify their preferred hand in writing and swinging, what eye is dominant, what their eye color is, how old they are, what gender they are, and what ethnicity they identify as. These covariates give us a better picture of our sample. For example, since we have about equal amounts of male and female measurements (2a) we can make some generalizations. But on the other hand, we do not have much diversity of ethnicity in subjects (2b) so we can not generalize our results as easily.

Some of the measurements seemed like they had more outliers than others. This is likely because they were either entered incorrectly or they were measured differently. The measurements with significant outliers are: hand length, arm reach, floor to knee-pit, and head height. Hand length was supposed to be measured from the tip of the middle finger to the wrist. Arm reach is supposed to be the measurement from the floor to the tip of the middle finger when the arms are pointed upwards above the head. The floor to knee-pit measurement is from the heel to the back of knee. Lastly the head height measurement is from the chin to the top of the head.

Below shows the handout I used to conduct my measurements and which was sent to those whom I could not personally measure.

6.1.1 Data Collection Handout

Figure 4: Handout Page 1

Measurement Project Handout

Name (first name + last initial):

Covariates:

Units	Writing	Eye	Eye Color	Swinging	Age	Gender	Ethnicity

Measurements:

	Info	Measurement	Side (L/R)
Height	No shoes		N/A
Head Height	Top of head to chin		N/A
Head Circumference	Right above ears/eyes		N/A
Hand Length	Middle finger to wrist		
Hand Length			
Hand Width	Thumb to pinky outstretched		
Hand Width			
Hand to Elbow	Middle finger to elbow		
Hand to Elbow			
Elbow to Armpit			
Elbow to Armpit			
Arm Reach	Floor to arm streched above head		
Arm Reach			
Arm Span	Arm to arm extended		N/A
Foot Length	From big toe to heel		
Foot Length			
Floor to Kneepit			
Floor to Kneepit			
Floor to Hip			
Floor to Hip			
Floor to Navel			N/A
Floor to Armpit			
Floor to Armpit			

Notes for Data Collector:

Quality	Minutes	Notes

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6.2 Preparing the Report Workspace

6.2.1 Preparing the Data

Below is the necessary functions and libraries required to run the code referenced in this document.

```
library(devtools);       # required for source_url

path.humanVerseWSU = "https://raw.githubusercontent.com/MonteShaffer/humanVerseWSU/"
source_url( paste0(path.humanVerseWSU,"master/misc/functions-project-measure.R") );
```

Below is the code to load the data and prepare it for analysis.

```
path.to.secret = "C:/Users/Nathan/Dropbox/__student_access__/_SECRET_/";

measure = utils::read.csv( paste0(path.to.secret, "measure-students.txt"),
                           header=TRUE, quote="", sep="|");
#path.my.github = "https://raw.githubusercontent.com/nshine787/WSU_STATS419_FALL2020/";
# source_url(paste0(path.my.github, 'master/functions/functions-project-measure.R'))

path.project = "C:/Users/Nathan/Documents/GitHub/WSU_STATS419_FALL2020/"
source(paste0(path.project, 'functions/functions-project-measure.R'))

relevantColumns = c('height', 'head.height','arm.span','
                    hand.length','foot.length','floor.kneepit','shoulder.width')
measure.df = prepareMeasureData(measure);
measure.males.df = grabGenderRows(measure.df,'m')[,relevantColumns]
measure.females.df = grabGenderRows(measure.df,'f')[,relevantColumns]

proportions.male = measure.males.df/measure.males.df$height
proportions.female = measure.females.df/measure.females.df$height
```

6.2.2 Creating Figures

The code below shows the distributions of gender and ethnicity in the sample as seen in Figure 2

```
barplot(sort(table(measure.df$ethnicity),decreasing=TRUE), main = 'Ethnicity',
        ylab = 'Number of Subjects')
barplot(sort(table(measure.df$gender),decreasing=TRUE), main = 'Gender',
        ylab = 'Number of Subjects')
```

Below is the code to generate the summary statistics and save them as a table that you see in Section 3.2. It uses a function created by Monte Shaffer, the instructor of the STAT 419 class at WSU.

```
path.tables = paste0(path.project,'PROJECT-01/tables/')
file.correlation = paste0(path.tables,"male-correlation-table.tex");

myData = as.matrix(proportions.male);
myData = myData[,c(2,4,6,11,12,15)]

buildLatexCorrelationTable(myData,
  rotateTable = FALSE,
  width.table = 1,
  width.names = "30mm",
  myFile = file.correlation,
```

```
  round.digits = c(2,3,2),
  myLabel = "table:correlation-male",
  myCaption = "Descriptive Statistics and Correlation Analysis (MALE)"
  );
Sys.sleep(2);

file.correlation = paste0(path.tables,"female-correlation-table.tex");

myData = as.matrix(proportions.female);
myData = myData[,c(2,4,6,11,12,15)]

buildLatexCorrelationTable(myData,
  rotateTable = FALSE,
  width.table = 1,
  width.names = "30mm",
  myFile = file.correlation,
  round.digits = c(2,3,2),
  myLabel = "table:correlation-female",
  myCaption = "Descriptive Statistics and Correlation Analysis (FEMALE)"
  );
Sys.sleep(2);
```

Below is the code to generate the plots in Section 4

```
proportions.both = merge.data.frame(myDataMale,myDataFemale,all.x=TRUE)

plot(proportions.both$hand.length,proportions.both$head.height,
     xlab = 'Hand Length Proportion', ylab='Head Height Proportion')
abline(lm(proportions.both$head.height~proportions.both$hand.length), col='red')

plot(proportions.both$hand.length, proportions.both$foot.length,
     xlab = 'Hand Length Proportion', ylab='Foot Length Proportion')
abline(lm(proportions.both$foot.length~proportions.both$hand.length), col='red')
```

6.2.3 Running the Tests

Below is the code to generate the t-tests in Section 4. The first chunk compares the male proportions to the ideal Vitruvian proportions. The second chunk tests the male and female observations against each other for each variable to see if the proportions vary significantly.

```
myData = proportions.male[,c('head.height','arm.span','hand.length','foot.length'
                              ,'floor.kneepit','shoulder.width')]
proportions.vitruvian = c(0.125,1,0.1,0.1666667,0.25,0.25)
for (i in 1:dim(myData)[2])
{
  print(colnames(myData)[i])
  test.result = t.test(myData[,i], mu=proportions.vitruvian[i], alternative='two.sided')
  print(test.result$p.value)
  print(test.result$conf.int)
  error = abs(test.result$conf.int[1]-test.result$conf.int[2])/proportions.vitruvian[i]
  print(paste0('Error percent: ',error))

}
```

```r
myDataMale = proportions.male[,c('head.height','arm.span','hand.length','foot.length',
                                 'floor.kneepit','shoulder.width')]
myDataFemale = proportions.female[,c('head.height','arm.span','hand.length','foot.length'
                                     ,'floor.kneepit','shoulder.width')]
proportions.vitruvian = c(0.125,1,0.1,0.1666667,0.25,0.25)
for (i in 1:dim(myData)[2])
{
  print(colnames(myData)[i])
  test.result = t.test(myDataMale[,i],myDataFemale[,i])
  print(test.result$p.value)
  print(test.result$conf.int)
}
```

ENDNOTES

[1] The terms knee-pit and knee height may be used interchangably throughout
[2] Our shoulder width data was computed by subtracting two times the length of the arm from the arm span. This gives the inner width of shoulders which likely differs from the method used by Vitruvius.
[3] Consistent here means that our measurement proportions are within 3% of the Vitruvian proportions.

REFERENCES

Vitruvius. 2006. *"Ten Books on Architecture"*. Harvard University Press.

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