# Ergonomical Evaluation for the Design of the Computer Laboratory PC Lab3 in the Department of Industrial Engineering at EMU and Proposing a Better Design

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# ABSTRACT

The aim of this study is evaluating both furniture and layout of the computer lab in the Industrial Engineering Department at EMU University and its effect on the student posture, performance and attention.

Fifty students were used as subjects. Their ages range between 18 to 35 years. Eleven anthropometric data of the subjects were measured including: Stature, shoulder height, shoulder elbow height, buttock popliteal length, popliteal height, knee height, forearm hand length, hip width, elbow sitting height, sitting height and eye sitting height. The mean, standard deviation, percentiles, minimum and maximum value of anthropometric dimensions were calculated.

The current layout of the lab was evaluated by observing the number of workstations, aisles, free areas available, placement of whiteboard and presentation screen. The current layout was found to fail to comply with Ergonomy design criteria.

The results from hypotheses testing showed that there are significant differences between male and female body dimensions.

A new design of furniture and a new layout for PC lab proposed to improve the level of comfort and the level of attention to lectures for students.

**Keywords:** Anthropometric data, Percentiles, Ergonomy design criteria, layout.

# ÖZ

Bu çalışmanın amacı, Endüstri Mühendisliği DAÜ Üniversitesi Bölümü ve öğrenci duruş, performans ve dikkat üzerindeki etkisi bilgisayar laboratuvarı mobilya ve düzeni hem de değerlendirmektedir.

Elli öğrenciler denek olarak kullanıldı. Yaşları 18 ile 35 yıl arasında değişmektedir. Boy, omuz yüksekliği, omuz dirsek yüksekliği, kalça popliteal uzunluk, popliteal yükseklik, diz yüksekliği, ön kol el uzunluk, kalça genişliği, dirsek oturma yüksekliği, yükseklik oturma ve göz yüksekliği oturma: Deneklerin on antropometrik verileri dahil olmak üzere ölçüldü.Ortalama, standart sapma, yüzdelik, minimum ve antropometrik boyutları maksimum değeri hesaplanmıştır.

Laboratuar mevcut düzeni iş istasyonları, koridorlar, boş alanlar, beyaz tahta ve sunum ekranınızda mevcut düzeni yerleştirilmesi Ergonomi tasarım kriterleri uymadığınız bulunmuştur sayısı gözlemleyerek değerlendirildi.

Hipotez testi elde edilen sonuçlar kadın ve erkek kasa ölçüleri arasında önemli farklılıklar olduğunu göstermiştir.

Mobilya ve bilgisayar laboratuarı için yeni bir düzen yeni bir tasarım konfor ve öğrenciler için ilgi düzeyi düzeyini artırmak için önerdi.

**Anahtar Kelimeler:** Antropometrik veriler,Yüzdelik,Ergonomi tasarım kriterleri, düzen.

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# INTRODUCTION

In recent decades of the twentieth century many universities are using computer labs in educational system as an approach to develop the students' knowledge in contact with the software and give them more practice that help them to apply the computer programs in their lectures and researches. Therefore, it is necessary to focus in workstation design and layout of a computer laboratory where many students spend hours in a day sitting in front of a computer performing their course-works assignments without thinking about the influence on their health.

The computer workstation can be defined as the environment around the computer system which includes the following components:

- Furniture such as seats, tables and other work surface.
- Computer equipment such as monitor, keyboard, mouse and CPU device.
- Accessories for instance document holder, footrest and Mouse Bridge.
- Environment factors as noise, illumination, glare, temperature and humidity.

Physically, the student's bodies are facing many significant stresses, without being aware of them, from extending their wrists; or slouching, or sitting without armchair and feet support or also straining to look at poorly placed monitors.

Such conditions may lead to cumulative trauma disorders or repetitive stress injuries, which can affect human health, and cause more pain, or muscular fatigue, or loss of sensation, or tingling and reduced performance.

The design of computer laboratory layout depends on the area of lab, equipment and furniture which are needed.

As we know the ergonomics as a science aims to reduce strain, fatigue, and injuries of human by improving the product design and workspace arrangement. It has always claimed a comfortable design and relaxed posture. Therefore, in the design of PC workstations, it is important to use anthropometric measures.

The dimensions needed for such a design are sitting elbow height, shoulder height, upper arm length, knee height, popliteal height, sitting eye height and buttock-popliteal length. Moreover, to assess the degree of success in product design we can determine the degree of fitness to human body dimensions which is known as 'mismatch ratios.'

In this thesis we firstly, present a literature review about the design of the physical layout of computer classroom and workstations in chapter two. Secondly, the methodology which is used, in this study, to gather the anthropometric measurements from industrial engineering students at Eastern Mediterranean University (EMU) is presented in chapter three. Additionally, the experimental design is considered in chapter four. After that, the results are analyzed and discussed in chapter five. Finally, the ergonomic design for workstation and the layout of the PC Lab-class are proposed.

# Chapter 2

# LITERATURE REVIEW

Universities and Colleges have been using computer technology for more than thirty years as a tool to support the educational process. Therefore, computer laboratories have played a major base in most universities in the world to assist teaching system.

Many high schools, colleges and universities are using computer labs to teach student actually how to use the important software which is needed and to facilitate understanding lectures clearly. However, these educational institutions did not give their attention to the layout design of the lab. They usually used a simple method to construct the computer room by filling it with computers and tables in a traditional way and having the blackboard in front of the class without applying any ergonomic principles in such a design.

(Mike May) listed the considerations needed in the physical layout of the computer classroom as follows. The teacher is moving through the room from a group to another to guide the students, she/he sometimes use the blackboard or electronic screen on the wall which is in front of the room in lecturing. She/he also makes comments for all students, while the students are working on computers.

(Scott-Webber, 2000) Mentioned that, the method of communication in the classroom is determined by activities, as lecturing, sharing information, motivating, and performing demonstrations.

(Cornell, 2003) Believed that a student prefers active teaching processes because it is more actually and mentally motivating. When the students are sitting for long periods of time listening and writing lecture notes without any active learning environment, they will be less interesting, even more tired and sleepy.

Using the computer lab technology and proper software such as PowerPoint this may help instructors to create an exciting learning environment where students are more focused and paying more attention to the lessons (Callahan, 2004).

When teachers poorly communicate with students in explaining the information, the result of this would be low learning. The computer lab session allows the students to apply what they are educated in the lecture by experimenting with computer technology (Callahan, 2004).

(Tamer, 2010) made a study to evaluate instructional computer laboratories according to the physical ergonomic criteria. In this study three computer labs were chosen from different departments at Suleyman Demirel University in Turkey. Data were gathered and recorded through observations about computer labs such as the technical features of keyboard and computer monitor, physical characteristics of lighting conditions, relative humidity, temperature levels, and noise levels. Moreover, all features of desks and chairs were recorded; It was found that the physical features of computer labs, monitor features, relative humidity and temperature levels were in agreement with the ergonomic criteria. But, tables, seats, keyboard features, and noise levels were not found to conform to the ergonomic criteria. This may have effect on students' health and the occurrence of performance problems in students' studies.

## 2.1 Design Layout

It is necessary to know how the design of computer lab classrooms supports the relationship between teachers and students and how the design of computer laboratories supports learning and teaching system.

(Callahan, 2004) Listed that, the classroom environment is affected by some physical factors as the followings:

(1) Dimensions such as room, aisles, ceiling heights and door widths.

(2) Entrances such as door location.

(3) Windows such as, placement and treatments.

(4) Finishes such as walls, ceilings and floors.

(5) Furnishings and equipment as instructor's desk, display surface, student seating.

(6) Heating system and air Conditioning.

(7) Lighting.

(Mike May) Specified the design requirements for the computer classroom as follows:

1. Students must be able to see both their own computer screens and the teacher's presentation screen without changing their places. Therefore the style of classroom will be arranged in a traditional row model.
2. The designers' team wanted several students to see the same screen while the instructor is explaining at the white board without any need for the students to move from their places. As a result they decided to use a screen on top of the table instead of one's sunk into desktops.
3. The teacher's computer screen can be fixed onto the front wall or put on the front of the whiteboard.
4. In addition, with respect to their experience in teaching in computer labs, they wanted the students to share activities so they should be sit in group forms such as each 4 students with 2 computers. This lead to a decision to put desks together so each four students would be sit at an extended desk with two of computers in the center of the table.
5. Moreover, the space between tables should be enough for the instructor to freely move throughout the lab while students are working.

(Nicolas, 2007) recommended for the space where no furniture are available, an area of 50 cm in front of any window , an area of 3m in front and 1m at both sides of the main entrance door of the room and  an area of 50 cm around any radiator. Additionally as related to the free area around the workstation as passages around them, as well as for unobstructed sitting and reaching to the seat they suggested an area of 55 cm along the front side of the desk, an area of 50 cm along the entry side of the workstation, an area of 75 cm along the back side of the desk for seat side, and an area of 100 cm along the back side of the desk if there is a storage area behind the desk.

(Callahan, 2004) Suggested that “the computer lab must be prepared with a presentation system, audio system, and network connections.” Additionally, all computer labs need mobile chairs, and more flexible seating arrangements. Accordingly, there may be three common arrangements of labs; U seating arrangement as shown in figure (2-1), clusters of computer's arrangement as shown in figure (2-2) and parallel row shape as illustrated in figure (2-3) .

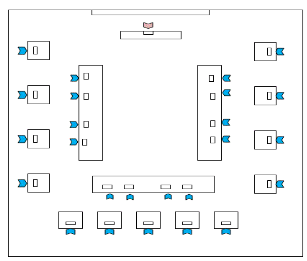

Figure 2.1: U Computer Lab Seating Arrangement

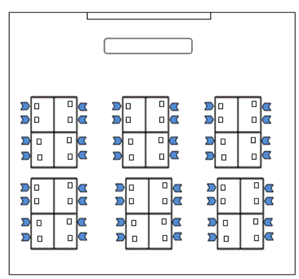

Figure 2.2: Cluster Seating Arrangement

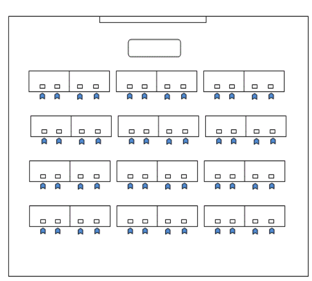

Figure 2.3: Conventional Straight Row

In the traditional classroom there are some factors that influence on functional place arrangement such as the nature of student activities, instructor's teaching methods, the physical dimensions and shape of the room (Sommer, 1967). The advantage of the computer lab classroom with U shape that it gives to the presenter sight of all of the students' computers. It is more beneficial for computer courses that use teaching methods as, lecture, group discussion, and presentation. The cluster seat model is similar to the straight row classroom layout. The main difference between them is the tables of computer are put in vertical shape to the front of the room in the cluster seating arrangement as illustrated in figure (2-2). This layout is the best for small groups and team work. The conventional straight row layout shown in figure (2-3) is a standard for a lecture classroom. This design consists of some rows that are parallel to the front of the classroom. This layout enhances the collaboration between the students. However, in this arrangement the instructor is not able to see the students' computer screens during the lecture (Callahan, 2004).

(Sommer, 1967) Concluded the followings. In the seminar-style room, the most of students around the teacher are participating more than other students. Additionally, the students of the straight row arrangement who are near the front and middle of the classroom are participating more than the students at the back and sides of the classroom.

In this study I will propose the layout of the PC computer laboratory in Industrial engineering department. First I will identify the important elements, for the design of the layout of a computer laboratory, such as the number of students, area of classroom, furniture, presentation system, aisles, entrance, and windows. Next, I will evaluate the current PC Lab design and determine the problems that may be facing the students during lab sessions. Finally, I will propose a new design for PC Lab with more facilities and flexibility that should support both students and teachers and enhance the students' participation during lecturing.

As we know, students spend many hours each day in front of the computer screen without thinking about the health impact of the related human posture. A physical stress may result on human bodies from sitting incorrectly at a workstation staring to the computer screen for a long period of time with no rest, or from using chairs without armrest or backrest etc.... The symptoms from such postures may be eye strain fatigue, or/and cumulative trauma or/and repetitive stress injuries that affect negatively the performance. This project focuses on the proper workstation design to reduce visual and musculoskeletal discomfort.

## 2.2 Workstation Design

Subjects that are concerned in the design of computer workstation are; Monitor placement, keyboard, work surface adjustability, chair design, foot rests, wrist rests, lighting and ease of adjustability. The poor design of these subjects (mentioned above) may result in physical disorders which are known as Musculoskeletal Disorders (MSD's) that may show up as (Sweere, 2002):

- Eye strain and headache.
- Neck and back fatigue.
- Wrist and shoulder diseases.

(Ashraf, 2007) made a study on 40 workstations to identify ergonomic deficiencies in computer workstation design by physical measurements and a questionnaire. As a result they found, eyestrain 58% , shoulder pain 45% , back pain 43% , arm pain 35% , wrist pain 30% , and neck pain 30% . These results indicated serious ergonomic disorders in office computer workstation design , layout, and usage. Therefore, they suggested providing the computer workstations in the offices by ergonomics standards guidelines, and recommendations. Additionally, they found out that employees must be trained in ergonomic layout to organize themselves their workstations.

(Timoteo-Afinidad, 2010) analyzed the workstation of Filipino users. Their considerations were health problems due to the present design, percentage fitting of current design, and the postures of the workers. They concluded that the current workstation design does not fit the average Filipino users. Additionally, the increase in the number of injuries during work due to the wrong dimensions and poor workspace design may lead to unsatisfactory motivational needs. Moreover, the use of uncomfortable workstation caused the increase of the probability of errors at work and reduced the performance of workers. Therefore, they recommended some immediate solutions as placing the back cushion for lower back support to avoid back pains and when the chairs used are made of wood the seat and back cushion should be used. Additionally, the monitor should be placed in front at a distance of 50 cm.

(Angsumalin, 2010) evaluated a desk-seat set that are used at Chulalongkorn University. By using applied statistics with optimization, they found as a result that 9% of users are matching with seat height and 36.3% of users are matching for desk height.

Additionally, they concluded that the most convenient heights both for seat and desk were (40.5 cm and 62 cm) instead of (47.7 cm and 75 cm) which were currently used. These proposed new dimensions would increase the percentage of matching to 63.4% for seat height and 98% for desk height.

## 2.3 Sitting

When users are sitting, tilting forward on a seat, a higher loading of the intervertebral will be occurred. This is occurring due to decreasing of the hip angle and would influence the breathing ability and Blood Circulation (Dowler, 1998).

The benefit of chair arms is to assist in unloading the spine as the body weight shifts to the facet joints and causing an elongation of height, as compared to the standard seated position, and therefore the discs would be unloaded (Callahan, 2004).

Backrests should be adjustable in tilting at least 85 degrees to 100 degrees while still it is possible to maintain at least a 90 degree sitting angle and have the adjustability for height between 16 to 20 inches from the seat pan. Additionally, it should be at least 13 inches wide (EOHSS, 2008).

### 2.3.1 Sitting at a VDT Workstation

The chair is the most commonly used piece of equipment of a computer workstation. In such a workstation where users spend many hours of their time sitting, it is necessary to select a proper adjustable chair and enable the users to sit comfortably and work efficiently by providing a suitable support to minimize fatigue (EOHSS, 2008).

The chair height should allow the workers to rest their feet on the floor or on a footrest. Additionally, it should allow the worker to use a suitable keyboard while keeping her/his forearm parallel to the floor and her/his wrists at the same plane of the forearm, and his/her legs should have enough clearance(Callahan, 2004). The optimal adjustability range for seat height is recommended to be 37cm to 55cm (Healthcare Ergonomics, 2003-2012).

(Min Yong, 2000) Made a study by using three dimensional human modeling tools to design a new chair which satisfies the anthropometric specifications for Korean population. They designed a workstation chair that fits the 5th percentile female Korean and the 95$^{th}$ percentile male Korean. They constructed the mock-up chair, where the seat pan can be moved up and down by as much as 20 cm. The height of the tray can also be adjusted up to 15 cm. The tray swings 180 around the pole connected to metal beam on the right side of the seat pan and slides forward and back by 20 cm. This designed new chair, when attached with a keyboard and mouse, decreased muscle activity and made subjects feel more comfortable than when using the conventional chair.

**2.3.2 Monitor**

The monitor is a necessary component of a computer workstation, the important factors needed to determine the placement of the monitor are viewing angle and viewing distance as shown in figure (2-4).

1- Viewing angle: indicate to the scale upper or lower of the horizontal line at the level of the user's eyes.

2- Viewing distance: refers to the dimension between the user's eyes and the screen.

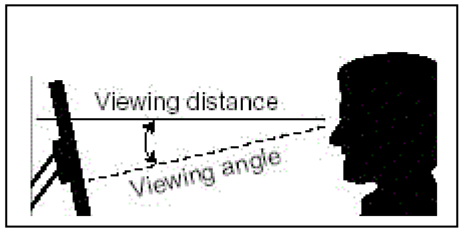


Figure 2.4: Viewing Angle Viewing Distance

The screen placement has an important effect on the neck movement, if the angle is incorrect this would cause both neck and shoulder discomfort. When the distance is not proper this can cause eyestrain. On the other hand the position of the document holder relative to screen placement should be at the same distance and as close together as possible from the eyes so, the user can see from one to another with no movement of his neck or back (EOHSS, 2008). The best viewing distance for VDTs is the range from 18 to 24 inches as equivalent (45.72 to 60.96 centimeters, respectively) (EOHSS, 2008).

Hedge and Powers declared, the best comfortable level of the screen distance was recorded when the position of the monitor is at 79 cm away from the worker. A range of screen distances between 6 to 93 cm was proposed earlier by Grandjean. The range of optimal visual angles between 15° to 22° was proposed by Cormick and Sanders (Dowler, 1998).

**2.3.3 Keyboard**

Keyboard should be comfortable for the operator, separate and adjustable to make proper position, and correct angle. The ideal working position for keyboard user is the posture where forearms are parallel to the floor and elbows at the sides of the body, so it allows the hands to work softly and easily on the keyboard. The wrist must be at the same line level of the forearm. When the keyboard is very high or very low awkward wrist, arm, and shoulder postures would result. Performing keying tasks in awkward postures such as these can result in hand, wrist, and shoulder discomfort (EOHSS, 2008).

### 2.3.4 Mouse

The mouse is a pointing device in a computer workstation. It should be put at the user's side closer to the worker's body. Additionally, a straight line between the hand and forearm should be maintained (EOHSS, 2008).

## 2.4 Mismatch Between Anthropometric Measures And Lab Furniture

The mismatch can be defined as the incompatibility between student's body dimensions and the dimensions of laboratory furniture's.

In this study we will calculate the mismatch between popliteal height and seat height, buttock popliteal length and seat depth, hip width and seat width, elbow sitting height and desk height, shoulder height and backrest height, knee height and table clearance .

(Gouvali, 2006) defined a mismatch between popliteal height and seat height when the current seat height is less than the cosine of thirty degree or greater than the cosine of five degree of popliteal height.(Parcells, 1999) Determined the mismatch between seat depth and buttock popliteal length when the seat depth is less than 80% or greater than 95% of buttock popliteal length (Castellucci, 2010). As presented in (Gouvali, 2006) the mismatch between seat width and hip breadth occurs when the seat width is less than1.1 or greater than 1.3 of hip width, and the backrest height as recommended to keep the backrest lesser than the scapula height, or at the upper edge of the scapula 60–80% of shoulder height. Hence, the mismatch appears when the backrest is greater than 0.8 or less than 0.6 of sitting shoulder height.

(Parcells, 1999) Recommended the table clearance should be at least 20 mm; this space allows the knees to be more comfortable under the table. He proposed the desk height should be designed to elbow- floor height. Therefore the lowest table height we will get it when the shoulders are not in flexion or abduction. When the shoulders are at 25° flexion and 20° abduction the table height will be at the maximum elevation as shown in figure (2-5).

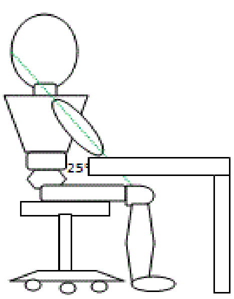


Figure 2.5.A: The Shoulder at 25° Flexion

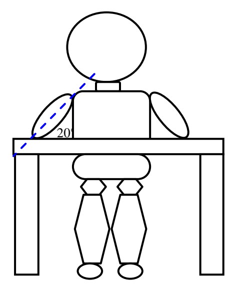


Figure 2.5:B: The Shoulder at 20° Abduction

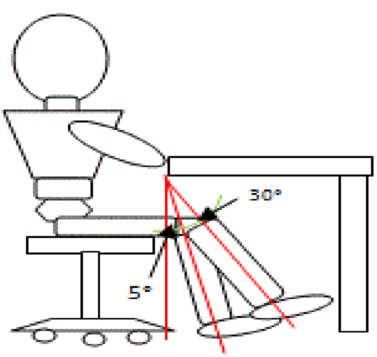


Figure 2.6: Sitting Posture at the Lower and Upper Limits of Seat Height

Thus, we can conclude the lowest desk height as following :

Min desk height = Elbow sitting height + low seat height

$$\text{Min DH} = EH + \cos 30° \, PH \qquad (2\text{-}1)$$

When; EH = sitting-elbow height, and DH = desk height

The maximum desk height can be calculated from

$$\text{Max DH} = \text{Max SH} + \text{Max EH}$$

$$\text{Max DH} = \cos 5° \, PH + \text{Max EH} \qquad (2.2)$$

Let AL is arm length then, AL = sitting shoulder height – elbow sitting height.

$$AL = SDH - EH \qquad (2.3)$$

Where SDH is the shoulder sitting height

Then, $\text{Max EH} = EH + (1-\cos 20°)\, AL + (1-\cos 25°)\cos 20° \, AL$

$$\text{Max EH} = EH + 0.0604\, AL + 0.0881\, AL \qquad (2\text{-}4)$$

Given (2.2) and (2.4)

$$\text{Max DH} = \cos 5° PH + 0.852\, EH + 0.148\, SDH \qquad (2\text{-}5)$$

Thus, from (2.1) and (2.5), formula to determine DH is

$$EH+\cos 30° PH < DH < \cos 5° PH+0.852EH+0.148SDH \qquad (2.6)$$

## 2.5 Illumination

In many fields of our lives we need sources of light which can be from the sun as daylight or from artificial sources such as overhead light. The amounts of lighting we need to complete our jobs depend on type of jobs. So, when a person works some activities on indoor or at night, it is necessary to provide him with some source of illumination whether from natural daylight or from artificial sources (McCormick, 1992).

Students are usually seating in front of a monitor for one hour or more this may have some effects on their vision. They often focus on the computer screens for long periods of time. This may cause the strain in muscles of their eyes and possibly they may feel headache and fatigue.

The glare and the intensity of light are the main factors that may have an effect on the eye strain. When a student read and write by using a computer in a poor lighting environment, he will feel muscle soreness and fatigue in his eyes. For instance, the student might tilt forward in low lighting environment to see her/his screen clearly, or tilt to backward to avoid the glare coming from either her/his screen or a bright light overhead. Improving the lighting, adjustment the height of workstation, taking time to rest and using eyeglasses during computer work, may help to solve many computer-related vision problems (EOHSS, 2008).

### 2.5.1 Glare

Glare is difficulty of vision due to the presence of bright light, whether from the sunlight or artificial sources or reflex surfaces. It is necessary to avoid glare as much as possible because it affects the performance of work. To avoid glare from windows, the curtains can be adjusted to reduce the amount of light on your screen. Additionally, we should sit beside or in parallel to the window while we face the monitor. Moreover, to avoid glare from overhead lights we should adjust the angle of computer screen (WorkSafeBC, 2009).

# Chapter 3

# METHODOLOGY

## 3.1 Subjects

A total of fifty undergraduate and postgraduate students, twenty-three males and twenty-seven females were participated in this study. Their ages ranged from eighteen to thirty-five years old. All subjects were students from EMU University.

## 3.2 Anthropometric Method

Anthropometry is an active field in industrial design, ergonomics and architecture where statistical data about the distribution of body dimensions in the population are used to improve products. Changes in life styles, nutrition and physical differences between global population lead to changes in the distribution of body dimensions, and require regular updating of anthropometric data collections.

In this research, eleven anthropometry dimensions were measured and directly used in designing chairs and tables for students' computer workstations. All anthropometric measurements were collected using the students of Industrial Engineering Department at EMU. During measurement each student was asked to keep two different postures; sitting up right where knees and elbow bent at ninety degrees as in figure (3-1), and standing erect without shoes. The measurements weight was done using a balance such as shown in the figure below.

Figure 3.1: Measurement Illustrations by Using Instruments

The measured dimensions were height, shoulder height, shoulder elbow height, buttock popliteal length, popliteal height, knee height, forearm hand length, hip width, elbow sitting height, sitting height and eye sitting height figure (3-2) shows all these dimensions. On the average, it took around 10 minutes to complete all the measurements required per one student.

The descriptions of human body dimensions which are recorded in this research are as follows:

1. Stature (or height): It is the vertical distance taken from the floor to the highest point of the head when the student stands erect and looking straight ahead.

2. Shoulder height: Is defined as the vertical distance from the top of the shoulder at the acromion to the subject's sitting plane or seat pan.

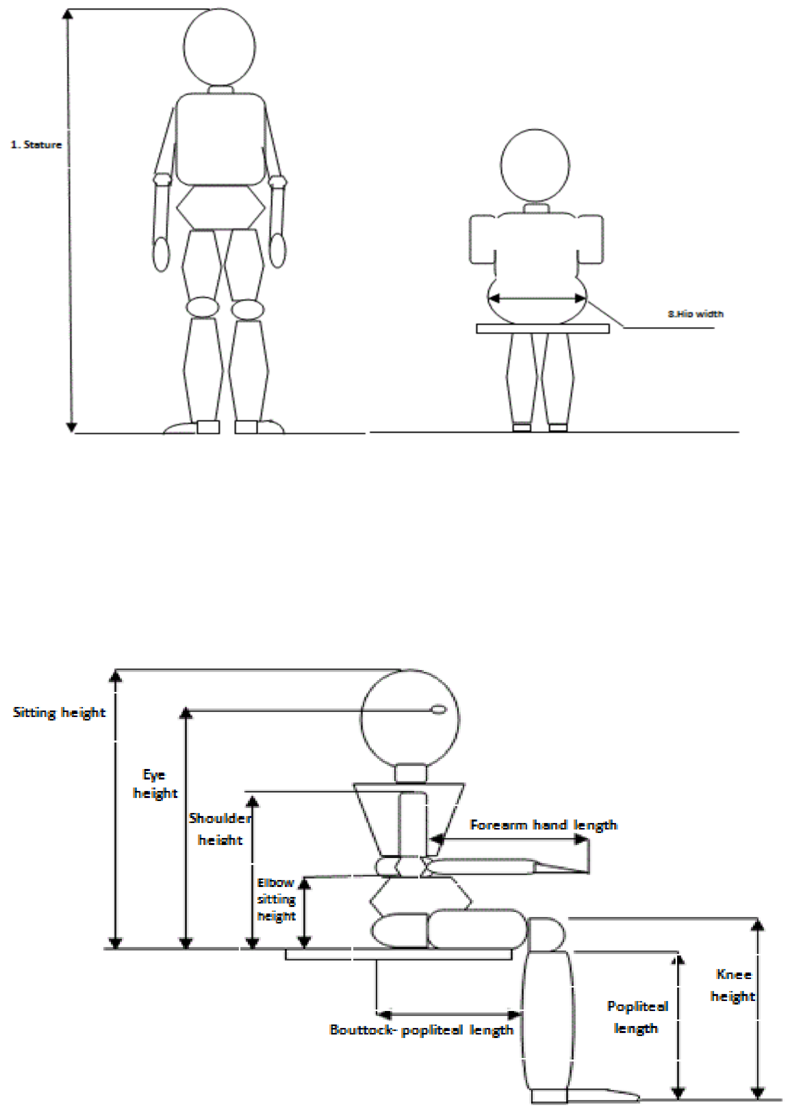


Figure 3.2: Measured Anthropometric Dimensions

3. Shoulder elbow length: Is referring to the difference between the elbow sitting height and shoulder height.

4. Buttock-popliteal length: When the student sitting with 90° knee flexion, the buttock-popliteal length is the horizontal distance from the posterior surface of the buttock to the posterior surface of the knee or popliteal space.

5. Popliteal height: Popliteal height is the vertical dimension, with 90° knee flexion, from the foot resting surface to the posterior surface of the knee or popliteal surface.

6. Knee height: Knee height is the vertical distance, with 90° knee flexion, from the foot surface to the top of the kneecap.

7. Forearm hand length: is the horizontal distance from the elbow to fingertip.

8. Hip width: is the maximum horizontal distance across the hips in the sitting surface.

9. Elbow sitting height: It is measured as the vertical distance from the bottom of the tip of the elbow, with 90° elbow flexion, to the subject's seated surface.

10. Sitting height: is the vertical distance from the tip of the head to the surface of the sitting object.

11. Eye height: is the vertical distance from the sitting surface to the landmark on the outer corner of the right eye.

## 3.3 The Dimensions and Layout of the PC Lab Including Furniture's Measurements

After the anthropometric measurements of students were taken the second stage of this study is to determine the followings:

1. Total square area of lab.

2. Number of workstations used.

3. The places of equipment which are used for teaching processes such as presentation screen and whiteboard.

4. Furniture dimensions for both seat and table's workstation.

5. Locations of workstations relative to the instructor's screen and whiteboard.

6. Number and dimensions of aisles which are used in present layout.

7. Locations of the windows and the entrance.

8. The student posture while he is sitting at his workstation.

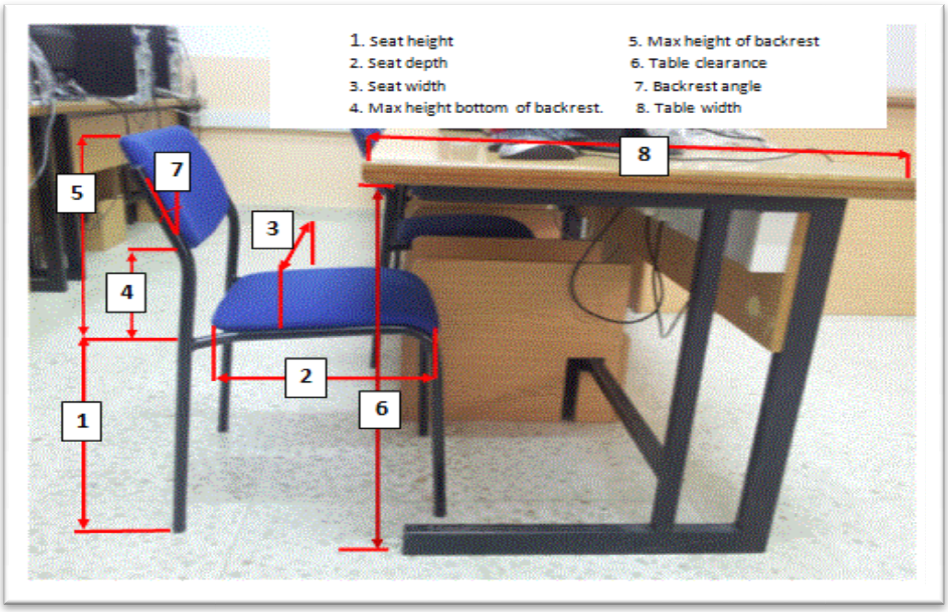


Figure 3.3: Furniture Dimensions A.

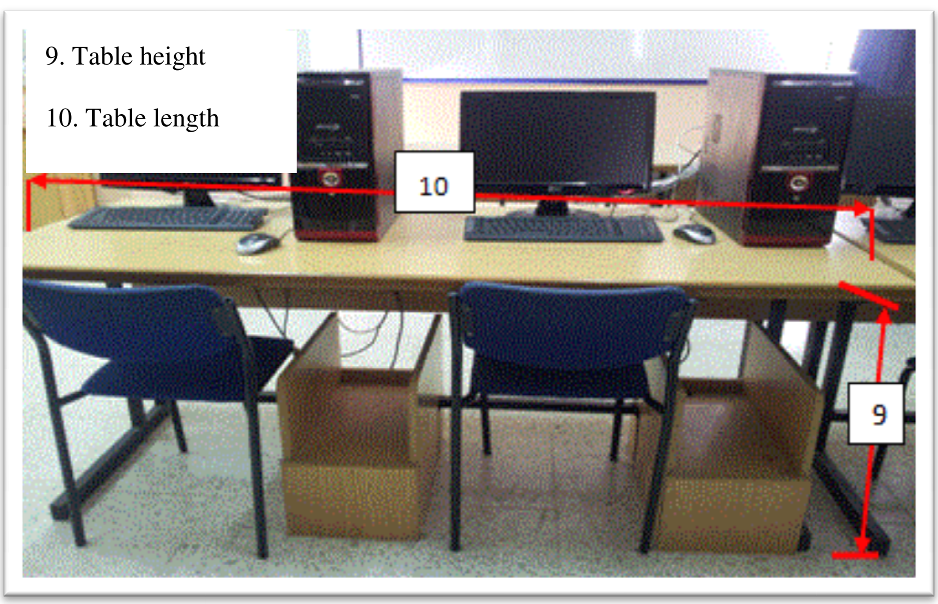


Figure 3.4: Furniture Dimensions B.

## 3.4 The Equipment Used in this Study Comprises the Followings

1. Anthropometer ruler.
2. Metal tape.
3. Angle finder.
4. Balance.

Figure 3.5: Instruments for Anthropometric Measurement.

## 3.5 Data Collection

The dimensions measured should be documented in a form, which includes some personal information such as name, age, sex, and student number. Each Student must fill her/his own personal information before the measurement process started. Table3-1 shows clearly the exact location for all eleven anthropometric dimensions, which is important to ensure the measurement process for each student is done correctly and accurately and to minimize the errors in the data collection process.

Table 3.1: Form to Record Measurements of Students

| Subjects | 1 | 2 | ………………………… | 50 |
|---|---|---|---|---|
| Name | | | | |
| Student number | | | | |
| Gender | | | | |
| Age | | | | |
| Weight kg. | | | | |
| Height | | | | |
| Shoulder height | | | | |
| Shoulder elbow height | | | | |
| Buttock popliteal height | | | | |
| popliteal height | | | | |
| knee height | | | | |
| Forearm length | | | | |
| hip width | | | | |
| Elbow sitting height | | | | |
| Sitting height | | | | |
| Sitting height | | | | |
| Sitting eye height | | | | |

# Chapter 4

## EXPERIMENTAL DESIGN

### 4.1 Experiment Design

Experimental design is a statistical procedure used to improve processes, where the process variables are studied and its final result shows to experimenter which variables are most important and which are insignificant.

In this research we consider the experiment to compare between two conditions that usually are named treatments. For example, the popliteal height of student is an important characteristic of the seat height design. Therefore, the designer is interested in comparing the popliteal height of males and females. In this project we need to compare between the pair of treatment (male and female) for all anthropometric dimensions of students such as height, shoulder height, shoulder elbow height, buttock popliteal length, popliteal height, knee height, and hip width that used in workstation design.

An experiment was designed and performed as follows. First, 50students (or subjects) were randomly selected. Then we use anthropometric set to measure the dimensions of students' body. Subjects were randomly scheduled to measurement. Additionally, the order of measurement of specific dimensions was randomized.

A completely randomized design was used in this research. The averages of all anthropometric measurements, male and female, were calculated and hypotheses were formulated and tested.

## 4.2 The Normality Assumption

Before applying statistical methods that suppose normality, it is necessary to perform a normality test on the anthropometric body dimensions. The normality assumptions are easy to check by using a normal probability plot. Generally, we can perform it quickly by Minitab 14 .Minitab 14 gives a p-value so; we can compare this value with our stated alpha level which is equal to 0.05.

The null hypothesis states that, the anthropometric data of male and female students follow a normal distribution. We will reject the null hypothesis when the p-value is less than alpha level. As can be seen from Minitab output, the p-value is larger than 0.05, this implies there is no sufficient evidence to reject the null hypothesis and it is concluded the data distribution is normal. Additionally, as illustrated in figure (4.1) all observations are close to the straight line on the graph. Hence, the null hypothesis about normality is verified.

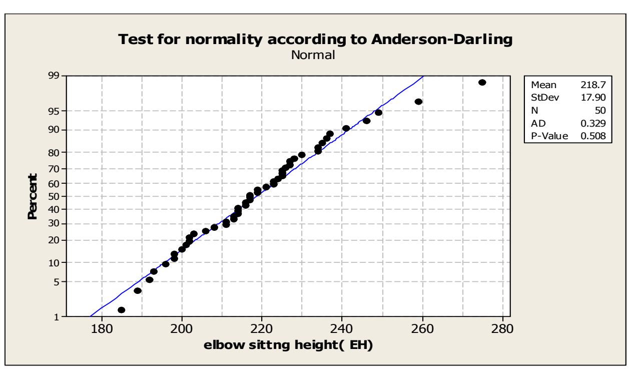


Figure 4.1: Normal Probability Plot of Elbow Sitting Height

To be noted that the normality tests for all other dimensions that are collected in this research can be seen the figures in appendix C from figure (C-18) to figure (C -26).

## 4.3 Percentile Calculation

The formula below is used to compute percentiles of a normal distribution.

$$K^{th} \text{ percentile} = \mu \mp z\,\sigma \qquad (4\text{-}1)$$

Where μ is the mean of anthropometric dimensions which are ( height, shoulder height, shoulder elbow height, buttock popliteal length , popliteal height, knee height, forearm hand length, , hip width , elbow sitting height , sitting height and eye sitting height figure ) and σ is their standard deviation and Z is the value from the standard normal distribution for the wanted percentile. If we take any human body dimension such as elbow sitting height, we will find the $5^{th}$ and $95^{th}$ percentiles as follow:

$5^{th}$ $\quad P_{\text{Elbow sitting height}} = \mu_{\text{Elbow sitting height}} - 1.65 * \sigma_{\text{Elbow sitting height}}$

$95^{th}$ $\quad P_{\text{Elbow sitting height}} = \mu_{\text{Elbow sitting height}} + 1.65 * \sigma_{\text{Elbow sitting height}}$

The average (μ) and the standard deviation (σ) of a human body dimension can be taken from the table (5-2).

## 4.4 Inferences about the Difference in Meaning

Comparison between the different genders of students starts by investigating and determining whether males and females have equal body dimensions. So hypothesis will be formulated and tested by using the data collected in this experiment.

### 4.4.1 Hypothesis Testing

The method of statistical inference used is named hypothesis testing or significance testing. It is used to discover whether males and females are having equal mean body dimension or not. Let $y_{f1}, y_{f2}, \ldots \ldots \ldots, y_{fn_f}$ represent the dimensions recorded from $n_f$ female students, and $y_{m1}, y_{m2}, \ldots \ldots \ldots, y_{mn_m}$ represent the dimensions recorded from $n_m$ male's students. The main assumption here is the collected measurements are normally distributed.

- **Statistical Hypothesis**

It is a statement about the distribution parameters.

$$H_0: \mu_f = \mu_m$$

$$H_1: \mu_f \neq \mu_m$$

Where $\mu_f$ and $\mu_m$ denote the, mean of a specific measured dimension for females and male respectively. The statement of null hypothesis $H_0$ implies that both females and males have equal mean in term of the specific recorded body measurement. Where the statement of alternative hypothesis implies $H_0$ is not true.

### 4.4.2 Inference on the Variances of Two Normal Population

Consider two populations male and female students to be compared. Let $n_f$ denoted the sample size of female students and $n_m$ denote the sample size of male populations. Let $Y_f'$ and $S_f$ denote the sample mean and standard deviation from female students and $Y_m'$ and $S_m$ denote the sample mean and standard deviation from male. Then the test statistic that can be used to test the equality of the female and male variances is:

$$F_0 = \frac{S_f^2}{S_m^2} \tag{4-2}$$

The test statistic follows the F distribution with degrees of freedom $v_f = (n_f - 1)$ and $v_m = (n_m - 1)$ for male and female respectively.

1. The statements for this hypothesis as:

$$H_0: \sigma_f^2 = \sigma_m^2$$

$$H_1: \sigma_f^2 \neq \sigma_m^2$$

2. Let the significance level $\alpha = 0.05$. Here the test statistic is based on the F distribution where $n_f = 27$ and $n_m = 23$.

   Given that $v_f = 26$ and $v_m = 22$ then, the null hypothesis $H_0$ is rejected if the test statistic $F_0$ is such that:

$$F_0 > F_{0.025,26,22}$$

$$F_0 < F_{0.975,26,22}$$

   Note that the table gives only upper-tail percentage of F. Thus, we can find the value of $F_{0.975,26,22}$ by this formula.

$$F_{0.975,26,22} = \frac{1}{F_{0.025,26,22}}$$

3. The value of the test statistic $F_0$ corresponding to the given data is:

$$F_0 = \frac{S_f^2}{S_m^2}$$

By using Excel 2007 we can compute the value of $F_0$, $t_0$, $v$ for all parameter or by using statistical software packages Minitab 14.

### 4.4.3 Two-Sample t-Test Independent Samples with Equal Variance

One of the most common statistical testing methods is the two sample t-test used for comparing the means of two populations.

The general setting is as follows: Consider two populations to be compared in terms of a particular variable. Let $n_f$ , $\mu_f$, $\sigma_f$ ,$n_m$ ,$\mu_m$ and $\sigma_m$ denote the sample size , mean and standard deviation of a specific recorded body dimension for the female and male subjects respectively. The hypothesis of the test is

$$H_0: \ \mu_f = \mu_m$$

$$H_1: \ \mu_f \neq \mu_m$$

The anthropometric measurements which have equal variances make sense to pool all the data from both female and male to estimate the common variance by the following formula

$$S_p^2 = \frac{(n_f-1)s_f{}^2+(n_m-1)s_m{}^2}{n_f+ n_m-2} \qquad (4\text{-}3)$$

The degrees of freedom for the pooled variance estimator is $n_f + n_m$- 2.

Thus, $v$= 27+23-2=48

The test statistic for the hypothesis test is simply the standardized difference between the sample means:

$$t_0 = \frac{\grave{Y}_f - \grave{Y}_m}{s_P\sqrt{1/n_f+1/n_m}} \qquad (4\text{-}4)$$

By using the Excel 2007 and Minitab 14 we can calculate the value of $t_0$ and p- Value.

### 4.4.4 Two-Sample t-Test with Unequal Variances

This section describes the testing procedure for equality of means when the assumption of equality of population variances in the two populations is violated.

$$H_0:\ \mu_f = \mu_m$$

| $H_1:\ \mu_f < \mu_m$ | $H_1:\ \mu_f > \mu_m$ |
|---|---|
| Reject the null hypothesis $H_0$ if $t_0 < -t_{0.05,v}$ | Reject the null hypothesis $H_0$ if $t_0 > -t_{0.05,v}$ |

The testing procedure is the same as before except the original test statistic is modified to be

$$t_0 = \frac{\grave{Y}_f - \grave{Y}_m}{\sqrt{s_f^2/n_f + s_m^2/n_m}} \tag{4-5}$$

$$v = \frac{\left(\frac{s_f^2}{n_f} + \frac{s_m^2}{n_m}\right)^2}{\frac{(s_f^2/n_f)^2}{n_f - 1} + \frac{(s_m^2/n_m)^2}{n_m - 1}} \tag{4-6}$$

# Chapter 5

# RESULTS AND DISCUSSION

## 5.1 Laboratory Furniture

The computer laboratory in the Industrial Engineering department under study consists of forty chairs and twenty tables. Only one type of chair and table exists in the lab and their dimensions are as shown in table 5-1 below.

Table 5.1: Dimensions of Furniture Used at Computer Workstations in IE Department.

| Dimensions | Measurement |
|---|---|
| Seat Height (cm) | 40 |
| Seat Depth | 39 |
| Seat Angle | 3° |
| Backrest angle | 10° |
| Seat width | 37 |
| Max height of backrest | 36.5 |
| Max height to bottom of backrest | 14.5 |
| Desk height | 74 |
| Desk clearance | 71 |
| Desk slop | 0 |
| Desk width | 180 |
| Desk length | 75 |

## 5.2 Anthropometric Measurement

The measurements of the students' bodies are listed in table 5-2 below. Analysis of data was done by Excel 2007 and Minitab 14. Basic descriptive statistics were used to compute both mean, median, standard deviation, maximum and minimum value for anthropometric data. As you can see in table 5-2, most of the means and medians are very close to each, indicating symmetrical distributions.

We can calculate the 5th and 95th percentile by using formula (4-1). If you take any dimension from table (5-2) such as sitting elbow height, you can see the average for all students is 218.58mm with a standard deviation of 17.45 mm, where the standard deviation value is directly proportional to the difference between each data and the mean.

Let: mean= $\mu$ Standard Deviation= $\sigma$

$5^{th}$ percentile = $\mu - 1.65\,\sigma$ = 218.68 – (1.65x17.89) = 189.16mm.

$95^{th}$ percentile = $\mu + 1.65\,\sigma$ = 218.68+ (1.65x17.89) = 248.2mm.

These distributions of sitting elbow heights seems to be normally distributed as you can see from figure (5.1).

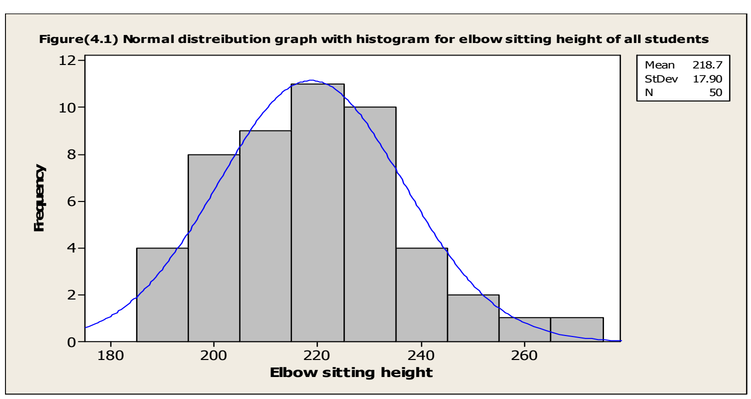


Figure 5.1: Normal Distribution Graph with Histogram for Elbow Sitting Height

Table 5.2: Anthropometric Data for the Overall Subjects

| Dimension | μ | Median | σ | Max | Min | 5th | 95th |
|---|---|---|---|---|---|---|---|
| Weight kg. | 69.43 | 65.25 | 14.214 | 115 | 47 | 45.976 | 92.883 |
| Height mm | 170.38 | 170.75 | 8.405 | 185 | 148 | 156.511 | 184.24 |
| Shoulder height | 535.28 | 539 | 26.23 | 584 | 472 | 492.00 | 578.56 |
| Shoulder elbow height | 316.6 | 317 | 23.37 | 371 | 258 | 278.03 | 335.16 |
| Buttock popliteal height | 460.2 | 453.5 | 22.28 | 518 | 425 | 423.44 | 496.96 |
| Popliteal height | 430.6 | 432 | 20.21 | 465 | 385 | 397.24 | 463.95 |
| Knee height | 514.6 | 511.5 | 26.78 | 564 | 448 | 470.42 | 558.78 |
| Forearm length | 455.02 | 455 | 25.39 | 502 | 385 | 413.12 | 496.92 |
| Hip width | 384.58 | 375 | 38.1 | 467 | 314 | 321.73 | 447.43 |
| Sitting elbow height | 221.4 | 223 | 17.42 | 240 | 154 | 189.16 | 248.2 |
| Sitting height | 813 | 820.5 | 52.32 | 896 | 670 | 726.67 | 899.33 |
| Sitting eye height | 728 | 733.5 | 51.31 | 804 | 585 | 643.33 | 812.67 |

## 5.3 Evaluate the Current Furniture of the PC Lab

For evaluation and redesign of the laboratory furniture, it is important to consider the applied of anthropometry and ergonomics principles, and use equations to calculate the limitations of furniture dimensions to determine the mismatch.

### 5.3.1 Popliteal height and seat height

(Gouvali, 2006) Presented the match criterion as the following:

$$PH \cos 30^\circ < SH < PH \cos 5^\circ \quad (5\text{-}1)$$

When PH = popliteal height

SH = seat height

Therefore the mismatch occurs when the current seat height is less than cos30ºor greater than cos5ºof popliteal height.

### 5.3.2 Buttock-popliteal Length and Seat Depth

Most designers recommended that, seat depth should be designated for the 5th percentile of the popliteal buttock length distribution. Poulakakis and Marmaras (1998) suggested that depth should be at least 5 cm shorter than popliteal buttock length. (Parcells, 1999) determined the mismatch when the seat depth was ≤80% or ≥95% of buttock popliteal length (Castellucci, 2010).

$$0.80PB \leq SD \leq 0.95PB \tag{5-2}$$

### 5.3.3 Hip width and Seat Width (SW)

The seat width must be large enough to provide accommodation for the users with the largest hip. To reduce the mismatch between hip width and seat width the seat width should be design at the 95th percentile of hip width distribution or the largest hip (Gouvali, 2006) proposed a modified equation (5-3).

$$1.1HW \leq SW \leq 1.30HW \tag{5-3}$$

As you see from equation (5-3) the mismatch occurs when the seat width is less than1.1 or greater than 1.3 of hip widths.

### 5.3.4 Shoulder Height and Backrest Height

The backrest height recommended by (Gouvali, 2006) as keeping the backrest lesser than the scapula height, or at the upper edge of the scapula (60–80% of shoulder height).

$$0.6\ SDH \leq BH \leq 0.8\ SDH \tag{5-4}$$

Thus the mismatch appears when the backrest is greater than 0.8 or less than 0.6 of sitting shoulder height.

### 5.3.5 Elbow Sitting Height and Desk Height

Elbow sitting height is the important dimension to determine the table height so that, the most researchers considered it as the major criterion for desk height (Parcells, 1999) reported that the desk height should be designed to elbow- floor height. Therefore the lowest table height we will get it when the shoulders are not in flexion or abduction, but when the shoulders are at 25° flexion and 20° abduction the table height will be at the maximum therefore, the criteria of a mismatch as in equation (2-6).

$$EH+\cos 30°PH < DH < \cos 5°PH+0.852EH+0.148SDH$$

### 5.3.6 Underneath Desk Height (Table Clearance)

Table clearance is indicated to be the space between the knees and the underneath surface of the desk. (Parcells, 1999) recommended the table clearance should be at least 20 mm. This space allows the knees to be more comfortable under the table.

$$UD \geq 20 + \text{knee height} \quad (5\text{-}6)$$

By using equations mentioned above from (5-1) to (5-6) we can determine the mismatch for all subjects as illustrated in table (5-3).

Table 5.3: Mismatch between Furniture and Body Dimensions for 50 Students

| Mismatch | Overall students | male | female |
|---|---|---|---|
| Mismatch between popliteal height and seat height | **22%** | **26%** | **18%** |
| Mismatch between Buttock popliteal height and seat depth | 14% | 26% | 4% |
| Mismatch between hip width and seat width | 56% | 56.5% | 55.5% |
| Mismatch between sitting elbow height and table height | 92% | 87% | 96.3% |
| Mismatch between Knee height and table clearance | 0% | 0% | 0% |

The objective of this study is to evaluate the design of PC lab in the Industrial Engineering Department by using the mismatch ratio. So, we proposed two techniques to design the tables and chairs of workstations. In each technique the design is based on the optimal proportion of matching. After that, the two designs will be compared and the best workstation model will be selected. Additionally, a proposed ergonomical design for the computer laboratory (i.e. PC Lab) at the department of Industrial Engineering will be developed.

## 5.4 Combination of Statistics and Optimization

The aim of this technique is to design the table and chair with respect to the maximum percentage of matching between target population’s body dimensions and the furniture set.

### 5.4.1 Chair Design

The chair is the most important piece of furniture used in a computer workstation where the student spends one hour or more of their time sitting in front of the computer workstation. Therefore, it is necessary to select a properly designed chair to enable the student to sit comfortably, work efficiently, and provide proper support for the human body to minimize fatigue.

- **Seat Height (SH)**

After many years of investigations a number of recommendations and guidelines are offered so that it can be used in the design of a seat. From equation (5-1).

$SH > 0.866PH \quad \& \quad SH < 0.996PH$

Then, $\frac{SH}{0.996} \leq PH \leq \frac{SH}{0.866}$

Thus, the population whose body dimension matches with current seat height of (400 mm) is:

$$\frac{400}{0.996} \leq \text{PH} \leq \frac{400}{0.866}$$

Thus, $$401.6 \leq \text{PH} \leq 461.9$$

When we refer to table (5-2), we can see the mean value of popliteal height for 50 students is 430 mm and the standard deviation is 20.21.

Proportion match of population =P $\left(\frac{401.6-430}{20.21} \leq \frac{\text{PH}-\mu}{\sigma} \leq \frac{461.9-430}{20.21}\right)$

The proportions of population match = P (-1.16≤ Z ≤2.18) = 0.82

As a result the current seat height is fitting for 82% of the students.

To optimize this percentage we will calculate this proportion for different seat heights. The proportion of students match (are seen in the table 5- 4 below) at different seat heights:

$$\text{P}\left(\frac{\left(\frac{\text{SH}}{0.996}\right)-430}{20.21} \leq \text{z} \leq \frac{\left(\frac{\text{SH}}{0.866}\right)-430}{20.21}\right).$$

Through varying the seat height from 400 mm to the different values between 330 and 480 mm, then the proportion of match is increased when the seat height is reduced from 480 to 400 mm. Then this proportion starts decreasing and gets closer to zero when the seat height approximately 330mm. With the optimization method, the maximum proportion of match population is found at 82% when the seat height is 400mm therefore; the current seat is more convenient for the most students and should remain the same (chair at 400mm height). This is obvious from looking at figure (5-2).

Table 5.4: Proportion of Students Match at Different Seat Height

| SH | SH/0.996 | SH/0.866 | P1 | P2 | P2-P1 |
|---|---|---|---|---|---|
| 330 | 331.325 | 381.0624 | 0 | 0.01 | 0.01 |
| 350 | 351.406 | 404.157 | 0 | 0.1 | 0.1 |
| 360 | 361.446 | 415.7044 | 0 | 0.23 | 0.23 |
| 365 | 366.466 | 421.4781 | 0 | 0.33 | 0.32 |
| 375 | 376.506 | 433.0254 | 0.01 | 0.55 | 0.54 |
| 380 | 381.526 | 438.7991 | 0.01 | 0.66 | 0.65 |
| 385 | 386.546 | 444.5727 | 0.02 | 0.76 | 0.73 |
| 390 | 391.566 | 450.3464 | 0.04 | 0.84 | 0.79 |
| 395 | 396.586 | 456.1201 | 0.08 | 0.9 | 0.818 |
| 400 | 401.606 | 461.8938 | 0.12 | 0.94 | 0.82 |
| 405 | 406.627 | 467.6674 | 0.19 | 0.97 | 0.78 |
| 410 | 411.647 | 473.4411 | 0.27 | 0.98 | 0.71 |
| 415 | 416.667 | 479.2148 | 0.37 | 0.99 | 0.62 |
| 420 | 421.687 | 484.9885 | 0.48 | 1 | 0.51 |
| 430 | 431.727 | 496.5358 | 0.7 | 1 | 0.3 |
| 450 | 451.807 | 519.6305 | 0.95 | 1 | 0.05 |
| 470 | 471.888 | 542.7252 | 1 | 1 | 0 |
| 480 | 481.928 | 554.2725 | 1 | 1 | 0 |

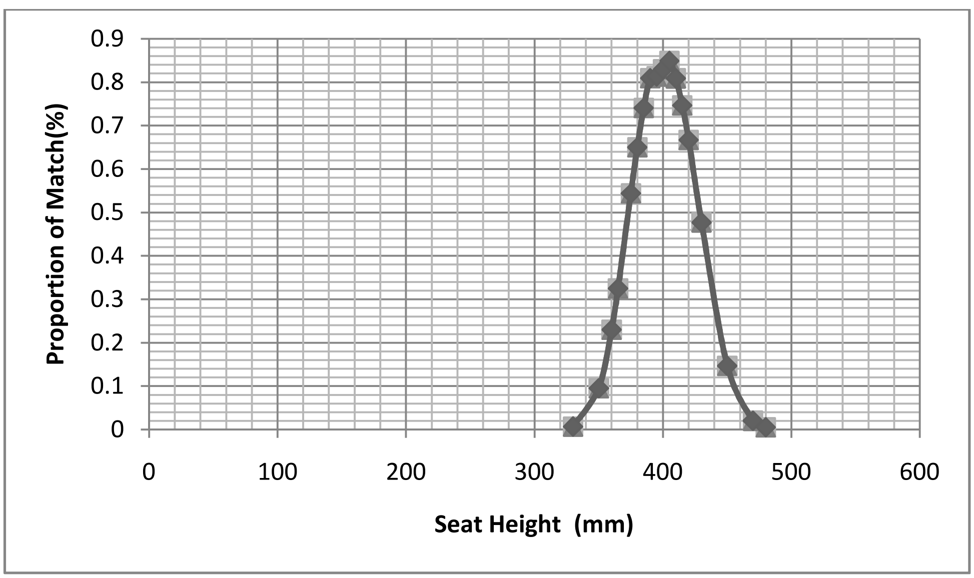


Figure 5.2: Proportion of Match Population at Different Seat Height.

- **Seat Depth (SD)**

(Gouvali, 2006) Mentioned that, most researchers recommended the seat depth should be designated for the fifth percentile of the popliteal buttock length distribution, including the shorter user. Poulakakis and Marmaras (1998) found the depth of the seat should be at least 5 cm shorter than the popliteal buttock length. Whereas, (Parcells, 1999) determined the mismatch in this case when the depth is less than 80% or greater than 95% of the popliteal-buttock length as in equation (5-2).

$0.80PB \leq SD \leq 0.95PB$

We can calculate the proportion of the matching students for the seat depth by using the same procedures that are explained above.

$SD > 0.80PB \quad \& \quad SD < 0.95PB$

Where SD is seat depth and PBL is popliteal buttock length.

Then, $\frac{SD}{0.95} \leq PB \leq \frac{SD}{0.80}$

Table 5.5: Anthropometric Dimensions

| Body dimension | (μ) & (σ) |
|---|---|
| Buttock popliteal (PBL) | 460.2 (22.28) |

Thus, students whose body dimension of PBL are between 393.9 and 487.5 mm they are matching the current seat depth with 88.8% of students. If we compute the proportion at different seat depths as shown in figure (5-3) and appendix table (B-8) we see that, the maximum proportion of match population is 97.12% when the seat depth is 410 mm.

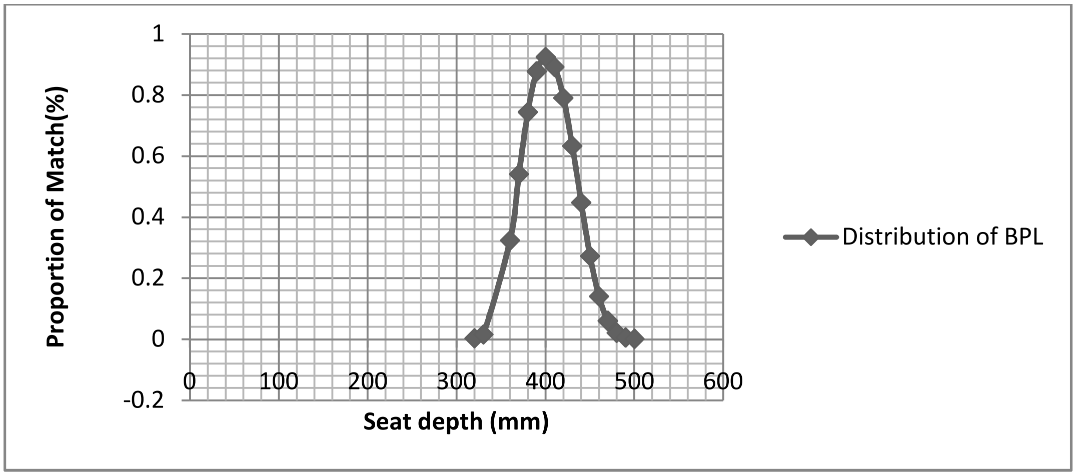


Figure 5.3: Proportion of Match Population at Different Seat Depth

- **Seat Width (SW)**

(Gouvali, 2006) mentioned that, seat width should be large enough to allow space for side movements.

From equation (5-3) then,

1.1HW≤SW≤1.30HW

The proportions of match for any different seat width = P $\left(\frac{\left(\frac{SW}{1.3}\right)-\mu}{\sigma} \leq \frac{PH-\mu}{\sigma} \leq \frac{\left(\frac{SW}{1.1}\right)-\mu}{\sigma}\right)$

Once again use the same procedures to find the proportion of matching the seat width so, with referee to the table (B-10) and figure (B-3) in Appendix B we found the maximum percentage of matching is 62.7% when seat width is 460mm.

- **Backrest Height (B)**

The equation recommends keeping the backrest lower than the scapula, or at most on the upper edge of the scapula (60–80% of shoulder height) by (Gouvali, 2006).

0.6SDH≤BH≤0.8SDH (5- 4)

So; BH≥0.6SDH and BH≤0.8SDH

Thus, $\frac{BH}{0.8} \leq SDH \leq \frac{BH}{0.6}$

Referring to the table (B-9) and figure (B-2) in Appendix B the maximum proportion of match population is 99.96 when the backrest height is 365 mm.

### 5.4.2 Table Design

As people with different heights perform different tasks, the computer desk should be designed to minimize stressful posture. To estimate the proportion of students matching the current table height, we can apply the same procedures which we used earlier to determine the proportion of matching of students for seat height. From table (5-1) the current desk height DH is 740 mm. From equation (2-6) that mentioned in section 2-4 the limitations of desk height are:

$EH+\cos 30°PH < DH < \cos 5°PH+0.852EH+0.148SDH$

Let , $ES = 0.852\ EH + 0.148\ SDH$ (5-7)

$DH > EH + 0.866\ PH$,

$EH < DH - 0.866\ PH$ (5-8)

When PH is the current seat height a 400mm,

Then, $EH< 740 - (0.866*400)$

$EH< 393.6$ mm.

$DH < 0.996\ PH + ES$,

By substituting (5-7) in (2-6) we get:

$ES > DH - 0.996\ PH$ (5-9)

When PH is the current seat height at 400mm, then $ES > 740 - (0.996*400)$

Or $ES > 341.6$ mm

From the above calculations we can note the followings, the percentage of students who fit the current table height is approximately 100% (for sitting elbow height less than

393.6 mm).On the other hand it is 0% for ES greater than 341.6 (Refer to table (5-7) and figure (5-4)).

According to the formula (5-8) and (5-9) we can find the match proportion (Table 5-7) at different table heights.

The proportion of the EH at different table height = p (z $\leq \frac{(DH-346.4)-218.58}{17.42}$) and

The proportion of ES at different table height = p ( z $\geq \frac{(DH-398.4)-265.4}{17.48}$).

Table 5.6: Anthropometric of EH and ES in mm

| Body dimension | Average, (std.dev.) |
|---|---|
| Elbow sitting height (EH) | 218.58, (17.42) |
| (ES) | 265.54 , (17.48) |

As you see in the table (5-7) if we change the desk height from 740 mm to 620 mm, we will find the proportion of match is 99.9% when EH is less than 273.6 mm. The proportion of match is 99%when ES is greater than221.6 mm. As a result we will record the maximum point of the percentage of matching (as 99%) at the intersection point between two curves of EH and ES. As seen in Fig.5-4 when the desk height is 620 mm.

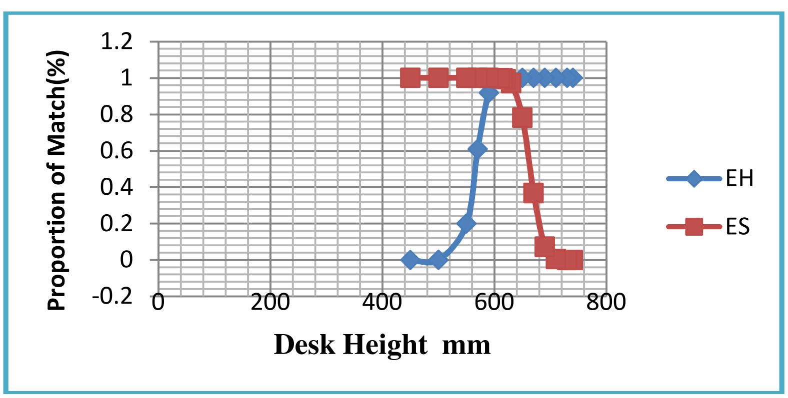


Figure 5.4: The Optimal Proportion of Match Population at Different Desk Height.

Table 5.7: Proportion of Match Students at Different Desk Heights

Current table height →

Optima table height →

| DH | EH≤DH – 346.4 | P1 | ES ≥ DH – 398.4. | P2 | 1-P2 |
|---|---|---|---|---|---|
| 740 | 393.6 | 1 | 341.6 | 1 | 0 |
| 730 | 383.6 | 1 | 331.6 | 1 | 0 |
| 710 | 363.6 | 1 | 311.6 | 0.99 | 0.01 |
| 690 | 343.6 | 1 | 291.6 | 0.93 | 0.07 |
| 670 | 323.6 | 1 | 271.6 | 0.63 | 0.37 |
| 650 | 303.6 | 1 | 251.6 | 0.22 | 0.78 |
| 630 | 283.6 | 1 | 231.6 | 0.03 | 0.97 |
| 620 | 273.6 | 0.999 | 221.6 | 0.01 | 0.99 |
| 615 | 268.6 | 0.997 | 216.6 | 0 | 1 |
| 610 | 263.6 | 0.994 | 211.6 | 0 | 1 |
| 590 | 243.6 | 0.918 | 191.6 | 0 | 1 |
| 570 | 223.6 | 0.608 | 171.6 | 0 | 1 |
| 550 | 203.6 | 0.2 | 151.6 | 0 | 1 |

- **Underneath Desk Height (Table Clearance)**

(Parcells, 1999) recommended that, the table clearance should be at least 20 mm, while (Gouvali, 2006) documented that both of Poulakakis and Marmaras (1998) Suggested at least 50 mm of clearance. According to Corlett and Clark (1995) and Helander (1997), this space should be provided to allow for knee of workers crossing and feel more comfort table. Therefore, desk-knee clearance must be exceeded by 20 mm (Gouvali, 2006).

From equation (5-6) in section 5-3-6

UD $\geq$ 20 + knee height.

$$KH \leq UD - 20 \tag{5-9}$$

Current desk clearance (UD) =710 mm.

From (5-9) then, knee height$\leq$ 710-20$\leq$ 690

Hence, KH$\leq$690

The populations of students whose body dimension matches with current table clearance (710 mm) are the population who's KH (knee height) is less than 690mm. The maximum proportion of match is found at 100% when the desk clearance 710 mm. See table (B-11) and figure (B-4). However, the desk clearance must be adjusted to 590 mm which is lower by 30 mm than the new height of the table.

As a result, the chair and table dimensions, by this technique, should be as following: Seat height = 400mm, Seat width = 460mm, Seat depth = 410 mm, Backrest height = 365mm, Table height = 620 mm.

The mismatch from this method was recorded as following:

Mismatch between popliteal height and seat height is $\frac{11}{50}$= 0.22 = 22%

Mismatch between Buttock popliteal height and seat depth is $\frac{6}{50}$= 0.12= 12%

Mismatch between hip width and seat width is $\frac{2}{50}$= 0.04 = 4%

Mismatch between sitting elbow height and table height is $\frac{5}{50}$ = 0.10 = 10%

## 5.5 Designing for Adjustable Range

The workstation should be adjustable for the users who work many hours a day. For example the perfect table of computer workstation which consists of two levels of adjustability for height, one for the screen and another for the keyboard and mouse. The monitor usually should be 50-60 cm wide to give a suitable work space for the screen. On the other hand, most users don't have an ideal computer desk so that. When the computer tables aren't adjustable it becomes important to have adjustable seat and a keyboard tray.

The percentile is a common concept in the ergonomic design which classifies data into groups. For each population, such as male and female, dimensions are sorted and described as percentiles. The 5% always indicates the smallest fifth percentile of the specific dimension of design. For more details on percentile definitions and calculations please refer to Appendix B table (B-1). The $5^{th}$percentile to the $95^{th}$percentile range gives approximately 90% of the population who are matching the design of the product.

In this study we will determine the adjustable dimensions of workstations that are needed in the computer laboratory of Industrial Engineering Department at EMU. Therefore, we can decide which part such as, seat height , backrest height , seat depth and table height in our design needs to be adjusted and any part to be fixed.

**5.5.1 Test for Equal Variance**

Considering the experimental design and hypothesis test with 95% confidence interval that mentioned in section (4-2-2) to examine the differences in the variance of anthropometric dimensions between male and female students .The test statistic follows the F distribution with ( $n_f$ -1 = 26), and ($n_m$ – 1 = 22) degrees of freedom where, the results shown in table (5-8).

The critical F-values are $F_{0.025,26,22}$ =2.315 and $F_{0.025,22,26}$= 2.25

$$F_{0.975,26,22} = \frac{1}{F_{0.025,22,26}} = \frac{1}{2.25} = 0.44$$

$$F_{0.975,26,22} = 0.44.$$

The criteria for rejection is $2.315 < F_0 < 0.44$.

Table 5.8: Values of $\mathbf{F_0}$ for Anthropometric Measurements

| Dimensions | $\mathbf{Y_f'}$ | $\mathbf{S_f}$ | $\mathbf{S_f^2}$ | $\mathbf{Y_m'}$ | $\mathbf{S_m}$ | $\mathbf{S_m^2}$ | $\mathbf{F_0}$ |
|---|---|---|---|---|---|---|---|
| Stature | 165.7 | 7.815 | 61.0742 | 175.91 | 5.089 | 25.9009 | 2.35798 |
| Shoulder height | 521.44 | 24.59 | 605.061 | 551 | 17.50 | 306.530 | 1.97390 |
| Buttock popliteal length | 451.19 | 17.41 | 303.282 | 470.91 | 22.91 | 525.005 | 0.57767 |
| Popliteal height | 422.5 | 18.57 | 344.844 | 440.48 | 17.69 | 312.936 | 1.10196 |
| Knee height | 501.5 | 25.88 | 669.774 | 529.96 | 18.67 | 348.568 | 1.92149 |
| Hip width | 394.518 | 43.74 | 1913.97 | 372.9 | 26.56 | 705.858 | 2.71155 |
| Elbow sitting height | 217.63 | 19.12 | 365.5744 | 219.9 | 16.689 | 278.5227 | 1.312548 |

From table (5-8) and also from the computer output of Minitab 14 table (C- 1) and table (C-8) to test for equal variances we can observe the following :

- The values of $F_{0,\ stature} = 2.357989$ and $F_{0,\ hipwidth} = 2.711556$ are in the rejection region.
- ($P_{Stature}$-Value=0.045) and ($P_{Hip\ breadth}$-Value=0. 02) are less than 0.05. So that, null hypothesis should be rejected. This result shows there is no evidence to indicate that, the variances of height and hip breadth for male and female are equal.
- Values of $F_0$for (Shoulder height, Shoulder elbow height, Buttock popliteal height, Popliteal height and knee height) are located in the acceptance region. As can be seen from P-values (obtained using Minitab 14) for these dimensions are 0.109, 0.196, 0.181, 0.824, 0.124 respectively which are greater than 0.05.So, we cannot reject the null hypothesis and we conclude that, the variances of these anthropometric dimensions between male and female are equal.

### 5.5.2 Two-Samples t-test for Independent Samples with Equal Variances

According to the result in section 5-5-1 the variances of both shoulder height, Shoulder elbow height, Buttock popliteal height, Popliteal height and knee height are equal, then we apply the second test to verify the differences between means of male and female.T-test applies to the students ‘dimensions with $\alpha = 0.05$ and degrees of freedom for the pooled variance estimator is $v$ =27 + 23- 2= 48.

Table 5.9: Values of $S_P$ and $t_0$ that Obtained by Excel 2007

| Dimensions | $Y'_f$ | $S_f$ | $S_f^2$ | $Y'_m$ | $S_m$ | $S_m^2$ | $S_P^2$ | $S_p$ | $t_0$ |
|---|---|---|---|---|---|---|---|---|---|
| Shoulder height | 521.44 | 24.59 | 605.1 | 551 | 17.51 | 306.5 | 468.23 | 21.639 | -4.81 |
| Shoulder elbow height | 303.8 | 21.06 | 443.5 | 331.6 | 16.01 | 256.4 | 357.77 | 18.915 | -5.18 |
| Buttock popliteal height | 451.19 | 17.4 | 303.2 | 470.9 | 22.91 | 525 | 404.91 | 20.122 | -3.45 |
| Popliteal height | 422.5 | 18.57 | 344.8 | 440.48 | 17.69 | 312.94 | 330.22 | 18.172 | -3.48 |
| knee height | 501.5 | 25.88 | 669.77 | 529.96 | 18.67 | 348.56 | 522.56 | 22.86 | -4.38 |
| Elbow sitting height | 217.63 | 19.12 | 365.57 | 219.9 | 16.68 | 278.52 | 325.67 | 18.05 | -0.44 |

The critical t-value: $t_{0.025.48} = 2.010$. From table 5-9 we find that;

- The absolute values of $t_0$ for all students' dimensions except elbow sitting height are greater than 2.0105 and as illustrated in appendix C p-value less than 0.05 hence, $H_0$ should be rejected and we conclude that the means of male and female's body dimensions are different. Thus, we should focus on these differences carefully, during the design phase.
- The elbow sitting height has $t_0$equal to - 0.443 and its absolute value is less than 2.0105 and p-value from appendix C Table ( C-16) is 0.658 greater than 0.05 therefore, we can't reject the null hypothesis so, the means of elbow sitting height for male and females are equal .

### 5.5.3 Two samples t-Test when Variances are Unequal.

Variances of male and female of both height and hip width are not equal; therefore, we will use this test as shown in the following table.

Table 5.10: Values of $\mathbf{t_0}$ when Variances are Unequal.

| Dimension | $Y'_f$ | $S_f$ | $S_f^2$ | $Y'_m$ | $S_m$ | $S_m^2$ | $Y'_f - Y'_m$ | $S_f^2/27 + S_m^2/23$ |
|---|---|---|---|---|---|---|---|---|
| Height | 165.7 | 7.815 | 61.07 | 175.91 | 5.09 | 25.91 | -10.21 | 3.389 |
| HW | 394.52 | 43.75 | 1913.98 | 372.913 | 26.57 | 705.86 | 21.605 | 101.58 |

| Dimension | $\sqrt{S_f^2/27 + S_m^2/23}$ | $t_0 = \frac{Y'_f - Y'_m}{\sqrt{S_f^2/27 + S_m^2/23}}$ |
|---|---|---|
| Height | 1.841 | -5.54683 |
| HW | 10.08 | 2.143658 |

The table below illustrates the calculations of the degree of freedom and $t_{\alpha,v}$ for students' body dimensions such as height and hip width and equation (4-9) in section 4-2-4was used.

Table 5.11: Value of Degree of Freedom and $\mathbf{t_{\alpha,v}}$

| Dimension | $(S_f^2/27 + S_m^2/23)^2$ | $\frac{(S_f^2/27)^2}{26}$ | $\frac{(S_m^2/23)^2}{22}$ | ( | $v$ | $t_{\alpha,v}$ |
|---|---|---|---|---|---|---|
| Height | 11.4794768 | 0.196795 | 0.057644 | 0.254439 | 45.117 | 1.678 |
| Hip width | 10317.98208 | 193.2732 | 42.81117 | 236.0844 | 43.705 | 1.681 |

From the outputs of computer Minitab 14 in appendix (C) the p-values of hip breadth and stature are 0.038 and zero respectively. Both are less than 0.05, which is in conformance with results in table 5-10 and table 5-11. Thus, we conclude the null hypothesis $H_0$ should be rejected and we can say, the mean height of the female is less than the mean height of male. Additionally, we found the mean of female's hip breadth is less than the mean of male's hip breadth. This is clearly shown in Boxplot and individual value plot of hip breadth's male and female in figures (5-5) & (5-6).

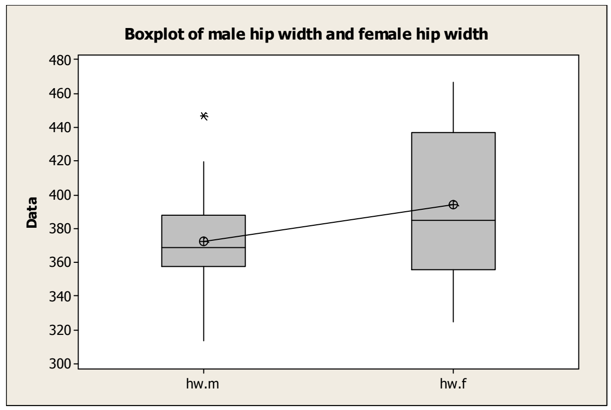

Figure 5.5: Boxplot of Female and Male's Hip Breadth

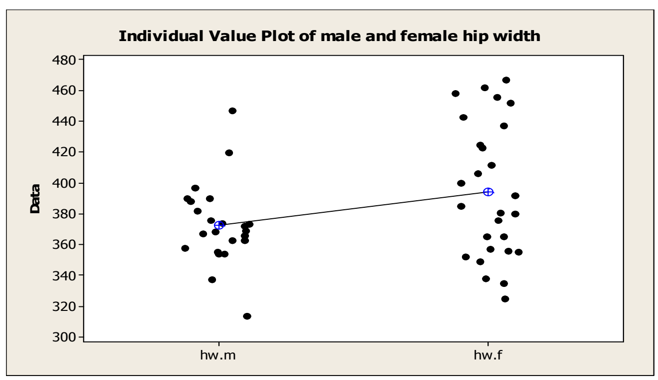

Figure 5.6: Individual Value Plot of Female and Male's Hip Breadth

As a result, it is necessary to design adjustability furniture for workstation of computer laboratory to reduce mismatch as low as possible. The mismatch of the current furniture was illustrated in table (5-3) and appendix (B-3).

## 5.6 Percentages of Mismatches for New Adjustable Chair and Table

### 5.6.1 Requirements for Adjustable Chair

**I. Seat Height**

The new seat height of the chair can be designed adjustable from 391.5mm to 470mm. This data was taken from 5th percentile of female student popliteal height in table (B-6) and 95th percentile of male student popliteal height in table (B-4). This allows the students to place their feet on the floor. This new seat height will reduce the mismatch from 22% to 4% for all 50 students; table (5-12) shows the mismatch between PH and SH. However the mismatch by optimization technique does not change and remained 22%.

Table 5.12: Mismatch Between Popliteal Height and Seat Height of Old and New Chair.

| Mismatch | Overall students | Male | Female |
|---|---|---|---|
| Mismatch between popliteal height & SH for old chair | 22% | 26% | 18% |
| Mismatch between popliteal height & SH for new | 4% | 0% | 7% |

**II. Armrest Chair**

The armrest chair was designed as high as 218.58mm, which is parallel to the floor. This dimension was taken from average of overall students' sitting elbow height from table (5-2) since, there isn't difference between male and female s' elbow sitting height as we have seen earlier in section 5-5-2. For this reason we are taken the average of all students. So, the wrist can be placed flat on the table and in the same plane as the forearm.

### III. Backrest Chair.

The current backrest it was too low for student as illustrated in figure 5-7.

Figure 5.7: Posture of Student at Computer Workstation

The maximum edge of the backrest can be found by equation (5-4)

Max backrest = 0.8 x SDH = 0.95 x 584 = 467.2 mm

The value of SDH is taken from the maximum value of male's shoulder height as the largest value to keep the backrest at the upper edge of the scapula of all students. We can find the lowest point of the backrest by calculating the thigh clearance, with reference to the data in table (B-4) and (B-6). The thigh clearance can be computed by subtracting the 5th percentile of female popliteal height from the 95th percentile of male knee height as follows: Thigh clearance = 560 -385=175 mm. This gives more comfort for the lower back.

### IV. Seat Depth

Seat depth could be designed as recommended as the fifth percentile of popliteal buttock length of female. This would include the shorter users. So, from equation (5-2), when the $5^{th}$ percentile for buttock popliteal length of female students is 422.34 is taken from table (B-6).

Max seating depth = 0.95 x BPL = 0.95 X 422.34 = 401.223 mm

Table 5.13: Mismatch Between Buttock Popliteal Height Seat

| Dimension | Male and female | Male | Female |
|---|---|---|---|
| Mismatch between Buttock popliteal height & SD of current chair | 14% | 26% | 4% |
| Mismatch between Buttock popliteal height & SD of proposed chair | 4% | 8% | 0% |

As a result the mismatch will be reduced from 14% to 4% for all students where as the mismatch ration by optimization technique reduced to 12%. In addition, we will get the same results if we are designed according to average as follows. From table (5-1) the mean of BPL of over all subjects is 460mm, and from equation (5-2) the range of match is: $368 \leq BPL \leq 437$

Then, the average value between the maximum and minimum limits is:

$$\frac{437+368}{2} = 402.\ 5mm$$

Therefore, the seat depth is 402.5mm is the best value, where it is compatible with the most students and the mismatch is reduced.

**V. Seat Width.**

The seat width should be large enough to accommodate the users with the largest hip width therefore, it is designed at 467mm this dimension was taken from for the maximum value of hip width in table (5-2) for all students so, the mismatch will be eliminated but, the optimization method reduced it to 4%.

Table 5.14: Mismatch Between Hip Breadth and Seat Width

| Dimension | Male and female | Male | Female |
|---|---|---|---|
| Mismatch between hip width & seat width | 56% | 56.5% | 55.5% |
| Mismatch for proposed chair | 0% | 0% | 0% |

### 5.6.2 Requirement for Table Design

#### I. Table Height.

The current tables of computer workstations are very high as you see in figure (5-7). Parcells (1999) had suggested that the table height should be adjusted to elbow height measured from the floor then, we can say the table height on the average could be as :

Table height = Popliteal height + Sitting elbow height.

From hypothesis testing the results show there are significant difference between male and female students dimensions. So, if we propose two types of tables one for male and another for female so we will be able to improve the compatibility for both genders.

Let $\text{Table height}_{\text{Female}} = \text{Popliteal height}_{\text{Female}} + \text{Sitting elbow height}_{\text{Female}}$

$$\text{Table height}_{\text{Male}} = \text{Popliteal height}_{\text{Male}} + \text{Sitting elbow height}_{\text{Male}}$$

Tables (5-16) and (5-17) display the table heights for all subjects that are participated in this research. Then we can compute the mean value and standard deviation for desk height by using Minitab 14 as shown in table (5-15).

Table 5.15: Minitab Descriptive Statistics for Table Height.

**Descriptive Statistics: (table height ) $_f$, (table height ) $_m$**

| Variable | N | N* | Mean | SE Mean | StDev | Minimum | Maximum |
|---|---|---|---|---|---|---|---|
| (Table height-female ) | 27 | 0 | 639.81 | 5.23 | 27.20 | 592.00 | 707.00 |
| (Table height- male ) | 23 | 0 | 660.39 | 6.18 | 29.64 | 606.00 | 737.00 |

Table 5.16**:** Table Height of Female Student

| PH | SEH | DH | PH | SHE | DH | PH | SEH | DH |
|---|---|---|---|---|---|---|---|---|
| 461 | 246 | 707 | 420 | 192 | 612 | 420 | 236 | 656 |
| 422 | 224 | 646 | 433 | 202 | 635 | 429 | 226 | 655 |
| 439 | 234 | 673 | 423 | 206 | 629 | 426 | 241 | 667 |
| 432 | 259 | 691 | 443 | 201 | 644 | 395 | 249 | 644 |
| 417 | 198 | 615 | 389 | 227 | 616 | 389 | 235 | 624 |
| 415 | 211 | 626 | 412 | 213 | 625 | 451 | 200 | 651 |
| 407 | 196 | 603 | 407 | 185 | 592 | 433 | 221 | 654 |
| 427 | 214 | 641 | 432 | 203 | 635 | 434 | 228 | 662 |
| 385 | 214 | 599 | 419 | 198 | 617 | 439 | 217 | 656 |

Table 5.17**:** Table Height of Male Student

| PH | SEH | DH | PH | SEH | DH | PH | SHE | DH |
|---|---|---|---|---|---|---|---|---|
| 437 | 227 | 664 | 433 | 211 | 644 | 430 | 217 | 647 |
| 408 | 216 | 624 | 441 | 219 | 660 | 463 | 230 | 693 |
| 413 | 193 | 606 | 452 | 214 | 666 | 461 | 202 | 663 |
| 443 | 225 | 668 | 431 | 208 | 639 | 465 | 223 | 688 |
| 420 | 189 | 609 | 462 | 275 | 737 | 460 | 217 | 677 |
| 432 | 219 | 651 | 435 | 223 | 658 | | | |
| 438 | 225 | 663 | 435 | 234 | 669 | | | |
| 461 | 237 | 698 | 448 | 225 | 673 | | | |
| 455 | 216 | 671 | 408 | 213 | 621 | | | |

.

As a result the desk height of male students is higher than the desk height of female students this appears from hypothesis test as given in table (5-18) the P- value is less than 0.05. Therefore, the null hypothesis should be rejected and conclude that, the mean of table height for males is greater than the mean of female’s table height (as you can see in figure (5-8)). Thus, it is very important to design more convenient table for both genders female an male.

Table 5.18: Minitab Two Sample t- Test for Table Height

**Two-Sample T-Test and CI: $(\text{table height})_m$ ,$(\text{table height})_f$**

```
Sample    N   Mean  StDev  SE Mean
1        23  660.4   29.6      6.2
2        27  639.8   27.2      5.2

Difference = mu (1) - mu (2)
Estimate for difference:  20.5800
95% lower bound for difference:  6.9778
T-Test of difference = 0 (vs>): T-Value = 2.54  P-Value = 0.007  DF = 45
```

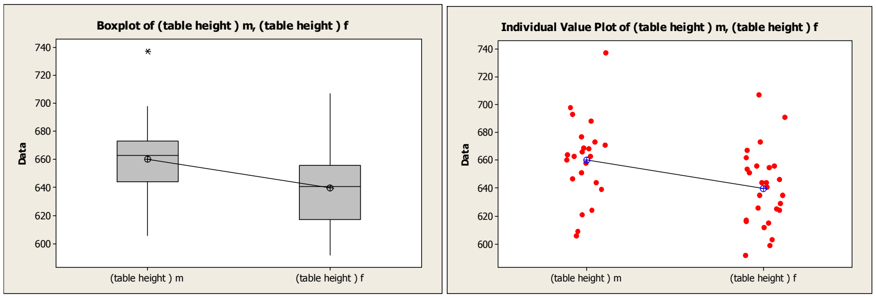


Figure 5.8: Boxplot and Individual Value Plot of Table Height for Male and Female

Therefore, if we propose two types of tables one for males with height 661 mm and another for females with height 640 mm, this would minimize the mismatch for males and females from 87% and 96.3% to 13% and 11.1% respectively. However, this method could be impractical because the number of males and females vary every semester so that, it is better if we suggest table height with the lowest average at 639.41mm. At that time, the mismatch will be reduced for male and female to 4.3% and 11.1% respectively, and the mismatch for all fifty students using the PC Laboratory will be reduced from 92% to 8%.On the other hand the optimization technique reduced the mismatch to 10%.

The design of adjustable table according to (Gouvali, 2006) needs to calculate the maximum and minimum limits of table height as follows:

$$EH + [(PH + 2) \cos 30°] \leq DH \leq [(PH+2) \cos 5°] + (EH0.8517) + (SDH\ 0.1483)$$

The EH, PH and SDH are mean values of sitting elbow height, popliteal height and sitting shoulder height which are taken from the table (5-2).

$$593.3116 \leq DH \leq 696.2556024$$

By this calculation the desk height is recommended to be adjustable from 593.3 mm to 696.5mm therefore, the mismatch will be eliminated.

## 5.7 Layout Workstation Design

The computer laboratory classroom in the Industrial Engineering Department has dimensions of 820 cm wide and 1350cm length. Its area is around 110.7 square meters.

During the study of the computer lab's layout we recorded these following results:

1. Workstations where conventional straight row style where all workstations are arranged as rows which are parallel to the front of the laboratory classroom.
2. As mentioned before the laboratory consists of 20 tables and 40 chairs. Each table consists of two workstations as shown in figure (5-9), where the workstations are arranged on both sides of the lab. On each side there are five rows of workstations while each row has four workstations as shown in figure below

Figure 5.9: Table of Computer Workstation Lab

Figure 5.10: The Layout of Computer

3. The total number of workstations in the lab is 40 workstations, if we compare this number with the number of students using the lab in each group; we will find that, the number of the workstations is too large respect to the number of students. Through our questions for teachers in the department, their answers were, the average number of students in the computer lab classroom doesn't exceed 25 students in each group. So, there are more workstations than required in the laboratory.

4. There is a presentation screen with dimensions of 300 cm wide and 180 cm long. It is placed at the front of the lab with 210 cm high on the wall above the main entrance and it is facing directly the students who sit on the left side of the laboratory. The distance from screen to the front row of workstations is240 cm

as illustrated in figure (5-11) and (5-12). In addition it is very high and close to the students who sit in the first row, which can lead to some injuries and pain in the neck. However, the students who sit on the right side of the lab, they need to move and change their posture to be able to view the screen well.

5. The current position of the presentation screen could cause the lack of concentration for the students during a lecture, when anybody enter or leave the lab.

6. The whiteboard is placed on the front right side of the lab at a distance 465 cm from workstations which are on the same side in the first row as illustrated in figure (5-11) and (5-12).But, the location of the whiteboard is very far for students who are sitting on the left side. Moreover, there is a window beside the whiteboard causing glares for the students attending the lab as you can see in figure (5-11).

Figure 5.11: The Placement of Presentation Screen and Whiteboard.

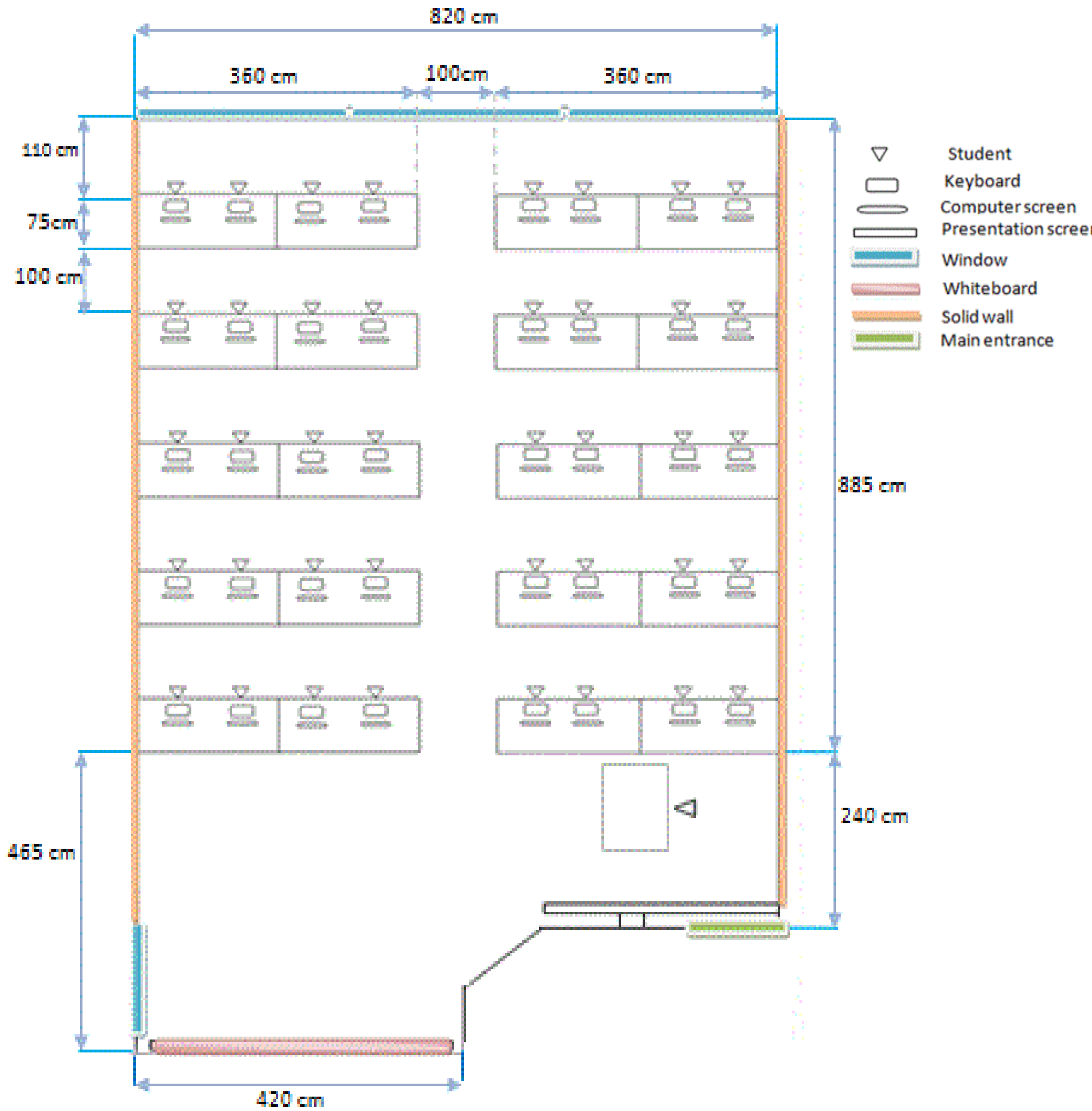


Figure 5.12: Top View for Current Layout of Computer Laboratory Classroom

7. The instructor's table was very close to the entrance as well as to the first row on the left side of the lab. Additionally, it is orthogonal to workstations in the front of the lab room, as can be seen in figure (5-13).

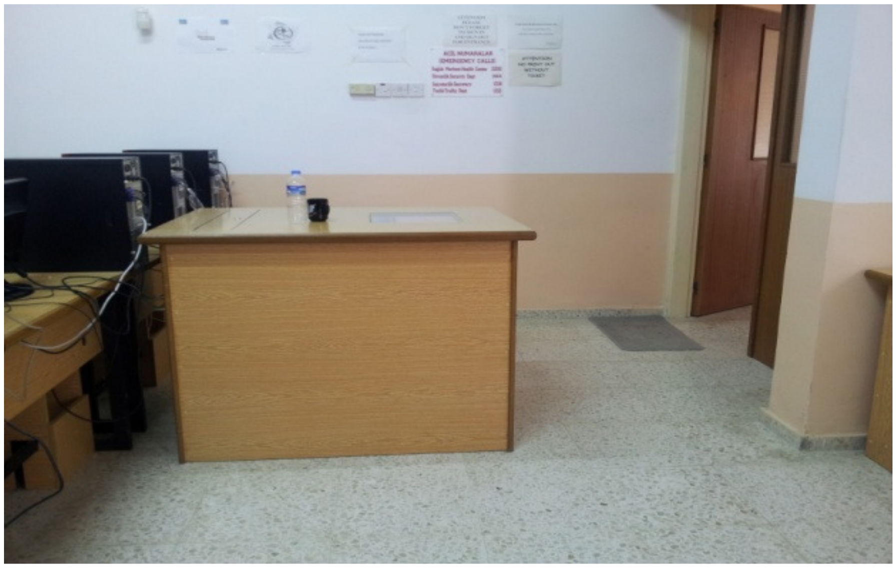

Figure 5.13: The Position of Teacher's Table

8. The windows which are at the end of the lab are covered by curtains. But, sometimes because of air flows they cause glare on the students' screens which are in the last row, as can be seen in figure (5-10) and (5-14).

Figure 5.14: Glare on Computer's Screen

9. Students who are sitting at the end of the sides either the right or left side are difficult to be reached by the professor as well as their entry or exit can cause noise.
10. There is a single corridor which constrains the movement of the professor. Therefore, he/she is not able to see all the student's computer screens.

## 5.8 Proposal for Computer Workstation and Layout Design

After evaluating the furniture of the lab and layout we become able to know the weak points that are affecting the performance of both teacher and students. Then, a proposed design is prepared to get rid of the weaknesses in the current lab design by applying the ergonomic principles in design. The new design would minimize the incompatibility in the current PC Lab design. Based on our ergonomical knowledge and analyzes we performed earlier in this research some important recommendations related to computer workstations such as screen angle, correct posture while sitting at computer, use document holder ect, are proposed to be implemented.

### 5.8.1 The Proposed Design of computer workstation

Table (5-19) and figure (5-15) show the proposal of ergonomic chair and desk design for computer lab.

Table 5.19-A: Dimensions of New Proposed Table

| TABLE DIMENSIONS | DISTANCE/ ANGLE |
|---|---|
| Table height | 640mm |
| Desk slop | 0 |
| Desk clearance | 610 mm |

Table 5.19-B: Dimensions of New Proposed Chair

| SEAT DIMENSIONS | DISTANCE/ ANGLE |
|---|---|
| Adjustable seat height | 390-470mm |
| Seat depth | 402.5 mm |
| Seat width | 467 mm |
| Maximum height to the bottom of the backrest | 175 mm |
| Maximum height to top of backrest | 467.2mm |
| Backrest tilt | 90°–110° |
| Seat pan tilt | 3° up 4° down |

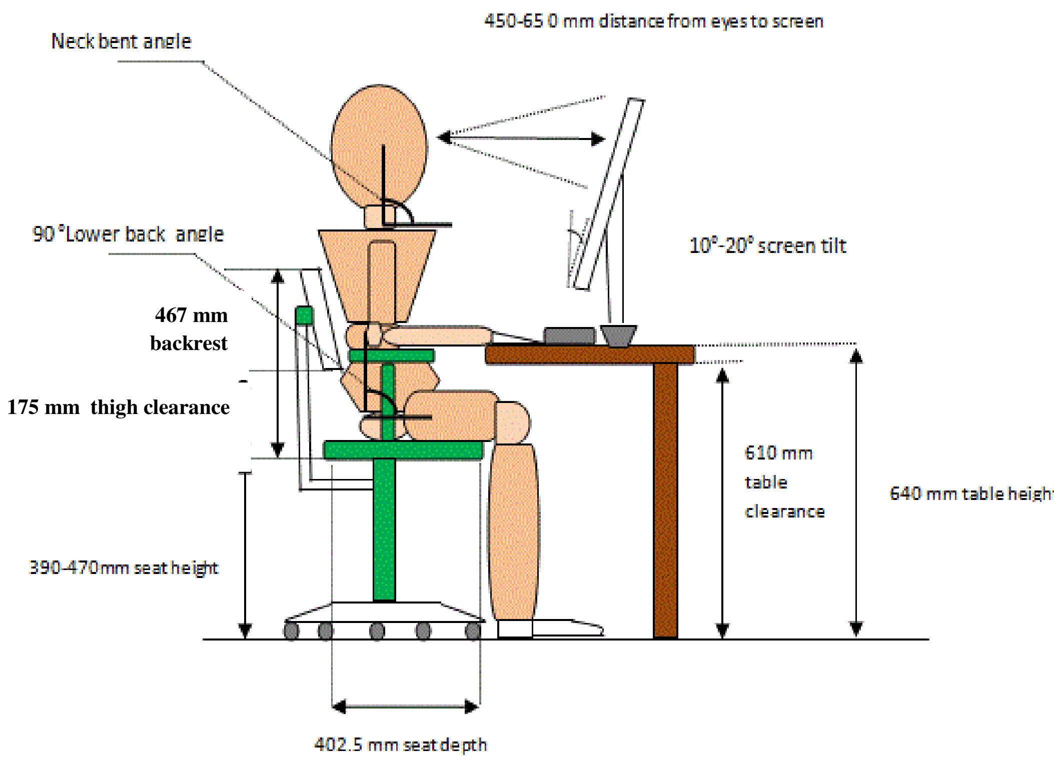


Figure 5.15: A Proposed Computer Workstation

**Attention Should be Paid to the Following Points:**

- The favorite viewing distance of the screen ranges from 45 to 65 cm.
- The height of the monitor surface should allow the position of the view center of the screen to be between 5 to 30 degrees below the horizontal plane through the eyes.
- Suitable monitor height can be accomplished by adjusting the screen surface or installing a screen stand that is height adjustable. If the monitor is very high, you can reduce the desk height when it is adjustable, or raises the chair and obtain a foot rest.
- Using the document holder could help to avoid the neck strain and reduce eye fatigue that are caused by looking up and down or moving the neck between the papers and computer screen.

### 5.8.2 The Proposed Layout of the Computer Lab.

Based on our study for the layout of computer lab, we identified problems related to the teacher and students such as, obstructing of movement through the lab, the placement of whiteboard and presentation screen.

Therefore, the following changes are proposed to the new sketch of lab layout:

- Create three corridors instead of one.
- Change the arrangement of workstations so that, they are perpendicular to the main entrance of the computer lab to reduce the glare of the windows as much as possible.
- Change the location of both the whiteboard and presentation screen where it is better to put them on the wall opposite to the all workstations and an in frontof the students.

The above proposed changes are implemented in the new proposed design of the PC Lab to facilitate and provide the appropriate environment for students to be able to concentrate on the lecture without fatigue or boredom, as well as for the professor to be able to interact with them. You can see the sketch of the proposed design as illustrated in figure (5-16).

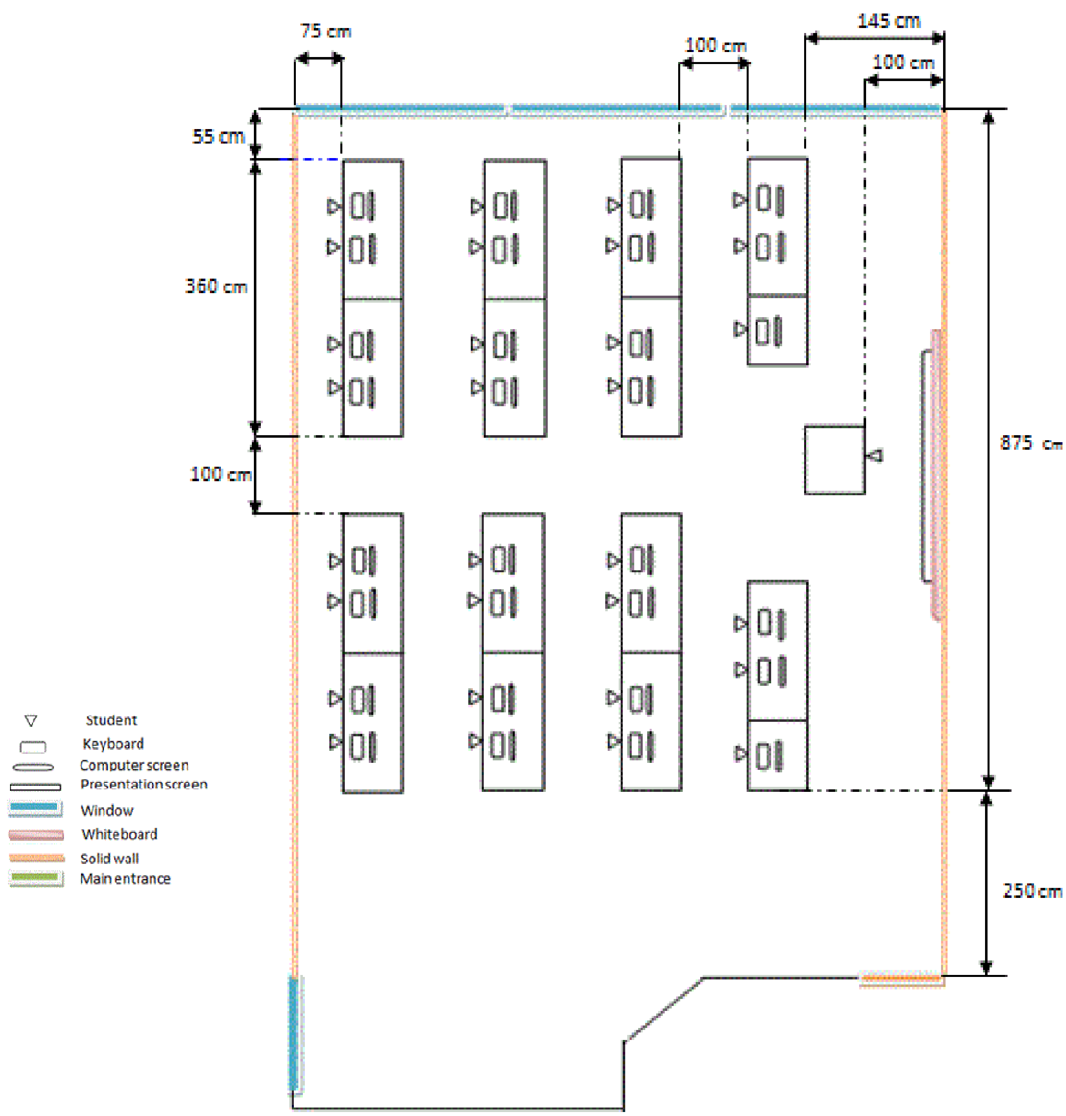


Figure 5.16: A proposed Computer Lab Layout.

# Chapter 6

## DISCUSSION AND CONCLUSION

**Our Observations, in this Thesis Work and Recommendations Can be Summarized as Follow:**

The number of existing workstations is large as compared to the average number of students enrolled in each lab group which is 25.

Hypotheses testing indicate there are statistically significant differences between body dimensions of female and male students. This result helped us to specify in the design which principles of anthropometry parts should be used (e.g. design for adjustable range, or design for extreme or design for average). In this way, we were able to improve the proportion of matching method and obtain the best matching rate for males and females students.

The current tables of computer workstations in the lab are very high so that, the students' posture is not good because the angle between the upper and lower arm was greater than 90 degrees. This can increase the tension in muscles and cause a decrease in the ability of students learning and concentration during the lecture and can cause serious health problems.

The mismatch ratio between female's sitting elbow height and table height was higher than male mismatch ratio. This appears clearly by referring to the hypotheses test which was done to examine the means of table height for both genders. It was found that a significant difference exists between male and females' table height. Therefore, we decided to design the table with height of 640 mm to reduce the mismatch from 87% and 96.3% to 13% and 11.1% for male and female students respectively. Noting that, this height was taken from the mean of female's table height.

The current chair doesn't have an armrest and also it isn't adjustable, thus , the incompatibility occurs between seat height and students' poplital height. The mismatch for male students were higher than females therefore, we have proposed an adjustable chair where the seat height ranges from 390 mm to 470mm. This reduced the mismatch ratio from 26% and 18% to 0% and 7% for male and female respectively.

The current arrangement of workstations is a conventional straight rows, also we found the aisles were' not enough for movement of the teacher throughout the lab in order to provide guidance for students. There was a single aisle dividing the lab into two sides. Students who sit at the end of each row on each side upon their late arrivals cause significant noise during a lesson session. Additionally, the teacher is not able to see all the screens available in the lab. Thus, we suggested creating new free spaces such as aisles to make possible the smooth movement of students and instructors around the sides of the lab. This would make the instructor capable to reach all students and enhance the cooperation between students and teachers.

The students who sit in the last rows of the lab were observed to suffer because of the distant location of the presentation screen and the whiteboard from them. It is very difficult for them to focus during the lecture and most of the time feels bored and sleepy. So, we proposed reducing the distance between the last row, and both the whiteboard and the presentation screen.

It was observed that, the placement of presentation screen is not suitable for teacher and students. It is placed above the main entrance of the lab. Looking at the screen continuously in this location may cause significant stresses in the neck region. This makes students not able to follow the explanation of teacher during a lesson. Therefore, a new proposed location for the presentation screen is suggested where all students can watch it carefully without any obstacles or any significant stress to the human body.

The table of teacher is put perpendicularly to the first row of workstations and very close to the entrance of the lab. This location causes dilemma near the door. Therefore, we recommend the distance from the entrance to any furniture should be at least 300 cm (It is 175 cm currently).

It is not possible to take advantage of the natural lighting in the current PC lab because, it may cause glares on the PC screens, especially who sit in the last rows. So, it is necessary to use curtains permanently in the lab with the Florentine Lighting. Therefore, to avoid this glare we proposed rearrangement of the computer workstations and to place them orthogonal rather than parallel to the windows. This would make, the glares coming from PC Lab windows not vertical to the computer screens.

**Further Study that Can be Done.**

- A study to provide the comfortable environmental conditions in the PC Lab for students, and to motivate them to work efficiently. For instance, humidity, temperature, noise and audio effects should be set properly, to increase motivation of the student to focus and pay more attention to the lecture, according to Ergonomy Principles of Design.
- Assessing the Safety factors of electricity installation in the computer lab.
- Extending this study to consider other computer labs in Industrial Engineering Department.

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# APPENDICES

# Appendix A: Anthropometric Measures of Eastern Mediterranean University Students

Table A.1: Anthropometric Measures of Fifty Students in mm.

| NO. | STUDENT NUMBER. | Sex | Age | Weight ( KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES= 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 81720 | f | 25 | 71 | 1820 | 579 | 333 | 485 | 461 | 549 | 472 | 462 | 246 | 874 | 772 | 295.284 |
| 2 | 47936 | f | 25 | 47 | 1650 | 545 | 321 | 446 | 422 | 500 | 421 | 349 | 224 | 782 | 684 | 271.508 |
| 3 | 47145 | m | 25 | 115 | 1760 | 564 | 337 | 479 | 437 | 562 | 461 | 447 | 227 | 844 | 768 | 276.876 |
| 4 | 51324 | m | 26 | 73.5 | 1700 | 544 | 328 | 453 | 408 | 508 | 455 | 366 | 216 | 839 | 759 | 264.544 |
| 5 | 81773 | m | 22 | 71 | 1710 | 523 | 330 | 460 | 413 | 526 | 465 | 355 | 193 | 837 | 752 | 241.84 |
| 6 | 71223 | f | 22 | 57.5 | 1740 | 547 | 313 | 467 | 439 | 523 | 450 | 352 | 234 | 834 | 747 | 280.324 |
| 7 | 72392 | f | 24 | 75 | 1760 | 572 | 313 | 463 | 432 | 524 | 457 | 452 | 259 | 865 | 769 | 305.324 |
| 8 | 89529 | m | 22 | 59 | 1705 | 541 | 316 | 456 | 443 | 504 | 426 | 337 | 225 | 806 | 730 | 271.768 |
| 9 | 118610 | f | 18 | 56 | 1610 | 490 | 292 | 435 | 417 | 502 | 434 | 357 | 198 | 758 | 664 | 241.216 |
| 10 | 89712 | f | 19 | 71 | 1740 | 545 | 334 | 481 | 415 | 562 | 471 | 406 | 211 | 844 | 769 | 260.432 |
| 11 | 47682 | f | 19 | 58 | 1590 | 505 | 309 | 446 | 407 | 508 | 426 | 392 | 196 | 737 | 646 | 241.732 |
| 12 | 115671 | f | 32 | 59 | 1650 | 518 | 304 | 451 | 427 | 503 | 445 | 425 | 214 | 772 | 678 | 258.992 |
| 13 | 115351 | f | 28 | 65 | 1480 | 472 | 258 | 425 | 385 | 448 | 385 | 365 | 214 | 670 | 585 | 252.184 |
| 14 | 116264 | f | 35 | 64 | 1670 | 509 | 317 | 457 | 420 | 502 | 433 | 456 | 192 | 793 | 708 | 238.916 |
| 15 | 118429 | f | 20 | 54 | 1700 | 513 | 311 | 452 | 433 | 512 | 447 | 380 | 202 | 815 | 716 | 248.028 |
| 16 | 118386 | f | 27 | 55 | 1630 | 506 | 300 | 447 | 423 | 510 | 460 | 355 | 206 | 760 | 668 | 250.4 |

Table A.1 Continued

| NO. | STUDENT NUMBER. | Sex | Age | Weight（KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES== 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 118631 | f | 23 | 52.5 | 1700 | 521 | 320 | 477 | 443 | 508 | 459 | 325 | 201 | 780 | 695 | 248.36 |
| 18 | 115532 | f | 29 | 62.5 | 1550 | 504 | 277 | 429 | 389 | 471 | 453 | 356 | 227 | 732 | 647 | 267.996 |
| 19 | 115670 | f | 28 | 54.5 | 1620 | 508 | 295 | 442 | 412 | 480 | 468 | 335 | 213 | 766 | 681 | 256.66 |
| 20 | 115779 | f | 28 | 54.5 | 1510 | 478 | 293 | 427 | 407 | 469 | 411 | 365 | 185 | 676 | 591 | 228.364 |
| 21 | 48325 | f | 18 | 54 | 1680 | 520 | 317 | 447 | 432 | 511 | 436 | 338 | 203 | 801 | 705 | 249.916 |
| 22 | 59452 | m | 24 | 75 | 1710 | 528 | 339 | 463 | 420 | 518 | 467 | 390 | 189 | 827 | 738 | 239.172 |
| 23 | 115722 | m | 23 | 86 | 1740 | 563 | 344 | 468 | 432 | 547 | 475 | 420 | 219 | 840 | 762 | 269.912 |
| 24 | 115169 | m | 24 | 64 | 1700 | 545 | 320 | 452 | 438 | 513 | 447 | 382 | 225 | 810 | 720 | 272.36 |
| 25 | 81724 | f | 27 | 64 | 1620 | 517 | 319 | 443 | 419 | 494 | 451 | 412 | 198 | 758 | 673 | 245.212 |
| 26 | 51323 | f | 24 | 65.5 | 1620 | 521 | 285 | 449 | 420 | 486 | 436 | 423 | 236 | 751 | 666 | 278.18 |
| 27 | 72379 | f | 23 | 70 | 1710 | 542 | 316 | 488 | 429 | 524 | 450 | 437 | 226 | 793 | 708 | 272.768 |
| 28 | 51338 | m | 25 | 90 | 1810 | 564 | 327 | 511 | 461 | 528 | 493 | 354 | 237 | 838 | 755 | 285.396 |
| 29 | 109518 | m | 22 | 100 | 1810 | 570 | 354 | 518 | 455 | 564 | 502 | 388 | 216 | 837 | 758 | 268.392 |
| 30 | 115609 | m | 25 | 63 | 1730 | 540 | 329 | 484 | 433 | 526 | 467 | 368 | 211 | 813 | 720 | 259.692 |
| 31 | 81793 | m | 22 | 73.5 | 1750 | 545 | 326 | 451 | 441 | 510 | 459 | 372 | 219 | 858 | 769 | 267.248 |
| 32 | 71217 | m | 24 | 95 | 1780 | 552 | 338 | 453 | 452 | 535 | 475 | 397 | 214 | 875 | 785 | 264.024 |

Table A.1 Continued

| NO. | STUDENT NUMBER. | Sex | Age | Weight (KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES== 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 72381 | m | 23 | 84.5 | 1775 | 544 | 336 | 448 | 431 | 549 | 487 | 363 | 208 | 896 | 804 | 257.728 |
| 34 | 81762 | m | 22 | 76.5 | 1825 | 584 | 309 | 470 | 462 | 535 | 498 | 373 | 275 | 893 | 798 | 320.732 |
| 35 | 57268 | m | 23 | 63 | 1710 | 538 | 315 | 449 | 435 | 512 | 450 | 314 | 223 | 826 | 737 | 269.62 |
| 36 | 81766 | m | 22 | 85 | 1760 | 543 | 309 | 456 | 435 | 544 | 451 | 358 | 234 | 869 | 765 | 279.732 |
| 37 | 72396 | f | 25 | 98 | 1680 | 527 | 286 | 461 | 426 | 510 | 431 | 467 | 241 | 793 | 708 | 283.328 |
| 38 | 71242 | m | 25 | 85 | 1770 | 558 | 333 | 466 | 448 | 506 | 467 | 374 | 225 | 856 | 768 | 274.284 |
| 39 | 89603 | m | 32 | 82 | 1680 | 530 | 317 | 439 | 408 | 503 | 455 | 367 | 213 | 833 | 751 | 259.916 |
| 40 | 48232 | m | 28 | 72 | 1725 | 525 | 308 | 458 | 430 | 527 | 478 | 363 | 217 | 837 | 755 | 262.584 |
| 41 | 112740 | f | 24 | 60.5 | 1600 | 510 | 261 | 427 | 395 | 462 | 426 | 458 | 249 | 778 | 693 | 287.628 |
| 42 | 105008 | f | 34 | 65 | 1620 | 515 | 280 | 431 | 389 | 460 | 421 | 400 | 235 | 800 | 715 | 276.44 |
| 43 | 47974 | f | 28 | 56 | 1790 | 547 | 347 | 453 | 451 | 524 | 462 | 443 | 200 | 886 | 794 | 251.356 |
| 44 | 105153 | m | 27 | 81 | 1810 | 573 | 343 | 502 | 463 | 547 | 488 | 390 | 230 | 845 | 768 | 280.764 |
| 45 | 116067 | m | 28 | 77 | 1850 | 573 | 371 | 497 | 461 | 535 | 493 | 376 | 202 | 892 | 792 | 256.908 |
| 46 | 81783 | f | 22 | 59 | 1680 | 528 | 307 | 451 | 433 | 510 | 425 | 385 | 221 | 796 | 698 | 266.436 |
| 47 | 71273 | f | 24 | 58 | 1680 | 530 | 302 | 454 | 434 | 491 | 431 | 381 | 228 | 792 | 707 | 272.696 |
| 48 | 72390 | f | 24 | 58 | 1630 | 510 | 293 | 445 | 439 | 498 | 435 | 376 | 217 | 746 | 661 | 260.364 |

Table A.1 Continued

| NO. | STUDENT NUMBER. | Sex | Age | Weight (KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES== 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 115081 | m | 27 | 67 | 1850 | 576 | 353 | 502 | 465 | 554 | 501 | 354 | 223 | 883 | 788 | 275.244 |
| 50 | 105493 | m | 27 | 69 | 1800 | 562 | 345 | 496 | 460 | 536 | 495 | 369 | 217 | 844 | 745 | 268.06 |

Table A.2: Anthropometric Measures of Male Students in mm.

| NO. | STUDENT NUMBER. | Sex | Age | Weight (KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES== 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 47145 | m | 25 | 115 | 1760 | 564 | 337 | 479 | 437 | 562 | 461 | 447 | 227 | 276.876 | 844 | 768 |
| 2 | 51324 | m | 26 | 73.5 | 1700 | 544 | 328 | 453 | 408 | 508 | 455 | 366 | 216 | 264.544 | 839 | 759 |
| 3 | 81773 | m | 22 | 71 | 1710 | 523 | 330 | 460 | 413 | 526 | 465 | 355 | 193 | 241.84 | 837 | 752 |
| 4 | 89529 | m | 22 | 59 | 1705 | 541 | 316 | 456 | 443 | 504 | 426 | 337 | 225 | 271.768 | 806 | 730 |
| 5 | 59452 | m | 24 | 75 | 1710 | 528 | 339 | 463 | 420 | 518 | 467 | 390 | 189 | 239.172 | 827 | 738 |
| 6 | 115722 | m | 23 | 86 | 1740 | 563 | 344 | 468 | 432 | 547 | 475 | 420 | 219 | 269.912 | 840 | 762 |
| 7 | 115169 | m | 24 | 64 | 1700 | 545 | 320 | 452 | 438 | 513 | 447 | 382 | 225 | 272.36 | 810 | 720 |
| 8 | 51338 | m | 25 | 90 | 1810 | 564 | 327 | 511 | 461 | 528 | 493 | 354 | 237 | 285.396 | 838 | 755 |
| 9 | 109518 | m | 22 | 100 | 1810 | 570 | 354 | 518 | 455 | 564 | 502 | 388 | 216 | 268.392 | 837 | 758 |

Table A.2 Continued

| NO. | STUDENT NUMBER. | Sex | Age | Weight （KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sittng height( EH) | Sitting height | Sitting eye height | ES== 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 115609 | m | 25 | 63 | 1730 | 540 | 329 | 484 | 433 | 526 | 467 | 368 | 211 | 259.692 | 813 | 720 |
| 11 | 81793 | m | 22 | 73.5 | 1750 | 545 | 326 | 451 | 441 | 510 | 459 | 372 | 219 | 267.248 | 858 | 769 |
| 12 | 71217 | m | 24 | 95 | 1780 | 552 | 338 | 453 | 452 | 535 | 475 | 397 | 214 | 264.024 | 875 | 785 |
| 13 | 72381 | m | 23 | 84.5 | 1775 | 544 | 336 | 448 | 431 | 549 | 487 | 363 | 208 | 257.728 | 896 | 804 |
| 14 | 81762 | m | 22 | 76.5 | 1825 | 584 | 309 | 470 | 462 | 535 | 498 | 373 | 275 | 320.732 | 893 | 798 |
| 15 | 57268 | m | 23 | 63 | 1710 | 538 | 315 | 449 | 435 | 512 | 450 | 314 | 223 | 269.62 | 826 | 737 |
| 16 | 81766 | m | 22 | 85 | 1760 | 543 | 309 | 456 | 435 | 544 | 451 | 358 | 234 | 279.732 | 869 | 765 |
| 17 | 71242 | m | 25 | 85 | 1770 | 558 | 333 | 466 | 448 | 506 | 467 | 374 | 225 | 274.284 | 856 | 768 |
| 18 | 89603 | m | 32 | 82 | 1680 | 530 | 317 | 439 | 408 | 503 | 455 | 367 | 213 | 259.916 | 833 | 751 |
| 19 | 48232 | m | 28 | 72 | 1725 | 525 | 308 | 458 | 430 | 527 | 478 | 363 | 217 | 262.584 | 837 | 755 |
| 20 | 105153 | m | 27 | 81 | 1810 | 573 | 343 | 502 | 463 | 547 | 488 | 390 | 230 | 280.764 | 845 | 768 |
| 21 | 116067 | m | 28 | 77 | 1850 | 573 | 371 | 497 | 461 | 535 | 493 | 376 | 202 | 256.908 | 892 | 792 |
| 22 | 115081 | m | 27 | 67 | 1850 | 576 | 353 | 502 | 465 | 554 | 501 | 354 | 223 | 275.244 | 883 | 788 |
| 23 | 105493 | m | 27 | 69 | 1800 | 562 | 345 | 496 | 460 | 536 | 495 | 369 | 217 | 268.06 | 844 | 745 |

Table A.3: Anthropometric Measures of Female Students in mm.

| NO. | STUDENT NUMBER. | Sex | Age | Weight (KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES== 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 81720 | f | 25 | 71 | 1820 | 579 | 333 | 485 | 461 | 549 | 472 | 462 | 246 | 295.3 | 874 | 772 |
| 2 | 47936 | f | 25 | 47 | 1650 | 545 | 321 | 446 | 422 | 500 | 421 | 349 | 224 | 271.5 | 782 | 684 |
| 3 | 71223 | f | 22 | 57.5 | 1740 | 547 | 313 | 467 | 439 | 523 | 450 | 352 | 234 | 280.3 | 834 | 747 |
| 4 | 72392 | f | 24 | 75 | 1760 | 572 | 313 | 463 | 432 | 524 | 457 | 452 | 259 | 305.3 | 865 | 769 |
| 5 | 118610 | f | 18 | 56 | 1610 | 490 | 292 | 435 | 417 | 502 | 434 | 357 | 198 | 241.2 | 758 | 664 |
| 6 | 89712 | f | 19 | 71 | 1740 | 545 | 334 | 481 | 415 | 562 | 471 | 406 | 211 | 260.4 | 844 | 769 |
| 7 | 47682 | f | 19 | 58 | 1590 | 505 | 309 | 446 | 407 | 508 | 426 | 392 | 196 | 241.7 | 737 | 646 |
| 8 | 115671 | f | 32 | 59 | 1650 | 518 | 304 | 451 | 427 | 503 | 445 | 425 | 214 | 259 | 772 | 678 |
| 9 | 115351 | f | 28 | 65 | 1480 | 472 | 258 | 425 | 385 | 448 | 385 | 365 | 214 | 252.2 | 670 | 585 |
| 10 | 116264 | f | 35 | 64 | 1670 | 509 | 317 | 457 | 420 | 502 | 433 | 456 | 192 | 238.9 | 793 | 708 |
| 11 | 118429 | f | 20 | 54 | 1700 | 513 | 311 | 452 | 433 | 512 | 447 | 380 | 202 | 248 | 815 | 716 |
| 12 | 118386 | f | 27 | 55 | 1630 | 506 | 300 | 447 | 423 | 510 | 460 | 355 | 206 | 250.4 | 760 | 668 |
| 13 | 118631 | f | 23 | 52.5 | 1700 | 521 | 320 | 477 | 443 | 508 | 459 | 325 | 201 | 248.4 | 780 | 695 |
| 14 | 115532 | f | 29 | 62.5 | 1550 | 504 | 277 | 429 | 389 | 471 | 453 | 356 | 227 | 268 | 732 | 647 |
| 15 | 115670 | f | 28 | 54.5 | 1620 | 508 | 295 | 442 | 412 | 480 | 468 | 335 | 213 | 256.7 | 766 | 681 |

Table A.3 Continued

| NO. | STUDENT NUMBER. | Sex | Age | Weight （KG) | Height | Shoulder height(SDH) | Shoulder elbow height | Buttock popliteal height | Popliteal height | Knee height | Forearm length | Hip width | Elbow sitting height( EH) | Sitting height | Sitting eye height | ES= 0.852 EH + 0.148 SDH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16 | 115779 | f | 28 | 54.5 | 1510 | 478 | 293 | 427 | 407 | 469 | 411 | 365 | 185 | 228.4 | 676 | 591 |
| 17 | 48325 | f | 18 | 54 | 1680 | 520 | 317 | 447 | 432 | 511 | 436 | 338 | 203 | 249.9 | 801 | 705 |
| 18 | 81724 | f | 27 | 64 | 1620 | 517 | 319 | 443 | 419 | 494 | 451 | 412 | 198 | 245.2 | 758 | 673 |
| 19 | 51323 | f | 24 | 65.5 | 1620 | 521 | 285 | 449 | 420 | 486 | 436 | 423 | 236 | 278.2 | 751 | 666 |
| 20 | 72379 | f | 23 | 70 | 1710 | 542 | 316 | 488 | 429 | 524 | 450 | 437 | 226 | 272.8 | 793 | 708 |
| 21 | 72396 | f | 25 | 98 | 1680 | 527 | 286 | 461 | 426 | 510 | 431 | 467 | 241 | 283.3 | 793 | 708 |
| 22 | 112740 | f | 24 | 60.5 | 1600 | 510 | 261 | 427 | 395 | 462 | 426 | 458 | 249 | 287.6 | 778 | 693 |
| 23 | 105008 | f | 34 | 65 | 1620 | 515 | 280 | 431 | 389 | 460 | 421 | 400 | 235 | 276.4 | 800 | 715 |
| 24 | 47974 | f | 28 | 56 | 1790 | 547 | 347 | 453 | 451 | 524 | 462 | 443 | 200 | 251.4 | 886 | 794 |
| 25 | 81783 | f | 22 | 59 | 1680 | 528 | 307 | 451 | 433 | 510 | 425 | 385 | 221 | 266.4 | 796 | 698 |
| 26 | 71273 | f | 24 | 58 | 1680 | 530 | 302 | 454 | 434 | 491 | 431 | 381 | 228 | 272.7 | 792 | 707 |
| 27 | 72390 | f | 24 | 58 | 1630 | 510 | 293 | 445 | 439 | 498 | 435 | 376 | 217 | 260.4 | 746 | 661 |

# Appendix B: Analysis of Anthropometric Measures

## Percentile Definition

Percentile is the value of a variable under which a specific percent of observations fall.

The $k^{th}$ percentile is that place in the data where k% of the data is below the cut point.

The $25^{th}$ percentile is that the area under the curve when (z = – 1.65) as shown in figure (B-1)

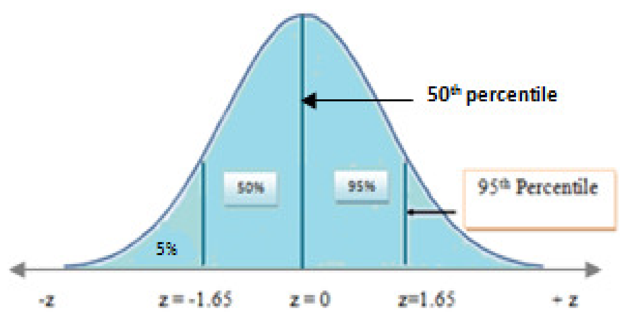


Figure B.1: The $5^{th}$ , $50^{th}$ and $95^{th}$ percentile

There are many alternative approaches to defining percentiles for instance the median is the $50^{th}$ percentile, the first quartile is the $25^{th}$ percentile, and the third quartile is the $75^{th}$ percentile. It could be of importance to compute other percentiles, such as the $5^{th}$ or $95^{th}$.

Notice to the percentiles above the mean have a positive Z-value and the lower average have a negative percentile.

Table B.1: The Common Percentiles

| | |
|---|---|
| $p_1 \quad = \mu - 2,33\ \sigma$ | $p_{99} \quad = \mu + 2.33\ \sigma$ |
| $p_{2.5} \quad = \mu - 1.96\ \sigma$ | $p_{97.5} \quad = \mu + 1.97\sigma$ |
| $p_5 \quad = \mu - 1.65\ \sigma$ | $p_{95} \quad = \mu + 1.65\sigma$ |
| $p_{10} \quad = \mu - 1.82\ \sigma$ | $p_{90} \quad = \mu + 1.82\sigma$ |
| $p_{20} \quad = \mu - 0.84\ \sigma$ | $p_{80} \quad = \mu + 0.84\sigma$ |
| $p_{25} \quad = \mu - 0.67\ \sigma$ | $p_{75} \quad = \mu + 0.67\sigma$ |

Table B.2: Anthropometric Data for the Overall Subjects

| Anthropometric measurement | Mean | Median | S.D ($\sigma$) | Max | Min | 5th | 95th |
|---|---|---|---|---|---|---|---|
| Weight kg. | 69.43 | 65.25 | 14.214 | 115 | 47 | 45.976 | 92.8 |
| Height mm | 170.38 | 170.75 | 8.405 | 185 | 148 | 156.512 | 184.24 |
| Shoulder height | 535.28 | 539 | 26.23 | 584 | 472 | 492.00 | 578.56 |
| Shoulder elbow height | 316.6 | 317 | 23.37 | 371 | 258 | 278.03 | 335.16 |
| Buttock popliteal length | 460.2 | 453.5 | 22.28 | 518 | 425 | 423.44 | 496.96 |
| Popliteal height | 430.6 | 432 | 20.21 | 465 | 385 | 397.24 | 463.95 |
| Knee height | 514.6 | 511.5 | 26.78 | 564 | 448 | 470.42 | 558.78 |
| Forearm length | 455.02 | 455 | 25.39 | 502 | 385 | 413.12 | 496.92 |
| Hip breadth | 384.58 | 375 | 38.1 | 467 | 314 | 321.73 | 447.43 |
| Elbow sitting height | 218.7 | 217 | 17.9 | 275 | 185 | 189.128 | 248.212 |
| Sitting height | 813 | 820.5 | 52.32 | 896 | 670 | 726.67 | 899.33 |
| Sitting eye height | 728 | 733.5 | 51.31 | 804 | 585 | 643.33 | 812.67 |

Table B.3: Mismatch Ratios for Fifty Students from Male and Females

| Mismatch between | Number of mismatches | Ratio | Percentage |
|---|---|---|---|
| Popliteal height and seat height | 11 | 11/50 | 22% |
| Buttock popliteal length and seat depth | 7 | 7/50 | 14% |
| Knee height and table clearance | 0 | 0 | 0 |
| Elbow height and table height | 46 | 46/50 | 92% |
| Hip breadth and seat width | 28 | 28/50 | 56% |

Table B.4: Anthropometric Data for Male

| Anthropometric measurement | Mean | Median | S.D (σ) | Max | Min | 5th | 95th |
|---|---|---|---|---|---|---|---|
| Weight kg. | 78.565 | 76.5 | 13.237 | 115 | 59 | 56.725 | 100.41 |
| Height mm | 175.91 | 176 | 5.0893 | 185 | 168 | 167.52 | 184.31 |
| Shoulder height | 551.52 | 545 | 17.508 | 584 | 523 | 522.63 | 580.41 |
| Shoulder elbow height | 331.61 | 330 | 16.013 | 371 | 308 | 305.19 | 358.03 |
| Buttock popliteal length | 470.91 | 463 | 22.913 | 518 | 439 | 433.11 | 508.72 |
| Popliteal height | 440.48 | 438 | 17.699 | 465 | 408 | 411.27 | 469.68 |
| Knee height | 529.96 | 528 | 18.671 | 564 | 503 | 499.15 | 560.76 |
| Forearm length | 471.96 | 467 | 20.25 | 502 | 426 | 327.27 | 435.86 |
| Hip breadth | 372.9 | 369 | 26.5689 | 447 | 314 | 329.07 | 416.75 |
| Elbow sittng height | 219.9 | 219 | 16.689 | 275 | 189 | 192.38 | 247.45 |
| Sitting height | 847.7 | 840 | 261.59 | 896 | 806 | 804.57 | 890.9 |
| Sitting eye height | 760.3 | 759 | 23.012 | 804 | 720 | 722 | 798 |

Table B.5: Mismatch Ratios for Male Students

| Mismatch between | Number of mismatches | Ratio | Percentage |
|---|---|---|---|
| Popliteal height and seat height | 6 | 6/23 | 26% |
| Buttock popliteal length and seat depth | 6 | 6/23 | 26% |
| Knee height and table clearance | 0 | 0 | 0 |
| Elbow height and table height | 20 | 20/23 | 87% |
| Hip breadth and seat width | 13 | 13/23 | 56.5% |

Table B.6: Anthropometric Data for Female

| Anthropometric measurement | Mean | Median | S.D (σ) | Max | Min | 5th | 95th |
|---|---|---|---|---|---|---|---|
| Weight kg. | 61.65 | 59 | 9.79 | 98 | 47 | 45.5 | 77.8 |
| Height mm | 165.7 | 165 | 7.815 | 182 | 148 | 152.8 | 178.6 |
| Shoulder height | 521.44 | 518 | 24.598 | 579 | 472 | 480.85 | 562.03 |
| Shoulder elbow height | 303.8 | 307 | 21.06 | 347 | 258 | 289.07 | 338.56 |
| Buttock popliteal length | 451.19 | 449 | 17.415 | 488 | 425 | 422.34 | 479.81 |
| Popliteal height | 422.5 | 423 | 18.57 | 461 | 385 | 391.53 | 452.83 |
| Knee height | 501.5 | 503 | 25.88 | 562 | 448 | 458.8 | 544.2 |
| Forearm length | 440.6 | 436 | 19.97 | 472 | 385 | 407.6 | 473.5 |
| Hip breadth | 394.51 | 385 | 43.74 | 467 | 325 | 322.3 | 466.71 |
| Elbow sittng height | 217.63 | 214 | 19.12 | 259 | 185 | 186.08 | 249.17 |
| Sitting height | 738.4 | 782 | 51.01 | 886 | 670 | 699.2 | 867.59 |
| Sitting eye height | 694.4 | 695 | 49.3 | 794 | 585 | 612.9 | 775.8 |

Table B.7: Mismatch Ratios for Female Students

| Mismatch between | Number of mismatches | Ratio | Percentage |
|---|---|---|---|
| Popliteal height and seat height | 5 | 5/27 | 18% |
| Buttock popliteal length and seat depth | 1 | 1/27 | 4% |
| Knee height and table clearance | 0 | 0 | 0 |
| Elbow height and table height | 26 | 26/27 | 96.3% |
| Hip breadth and seat width | 15 | 15/27 | 55.5% |

Table B.8: Proportion of Match Students at Different Seat Depth (SD)

| SD | SD/.99 | SD/0.8 | P1 | P2 | P=P2-P1 |
|---|---|---|---|---|---|
| 320 | 336.8421 | 400 | 0 | 0.0034 | 0.003446 |
| 330 | 347.3684 | 412.5 | 0 | 0.0161 | 0.016139 |
| 360 | 378.9474 | 450 | 0 | 0.3235 | 0.323412 |
| 370 | 389.4737 | 462.5 | 0 | 0.5411 | 0.54036 |
| 380 | 400 | 475 | 0 | 0.7467 | 0.743296 |
| 390 | 410.5263 | 487.5 | 0.01 | 0.8898 | 0.876882 |
| 400 | 421.0526 | 500 | 0.04 | 0.963 | 0.923526 |
| 410 | 431.5789 | 512.5 | 0.1 | 0.9905 | 0.891083 |
| 420 | 442.1053 | 525 | 0.21 | 0.9982 | 0.789831 |
| 430 | 452.6316 | 537.5 | 0.37 | 0.9997 | 0.632696 |
| 440 | 463.1579 | 550 | 0.55 | 1 | 0.447164 |
| 450 | 473.6842 | 562.5 | 0.73 | 1 | 0.272516 |
| 460 | 484.2105 | 575 | 0.86 | 1 | 0.14059 |
| 470 | 494.7368 | 587.5 | 0.94 | 1 | 0.060555 |
| 480 | 505.2632 | 600 | 0.98 | 1 | 0.021558 |
| 490 | 515.7895 | 612.5 | 0.99 | 1 | 0.006297 |
| 500 | 526.3158 | 625 | 1 | 1 | 0.001501 |

Table B.9: Proportion of Match Students at Different Height of Backrest

| Backrest | BH/0.8 | BH/0.6 | P1 | P2 | P=P2-P1 |
|---|---|---|---|---|---|
| 250 | 312.5 | 416.67 | 1E-17 | 5E-08 | 4.76E-08 |
| 275 | 343.8 | 458.33 | 1.4E-13 | 0.0003 | 0.000269 |
| 300 | 375 | 500 | 5E-10 | 0.0563 | 0.056251 |
| 320 | 400 | 533.33 | 1.3E-07 | 0.4651 | 0.465109 |
| 330 | 412.5 | 550 | 1.4E-06 | 0.7461 | 0.746067 |
| 360 | 450 | 600 | 0.00057 | 0.9982 | 0.997626 |
| 365 | 456.3 | 608.33 | 0.00129 | 0.9995 | 0.998199 |
| 370 | 462.5 | 616.67 | 0.00276 | 0.9999 | 0.997112 |
| 380 | 475 | 633.33 | 0.01078 | 1 | 0.989218 |
| 390 | 487.5 | 650 | 0.03426 | 1 | 0.96574 |
| 400 | 500 | 666.67 | 0.08931 | 1 | 0.910691 |
| 410 | 512.5 | 683.33 | 0.19257 | 1 | 0.807432 |
| 420 | 525 | 700 | 0.34756 | 1 | 0.65244 |
| 430 | 537.5 | 716.67 | 0.53372 | 1 | 0.466275 |
| 440 | 550 | 733.33 | 0.71267 | 1 | 0.287334 |
| 450 | 562.5 | 750 | 0.85031 | 1 | 0.149695 |
| 460 | 575 | 766.67 | 0.93502 | 1 | 0.064975 |
| 470 | 587.5 | 783.33 | 0.97675 | 1 | 0.023249 |
| 480 | 600 | 800 | 0.9932 | 1 | 0.006805 |
| 490 | 612.5 | 816.67 | 0.99838 | 1 | 0.00162 |
| 500 | 625 | 833.33 | 0.99969 | 1 | 0.000313 |

Table B.10: Proportion of Match Students at Different Seat Width

| S W | SW/1.3 | SW/1.1 | P1 | P2 | P=P2-P1 |
|---|---|---|---|---|---|
| 320 | 246.1538 | 290.9091 | 0.00013943 | 0.007 | 0.006823 |
| 330 | 253.8462 | 300 | 0.000299314 | 0.013 | 0.012892 |
| 360 | 276.9231 | 327.2727 | 0.002353848 | 0.066 | 0.06387 |
| 370 | 284.6154 | 336.3636 | 0.004339681 | 0.103 | 0.098443 |
| 380 | 292.3077 | 345.4545 | 0.007707462 | 0.152 | 0.144459 |
| 390 | 300 | 354.5455 | 0.013191395 | 0.215 | 0.202006 |
| 400 | 307.6923 | 363.6364 | 0.021765473 | 0.291 | 0.269447 |
| 410 | 315.3846 | 372.7273 | 0.034636998 | 0.378 | 0.343196 |
| 420 | 323.0769 | 381.8182 | 0.053190245 | 0.471 | 0.417909 |
| 430 | 330.7692 | 390.9091 | 0.078868013 | 0.566 | 0.487117 |
| 440 | 338.4615 | 400 | 0.112990614 | 0.657 | 0.544208 |
| 450 | 346.1538 | 409.0909 | 0.156529224 | 0.74 | 0.583521 |
| 460 | 353.8462 | 418.1818 | 0.209869423 | 0.811 | 0.601288 |
| 470 | 361.5385 | 427.2727 | 0.272614893 | 0.869 | 0.596207 |
| 480 | 369.2308 | 436.3636 | 0.343484148 | 0.913 | 0.569523 |
| 490 | 376.9231 | 445.4545 | 0.420340736 | 0.945 | 0.524657 |
| 500 | 384.6154 | 454.5455 | 0.500370607 | 0.967 | 0.466513 |
| 520 | 400 | 472.7273 | 0.657199006 | 0.99 | 0.332472 |
| 540 | 415.3846 | 490.9091 | 0.790665443 | 0.997 | 0.206712 |
| 600 | 461.5385 | 545.4545 | 0.978330983 | 1 | 0.021657 |

Table B.11: Proportion of Match Students at Different Table Clearance

| DU | UD-20 | P(Z≤UD-20) |
|---|---|---|
| 400 | 380 | 2.50227E-07 |
| 450 | 430 | 0.000791357 |
| 500 | 480 | 0.098177021 |
| 550 | 530 | 0.717373292 |
| 570 | 550 | 0.906896277 |
| 580 | 560 | 0.954990263 |
| 590 | 570 | 0.980713252 |
| 600 | 580 | 0.992699374 |
| 620 | 600 | 0.99928604 |
| 640 | 620 | 0.999958535 |
| 680 | 660 | 0.999999972 |
| 700 | 680 | 1 |
| 710 | 690 | 1 |
| 720 | 700 | 1 |
| 740 | 720 | 1 |
| 780 | 760 | 1 |

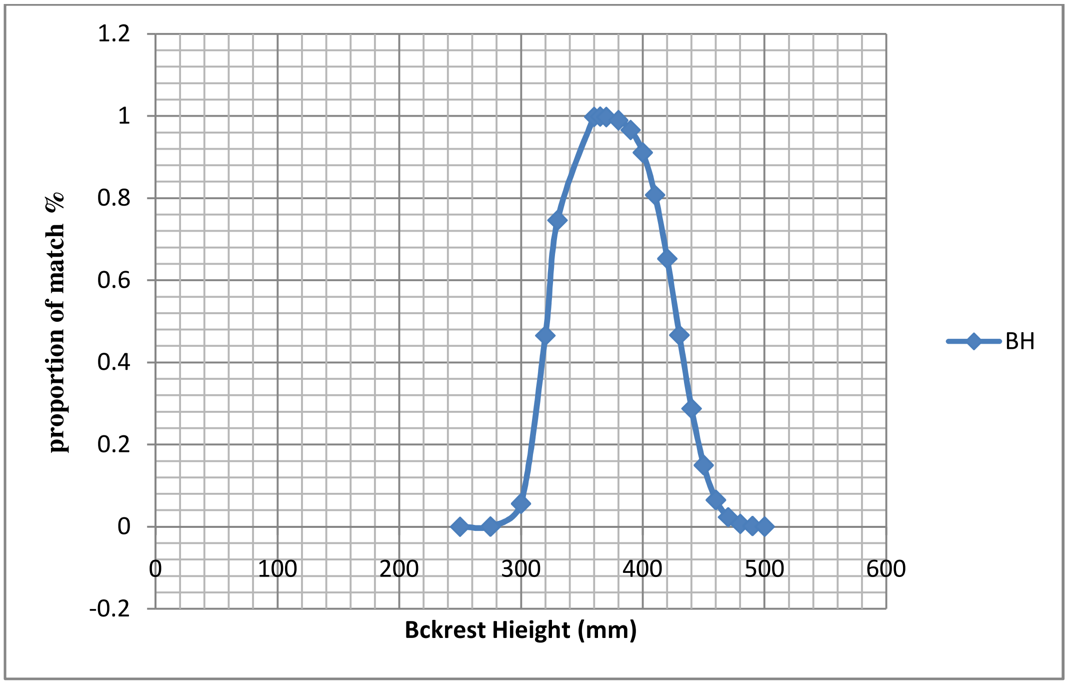


Figure B.2: Proportion of Match Population at Different Backrest Height.

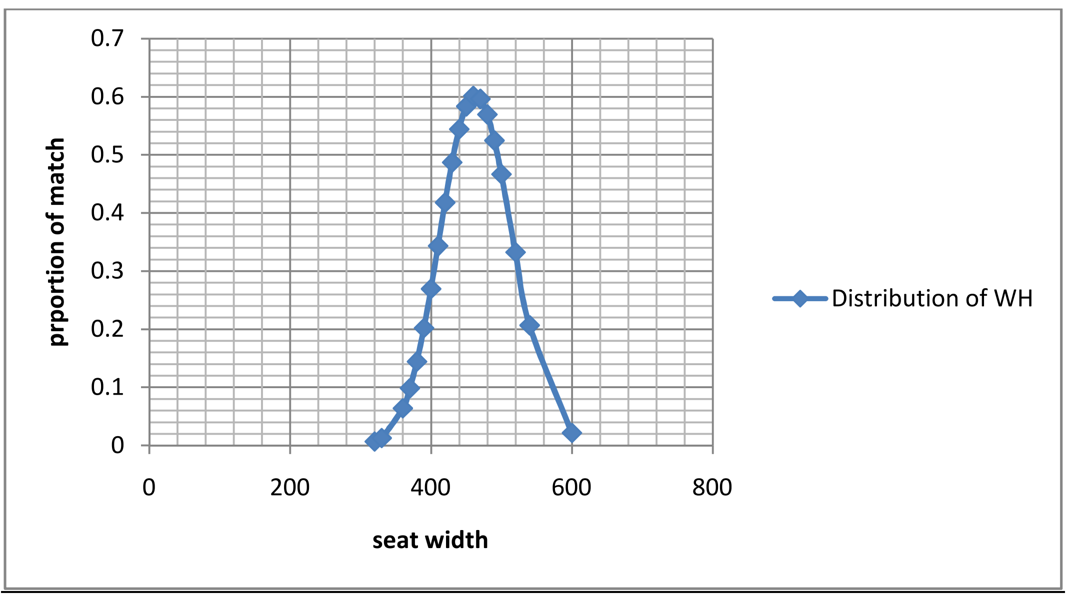


Figure B.3: Proportion of Match Population at Different Seat Width

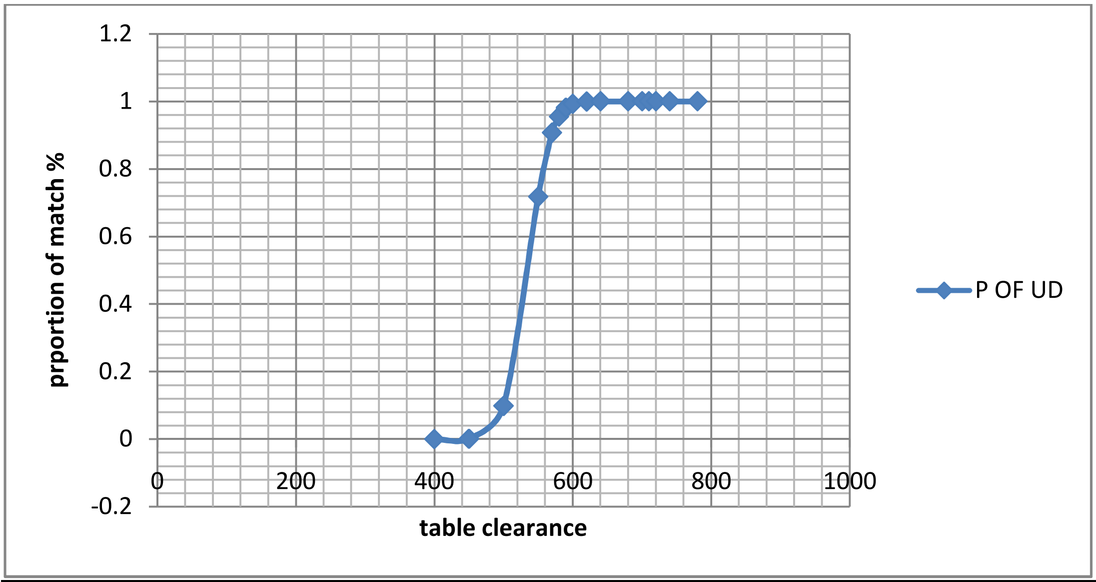


Figure B.4: Proportion of Match Population at Different Table Clearance.

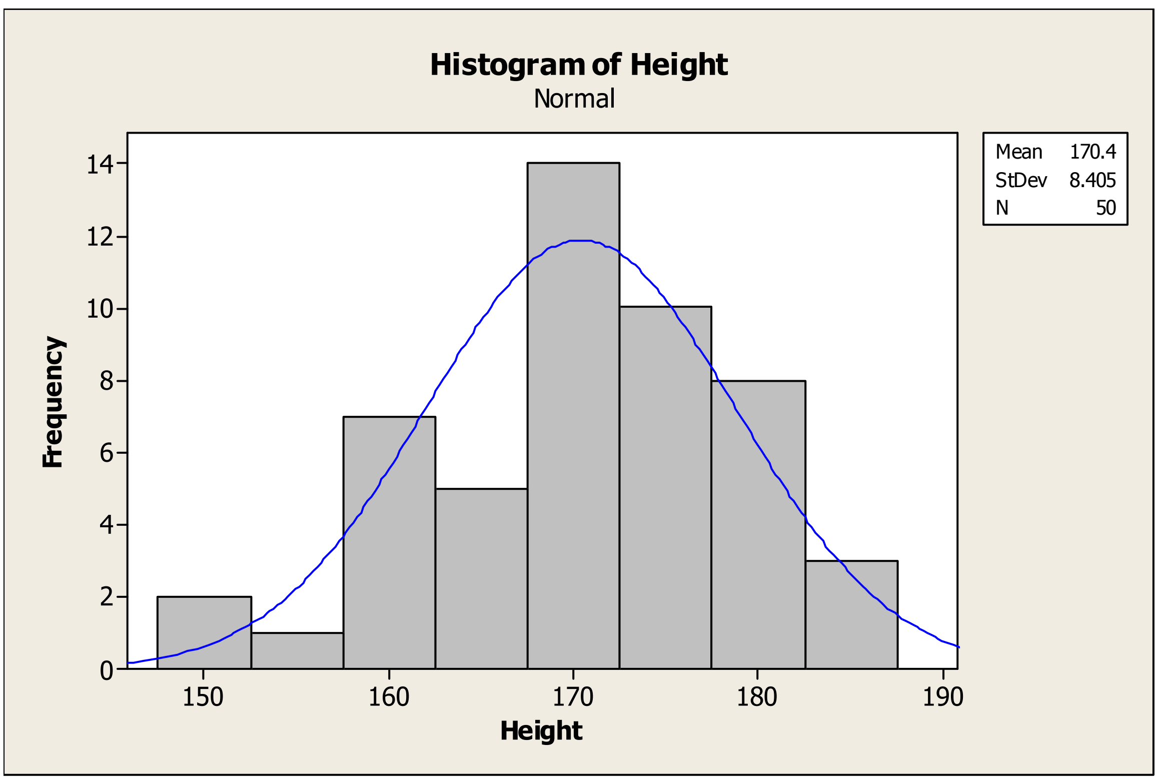


Figure B.5: Histogram of Students' Height

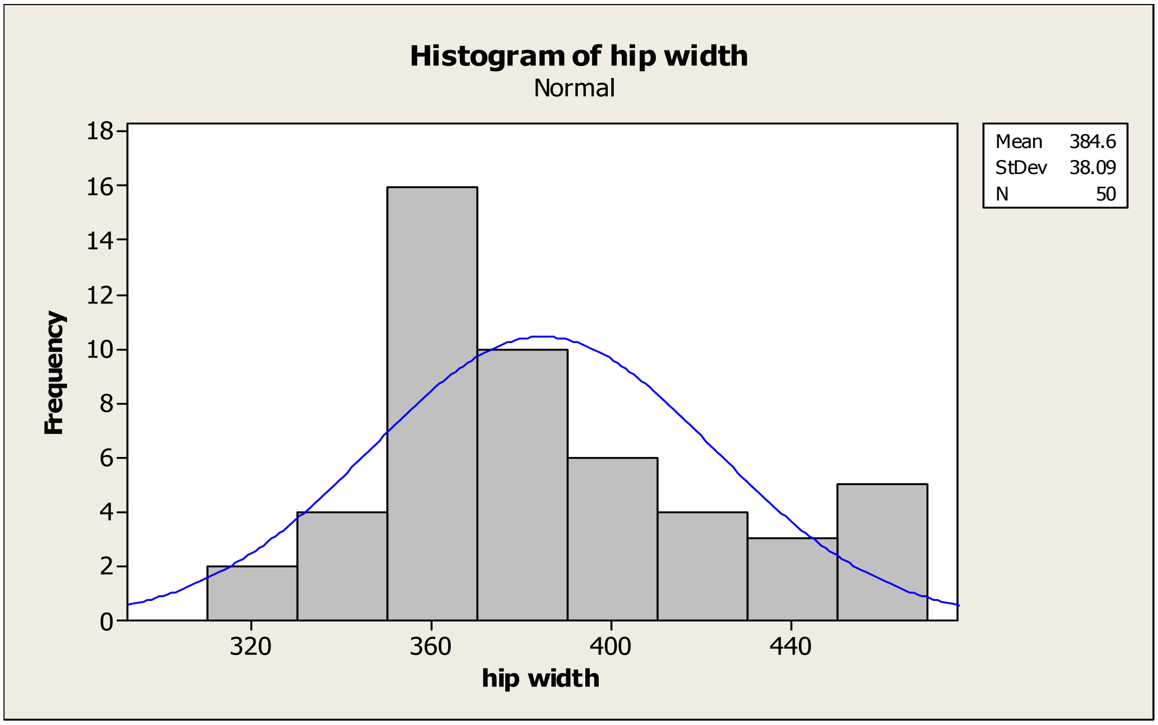


Figure B.6: Histogram of Hip Width

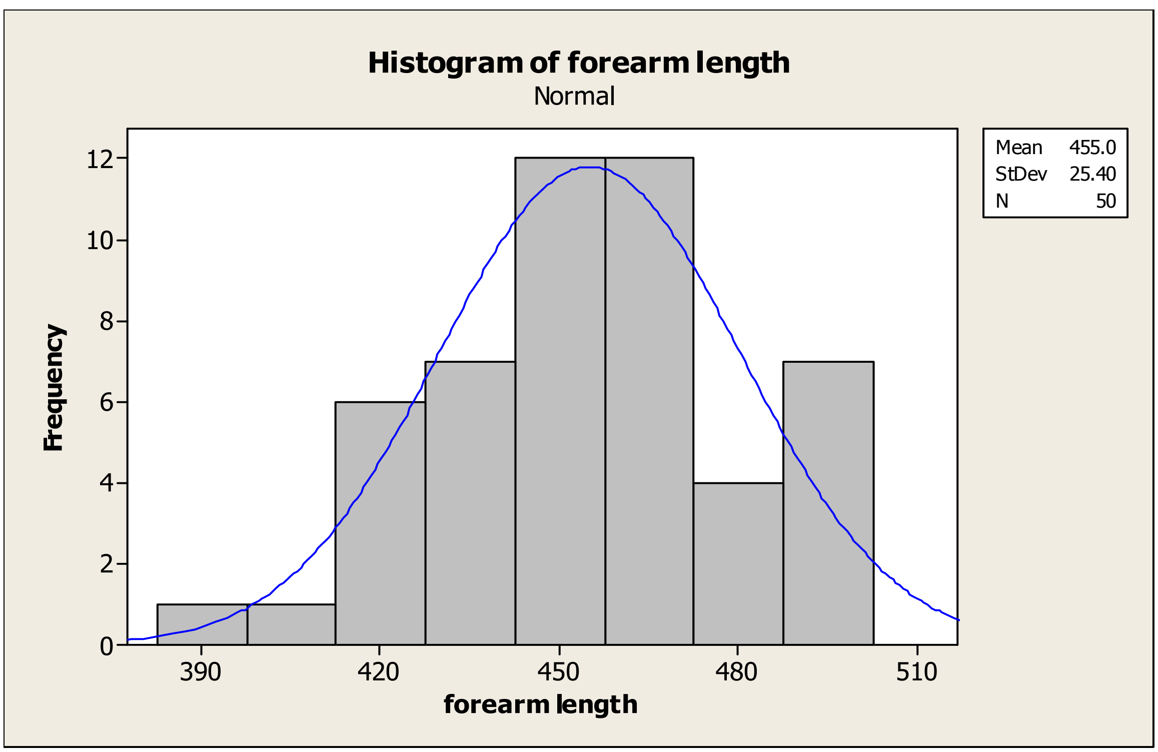


Figure B.7: Histogram of Forearm Length

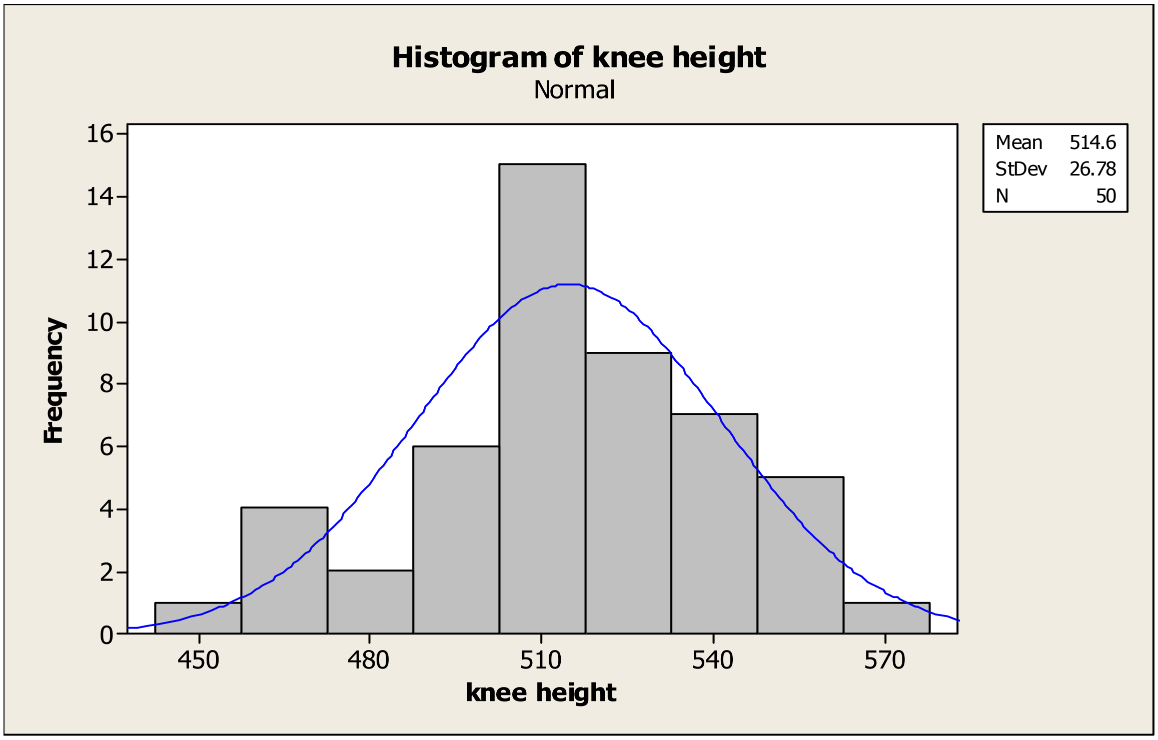

Figure B.8: Histogram of Knee Height

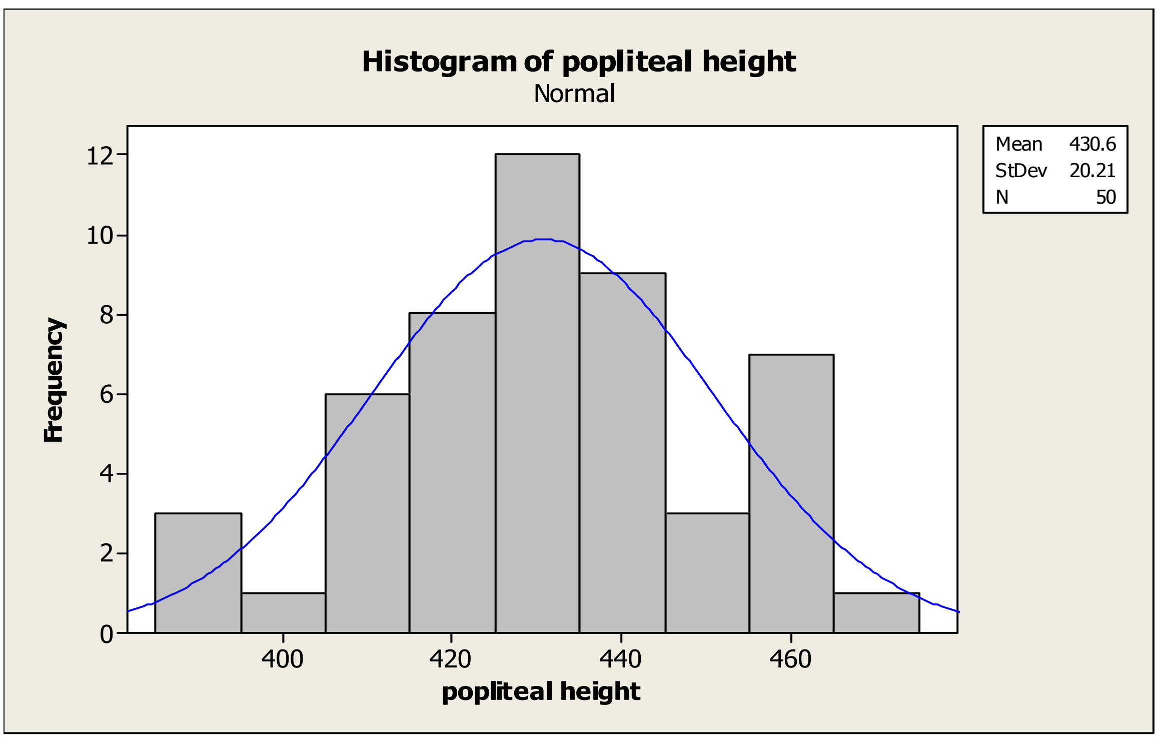

Figure B.9: Histogram of Popliteal Height

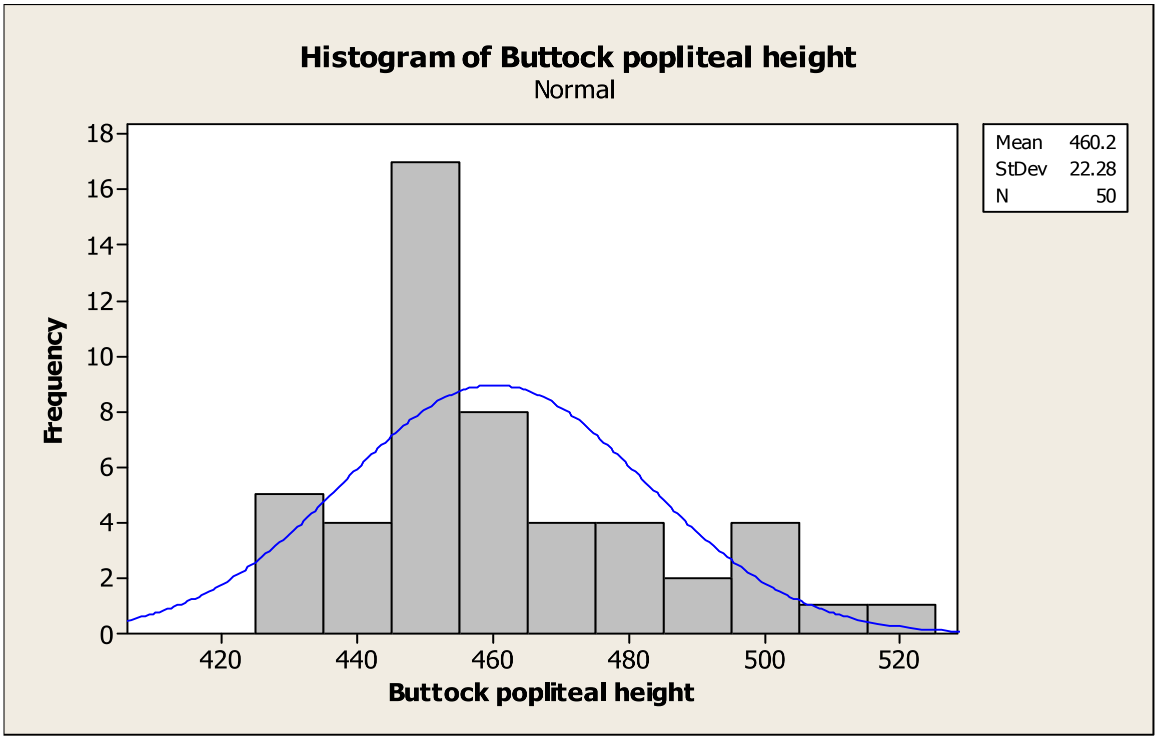

Figure B.10: Histogram of Elbow Height

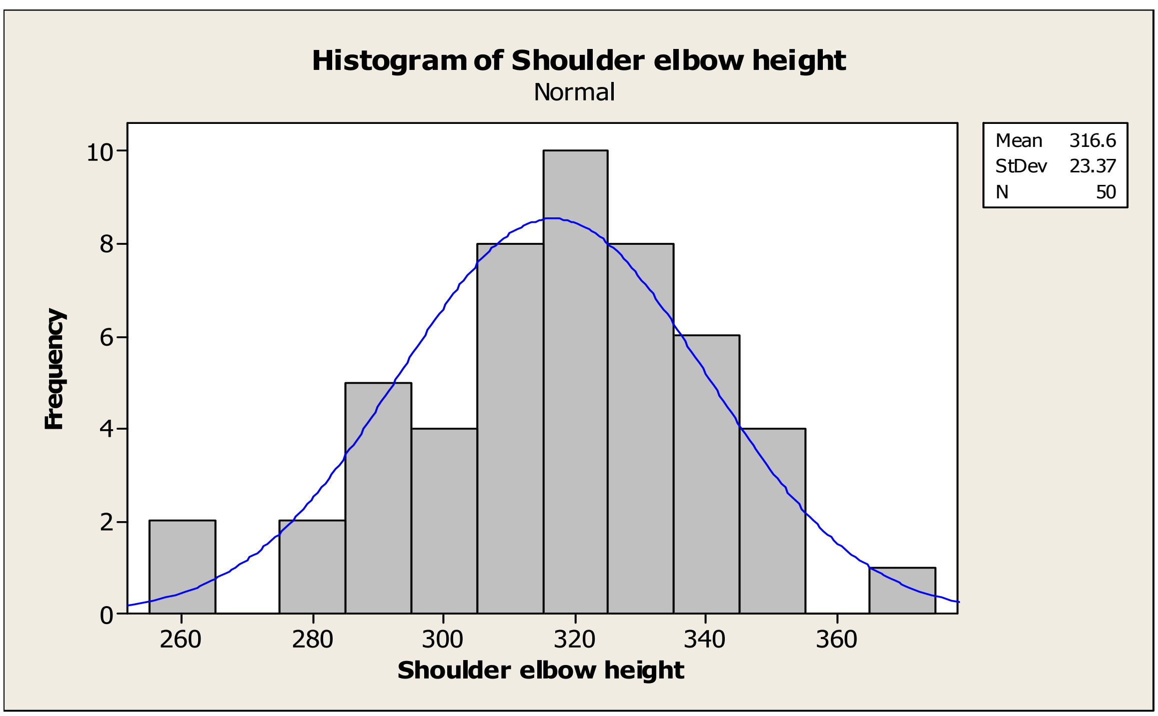

Figure B.11: Histogram of Shoulder Elbow Height

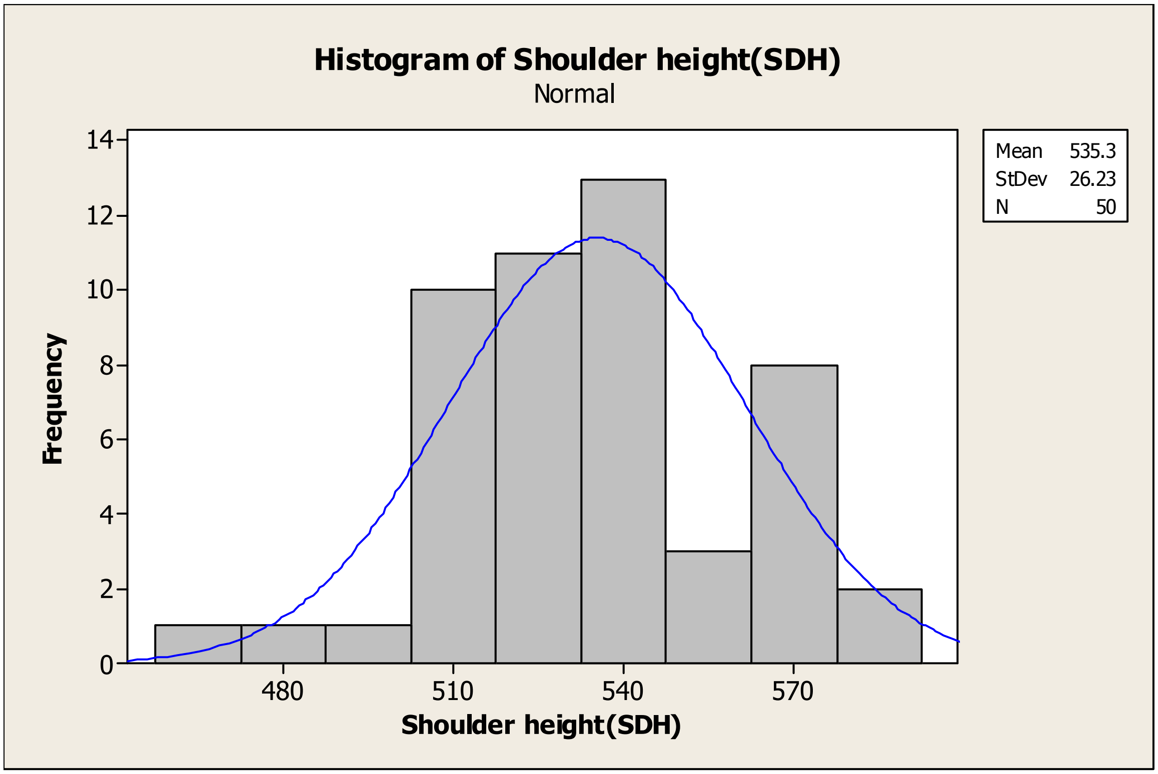


Figure B.12: Histogram of Shoulder Height

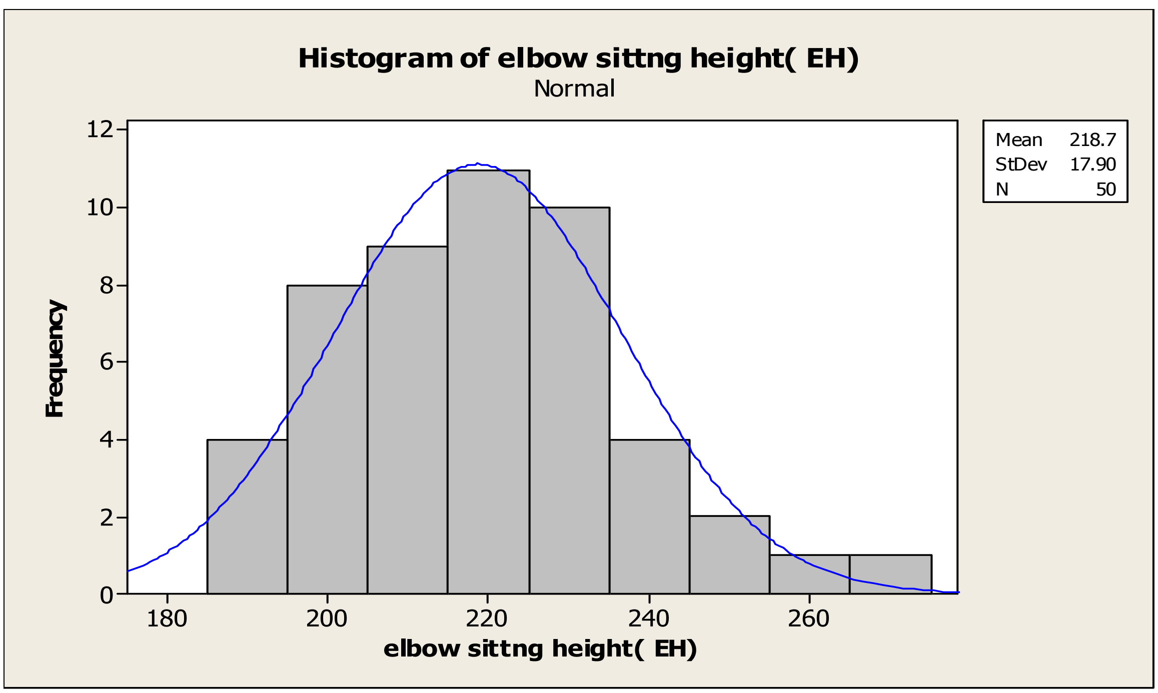


Figure B.13: Histogram of Elbow Sitting Height

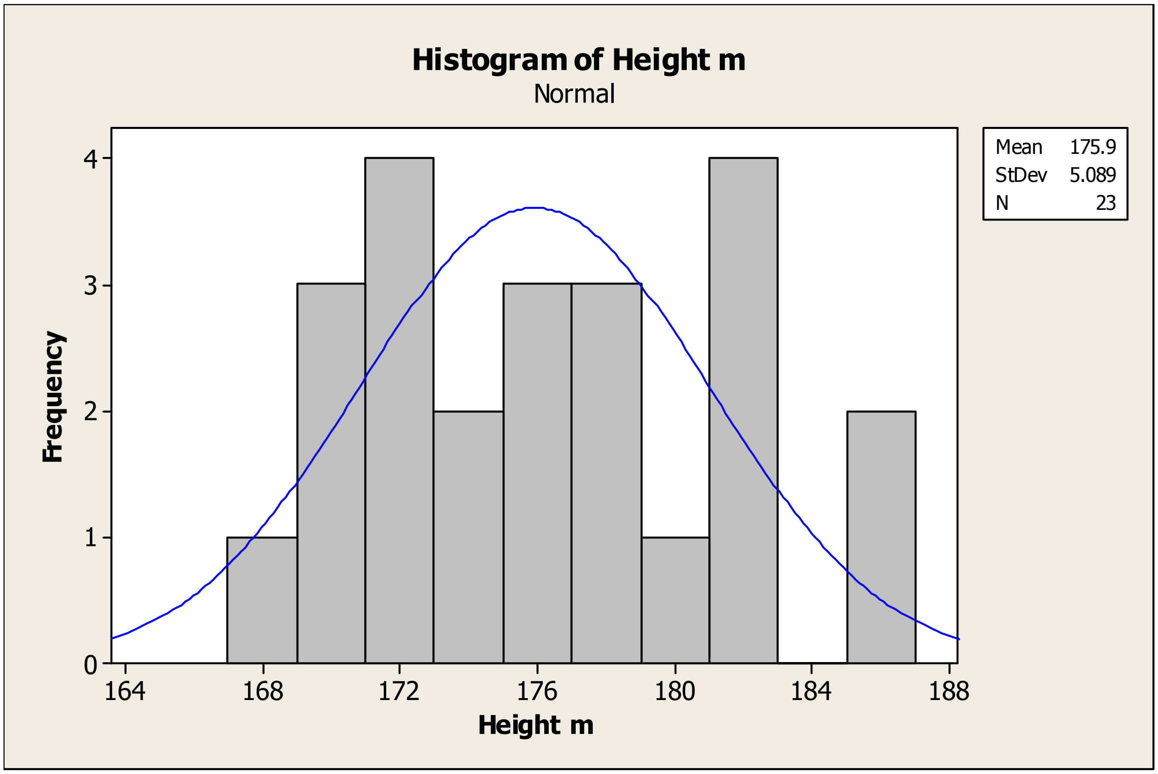


Figure B.14: Histogram of Male‘s Height

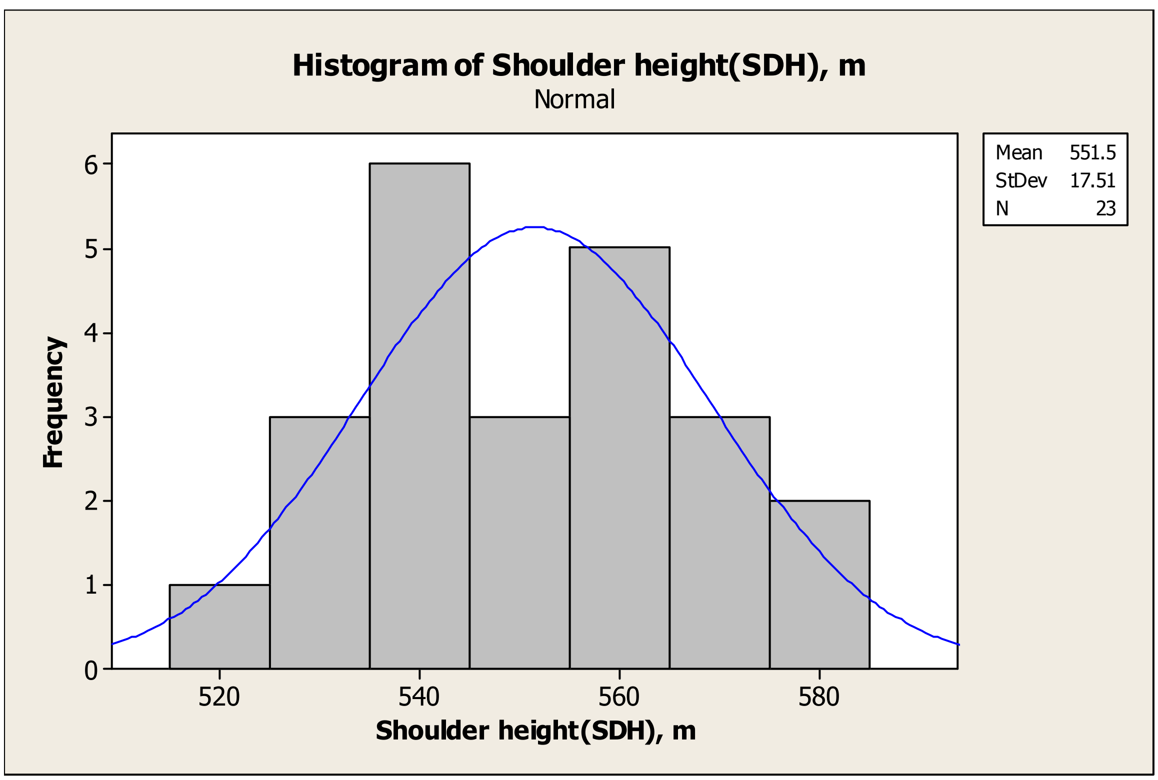


Figure B.15: Histogram of Male‘s Shoulder Height

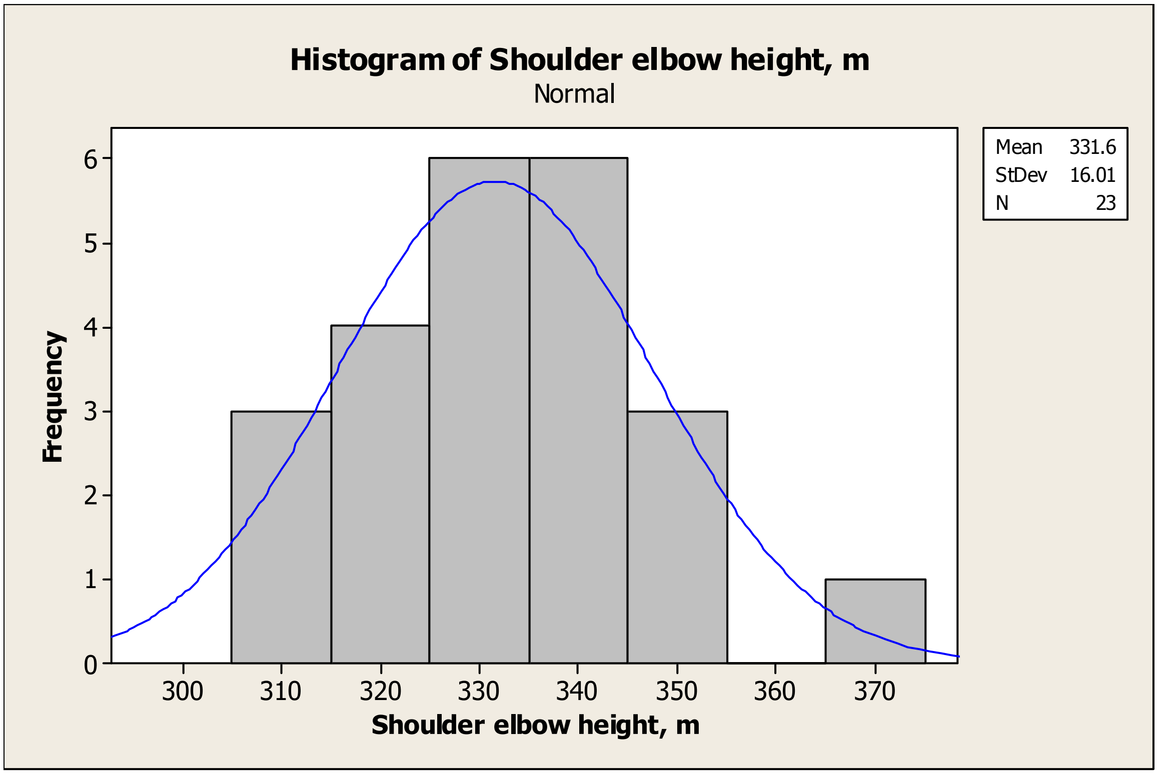


Figure B.16: Histogram of Male‘s Shoulder elbow Height

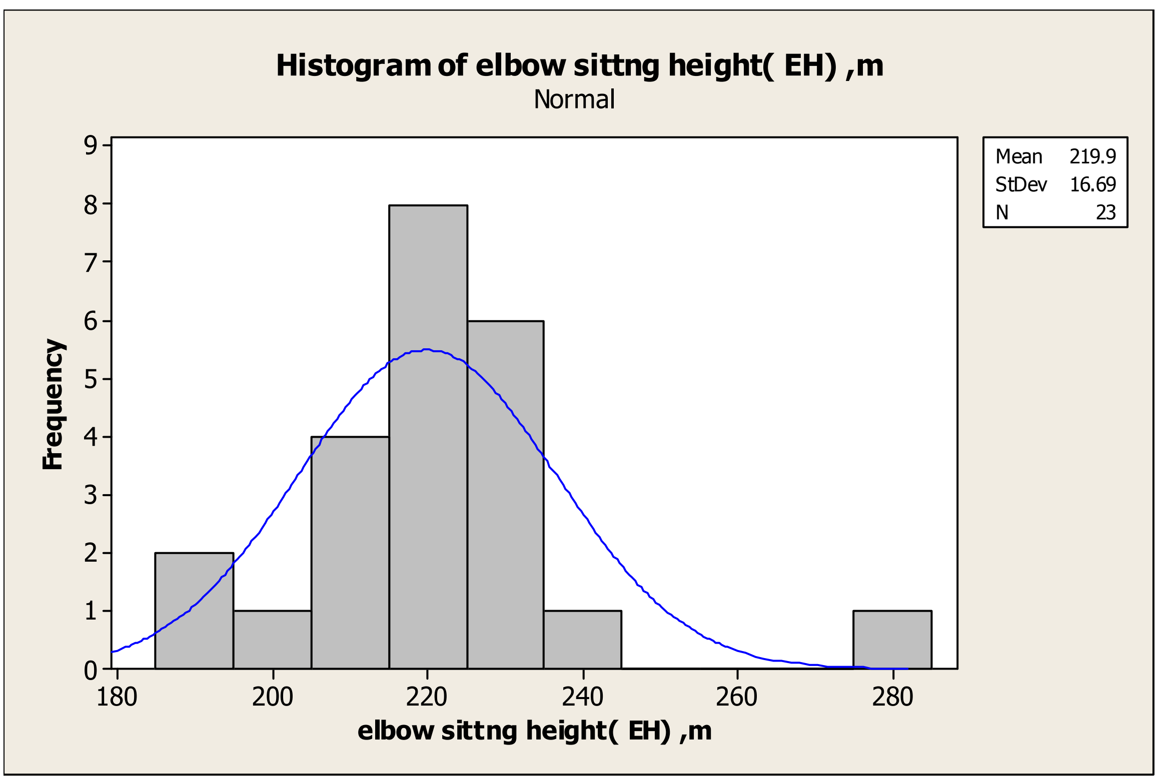


Figure B.17: Histogram of Male‘s Elbow Sitting Height

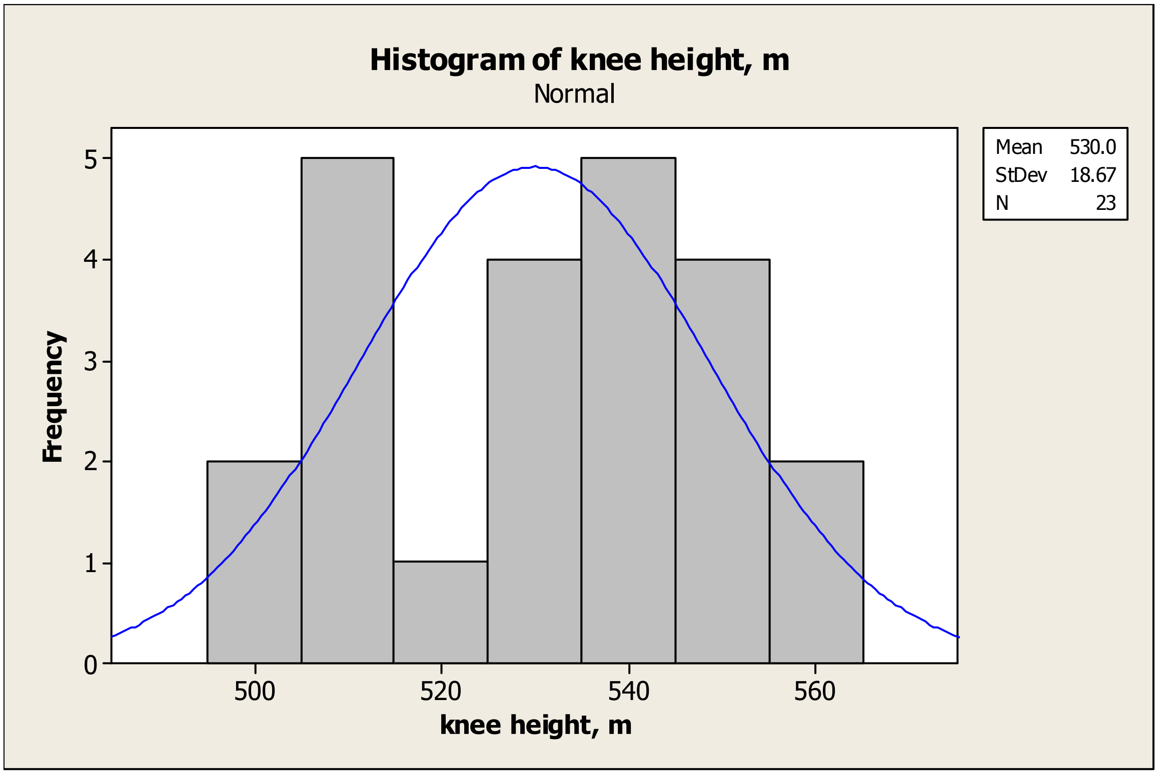


Figure B.18: Histogram of Male‘s Knee Height

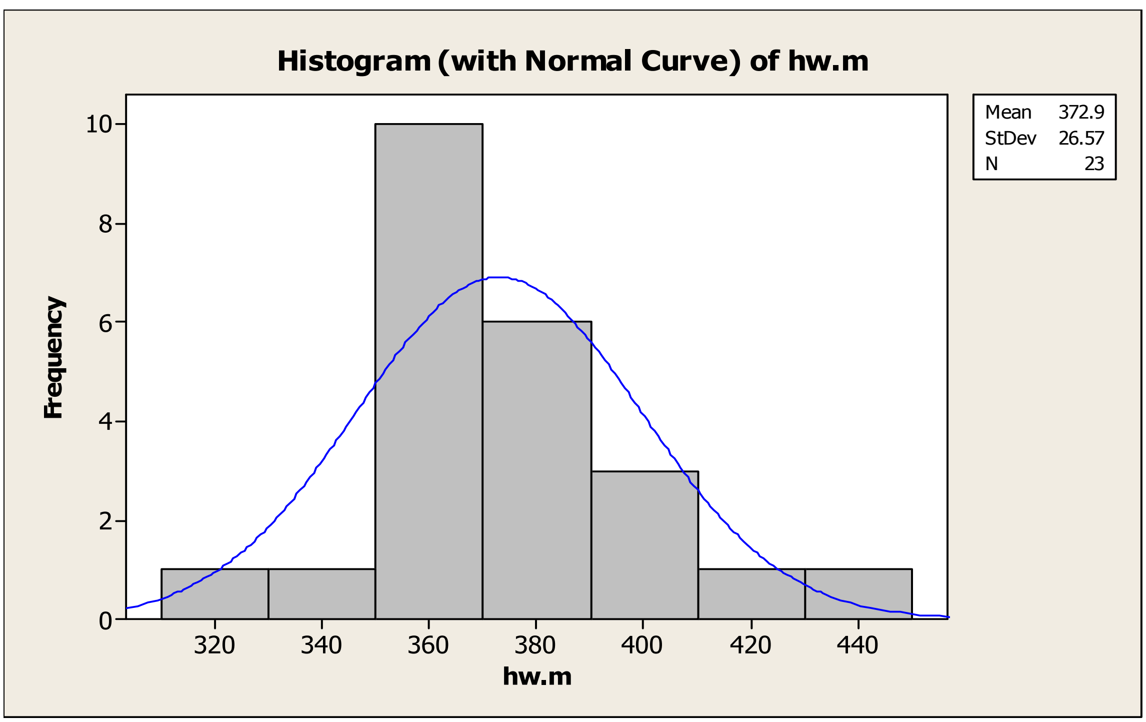


Figure B.19: Histogram of Male‘s Hip Breadth

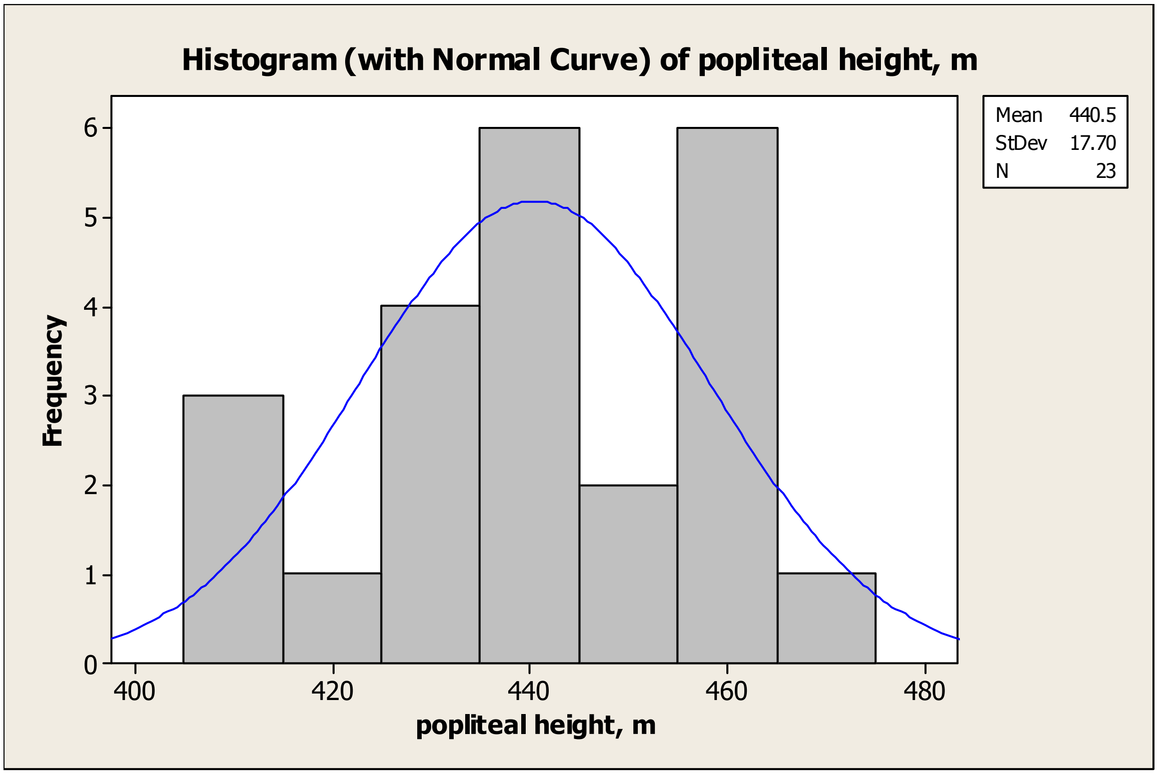

Figure B.20: Histogram of Male‘s popliteal Height

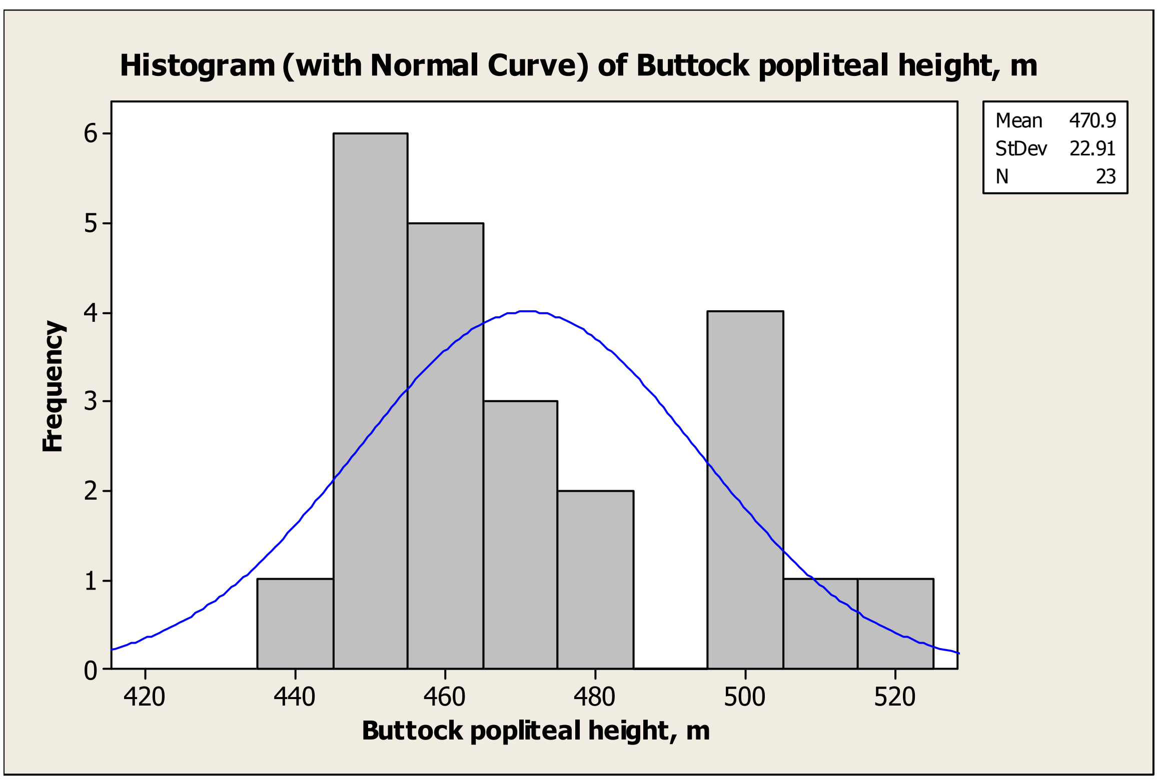

Figure B.21: Histogram of Male‘s Buttock Popliteal Length

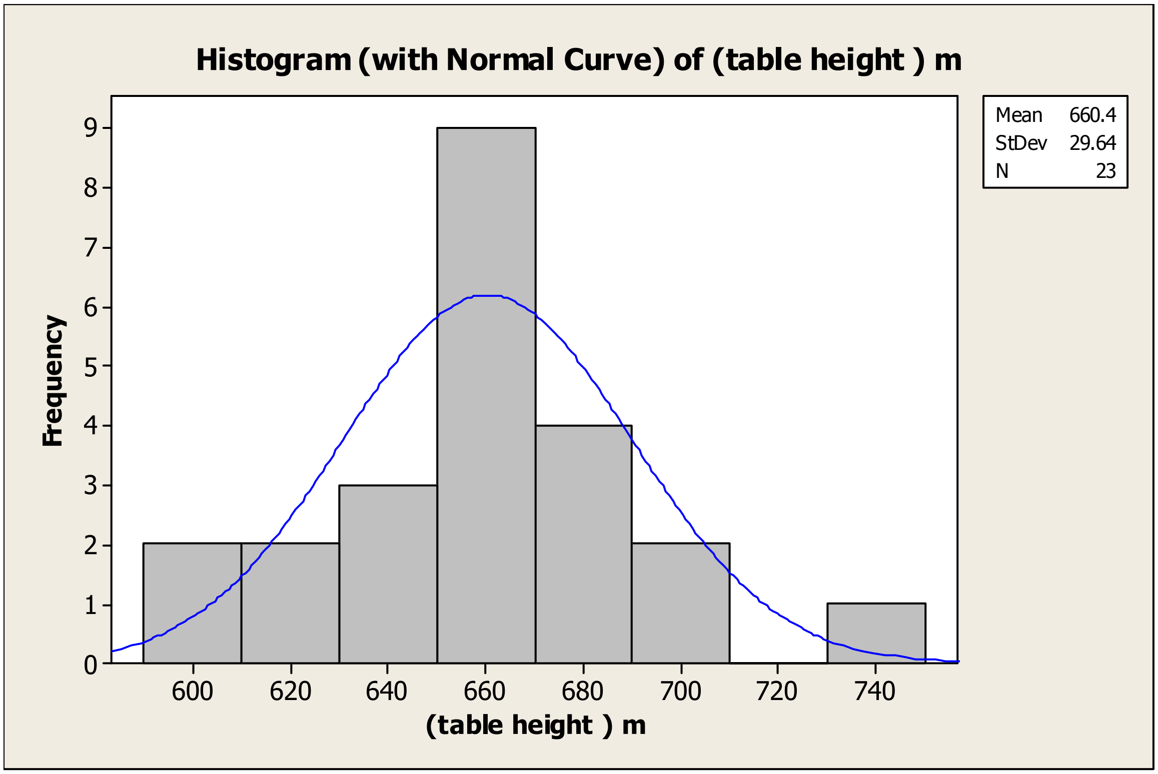


Figure B.22: Histogram of Male's Table Height

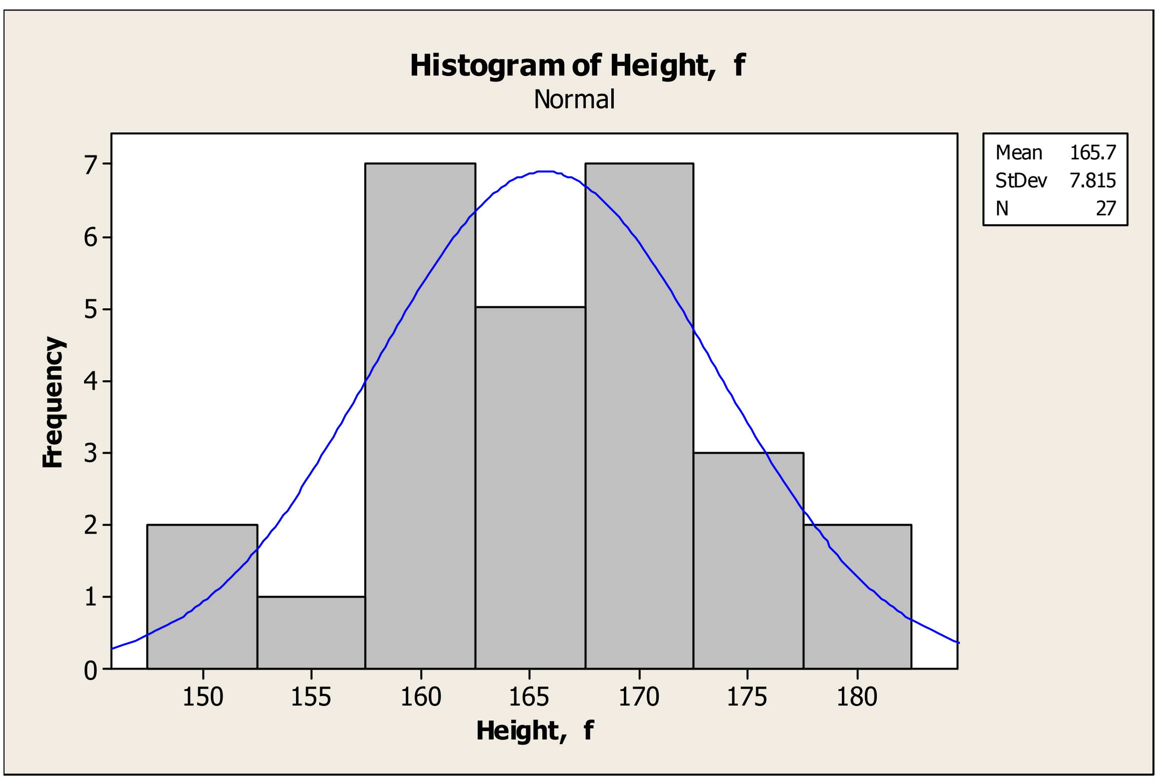


Figure B.23: Histogram of Female's Height

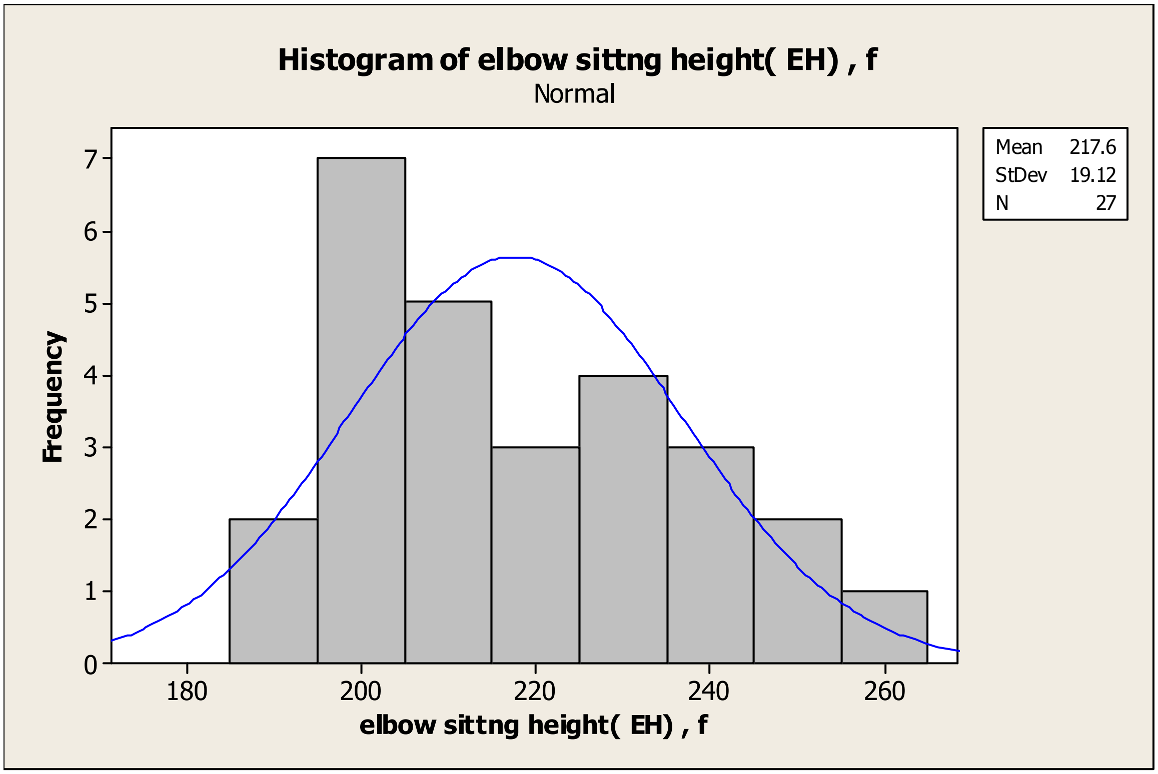

Figure B.24: Histogram of Female‘s Sitting Elbow Height

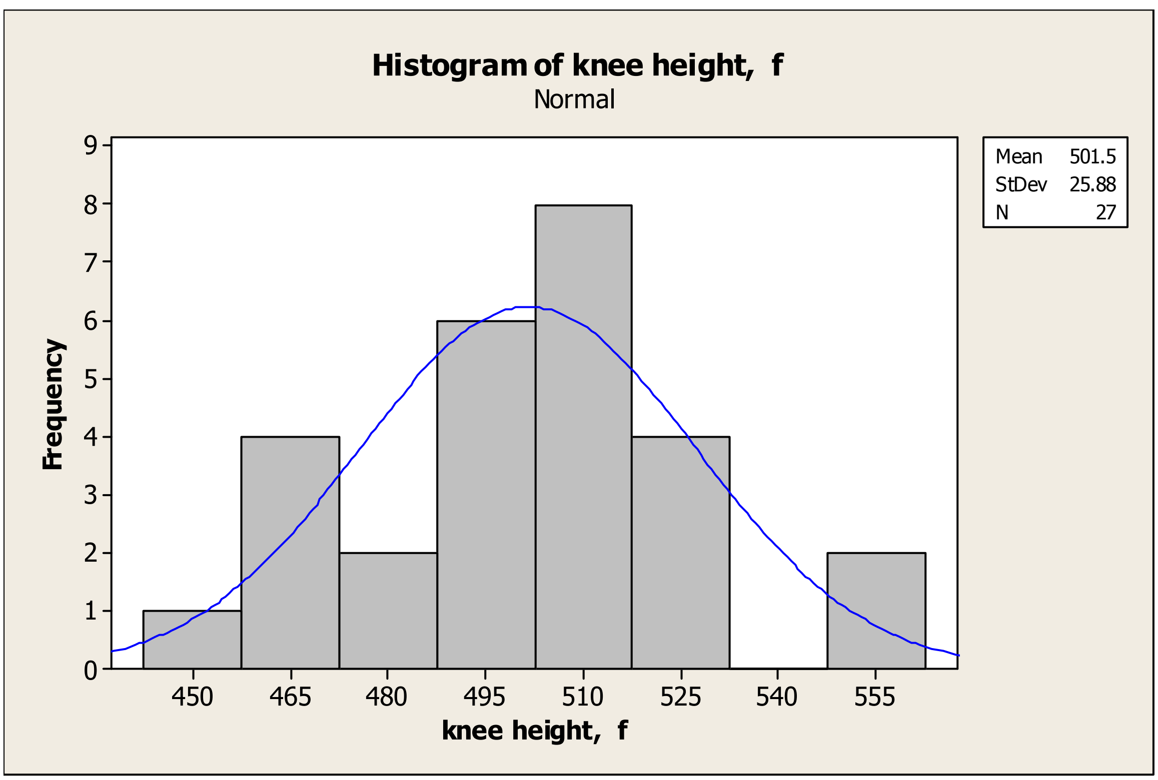

Figure B.25: Histogram of Female‘s Knee Height

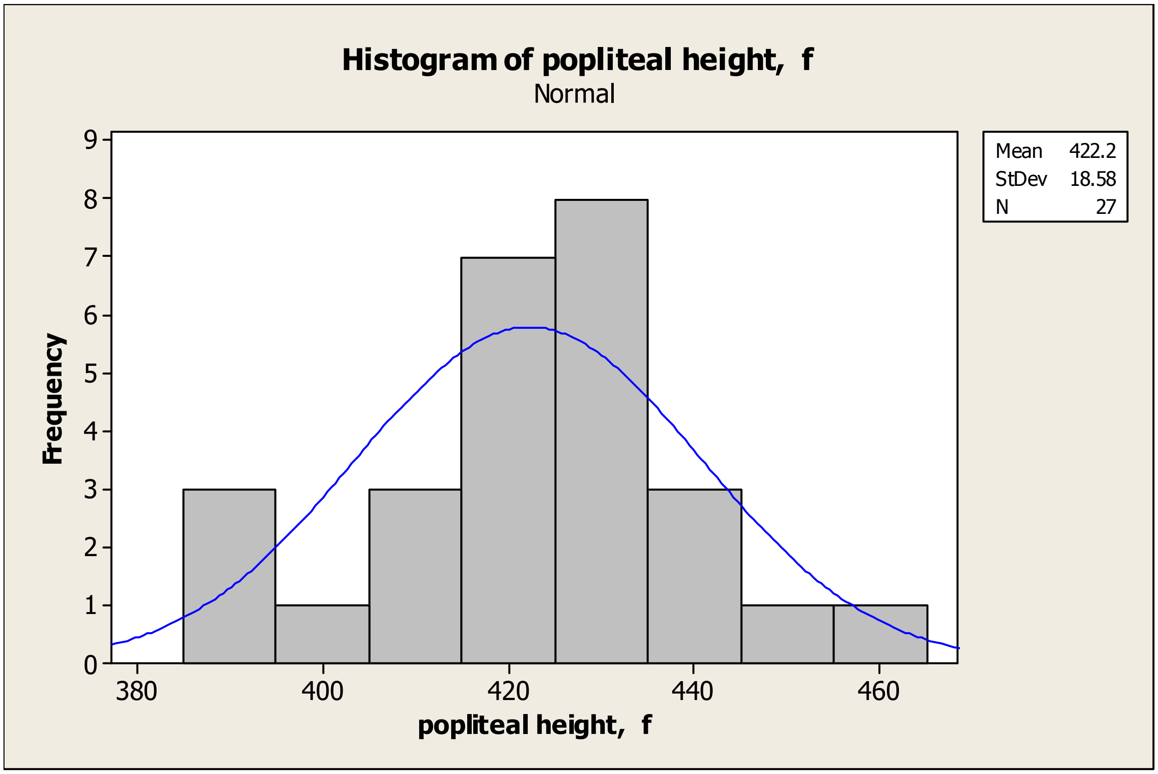


Figure B.26: Histogram of Female's Popliteal Height

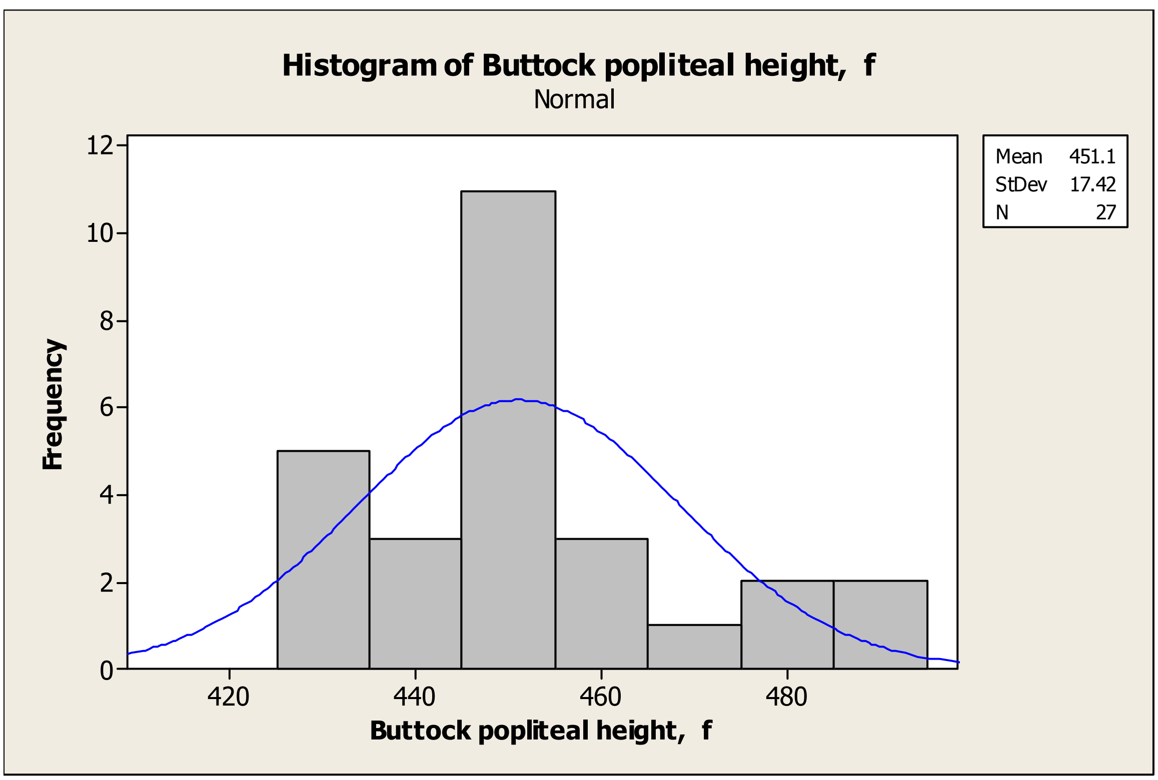


Figure B.27: Histogram of Female's Buttock Popliteal Length

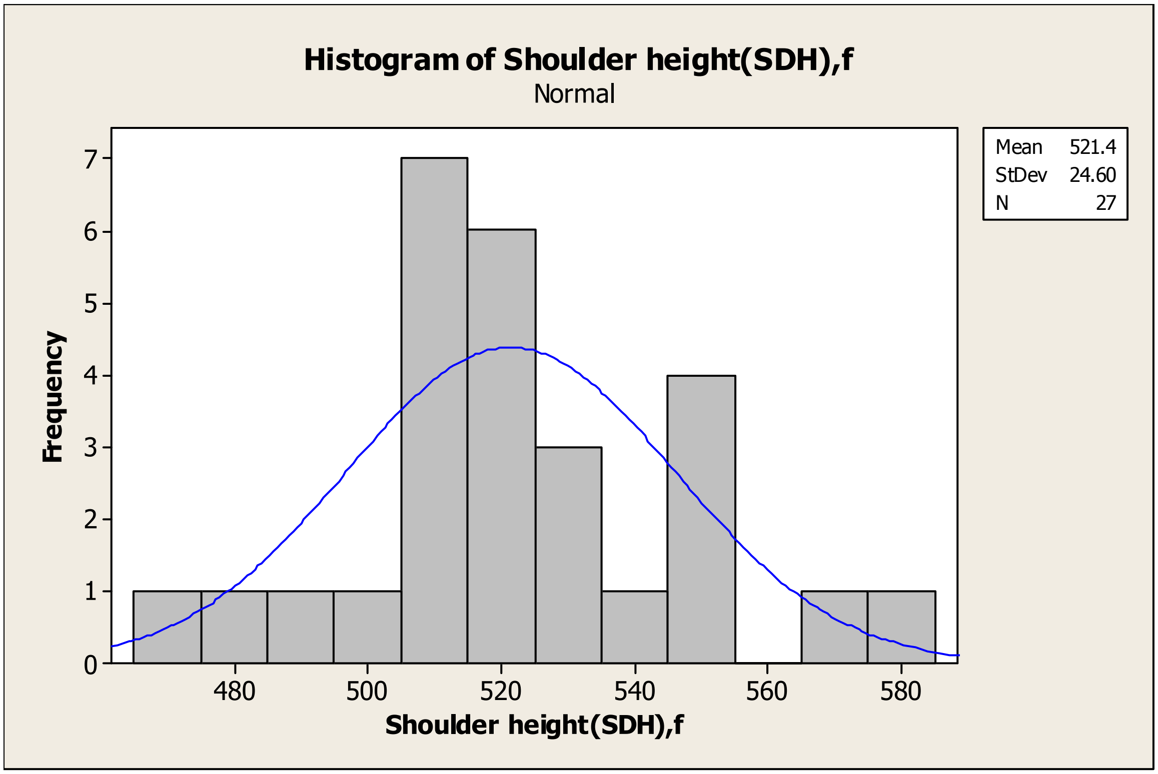


Figure B.28: Histogram of Female's Shoulder Height

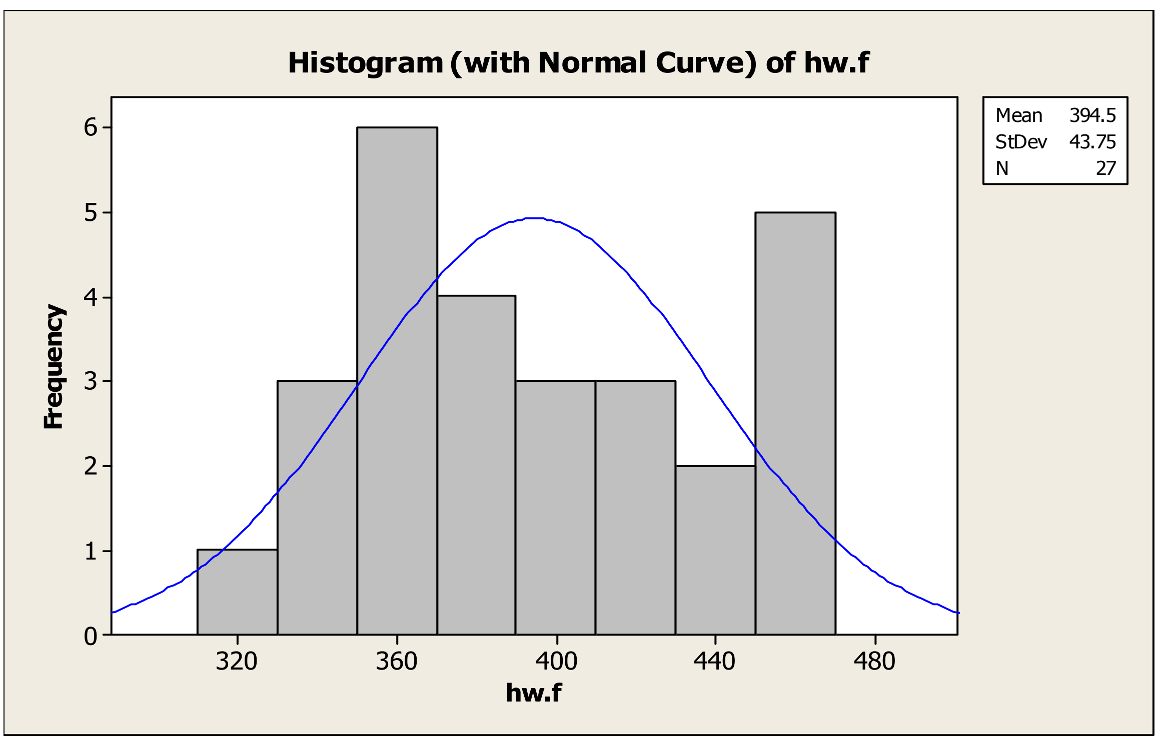


Figure B.29: Histogram of Female's Hip Breadth

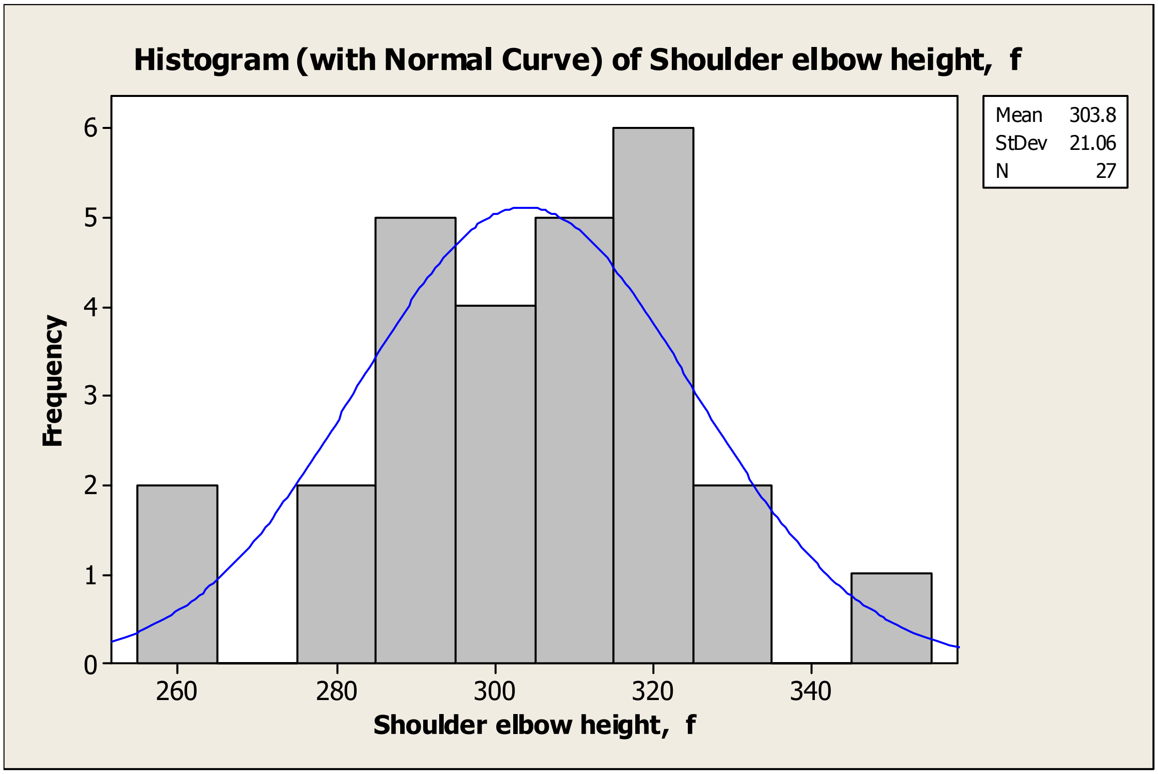


Figure B.30: Histogram of Female's Shoulder Elbow Height

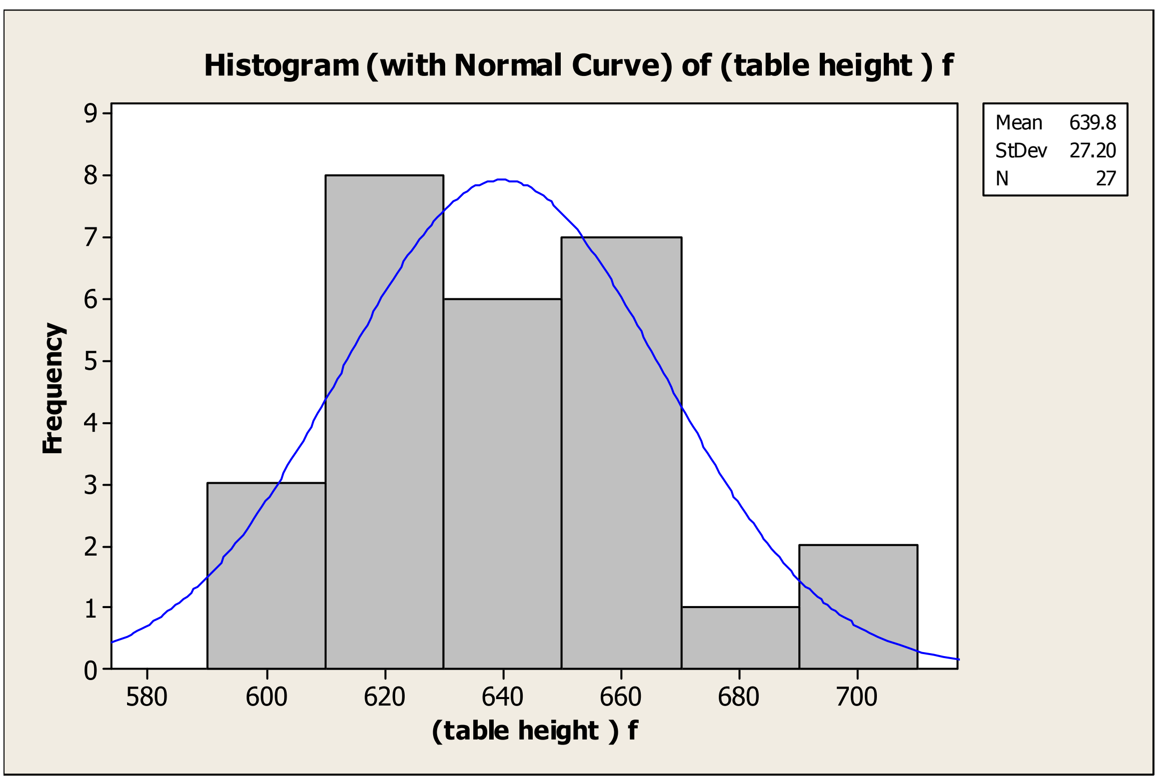


Figure B.31: Histogram of Female's Table Height

# Appendix C: Results of Hypothesis Test by Minitab 14

**3/9/2013 4:38:11 PM** ————————————————

```
Welcome to Minitab, press F1 for help.

Executing from file: C:\Users\Sony\Desktop\MINITAB
14\MACROS\STARTUP.MAC

This Software was purchased for academic use only.

 Commercial use of the Software is prohibited.
```

**Table C.1: Test for Equal Variances ( student's height )**

```
95% Bonferroni confidence intervals for standard deviations

Sample   N    Lower    StDev    Upper

1  23  3.80010  5.08920   7.6005

2  27  5.95591  7.81473  11.2406

F-Test (normal distribution)

Test statistic = 0.42, p-value = 0.045
```

**Table C.2: Test for Equal Variances ( Shoulder height , SDH )**

```
95% Bonferroni confidence intervals for standard deviations

Sample   N    Lower    StDev    Upper

1  23  13.0732  17.5080  26.1475

2  27  18.7477  24.5988  35.3827

F-Test (normal distribution)

Test statistic = 0.51, p-value = 0.109
```

**Table C.3: Test for Equal Variances ( Shoulder elbow height)**

```
95% Bonferroni confidence intervals for standard deviations

Sample   N    Lower    StDev    Upper
```

| | | | | |
|---|---|---|---|---|
| 1 | 23 | 11.9572 | 16.0134 | 23.9155 |
| 2 | 27 | 16.0480 | 21.0566 | 30.2876 |

F-Test (normal distribution)

Test statistic = 0.58, p-value = 0.196

**Table C.4: Test for Equal Variances (Buttock popliteal length )**

95% Bonferroni confidence intervals for standard deviations

| Sample | N | Lower | StDev | Upper |
|---|---|---|---|---|
| 1 | 23 | 17.1088 | 22.9127 | 34.2192 |
| 2 | 27 | 13.2731 | 17.4156 | 25.0504 |

F-Test (normal distribution)

Test statistic = 1.73, p-value = 0.181

**Table C.5: Test for Equal Variances (popliteal height)**

95% Bonferroni confidence intervals for standard deviations

| Sample | N | Lower | StDev | Upper |
|---|---|---|---|---|
| 1 | 23 | 13.2159 | 17.6992 | 26.4330 |
| 2 | 27 | 14.1593 | 18.5784 | 26.7230 |

F-Test (normal distribution)

Test statistic = 0.91, p-value = 0.824

**Table C. 6: Test for Equal Variances ( knee height )**

95% Bonferroni confidence intervals for standard deviations

| Sample | N | Lower | StDev | Upper |
|---|---|---|---|---|
| 1 | 23 | 13.9413 | 18.6706 | 27.8838 |

| | | | | |
|---|---|---|---|---|
| 2 | 27 | 19.7256 | 25.8818 | 37.2282 |

F-Test (normal distribution)

Test statistic = 0.52, p-value = 0.124

**Table C. 7: Test for Equal Variances ( elbowsittng height EH )**

95% Bonferroni confidence intervals for standard deviations

| Sample | N | Lower | StDev | Upper |
|---|---|---|---|---|
| 1 | 23 | 12.4620 | 16.6895 | 24.9252 |
| 2 | 27 | 14.5716 | 19.1193 | 27.5011 |

F-Test (normal distribution)

Test statistic = 0.76, p-value = 0.521

**Table C.8 Test for Equal Variances (Hip breadth)**

95% Bonferroni confidence intervals for standard deviations

| Sample | N | Lower | StDev | Upper |
|---|---|---|---|---|
| 1 | 23 | 19.8262 | 26.5518 | 39.6542 |
| 2 | 27 | 33.3426 | 43.7487 | 62.9277 |

F-Test (normal distribution)
Test statistic = 0.37, p-value = 0.020

**Table C.9: Two-Sample T-Test and CI (Shoulder height, SDH)**

| Sample | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| 1 | 23 | 551.5 | 17.5 | 3.7 |
| 2 | 27 | 521.4 | 24.6 | 4.7 |

Difference = mu (1) - mu (2)

Estimate for difference: 30.1200

95% CI for difference: (17.7770, 42.4630)

```
T-Test of difference = 0 (vs not =): T-Value = 4.91  P-Value = 0.000  DF = 48

Both use Pooled StDev = 21.6345
```

**Table C. 10: Two-Sample T-Test and CI ( Shoulder elbow height )**

```
Sample    N   Mean  StDev  SE Mean

1        23  331.6   16.0      3.3

2        27  303.8   21.1      4.1

Difference = mu (1) - mu (2)

Estimate for difference:  27.8100

95% CI for difference:  (17.0201, 38.5999)

T-Test of difference = 0 (vs not =): T-Value = 5.18  P-Value = 0.000  DF = 48

Both use Pooled StDev = 18.9123
```

**Table C.11: Two-Sample T-Test and CI (Buttock popliteal length )**

```
Sample    N   Mean  StDev  SE Mean

1        23  470.9   22.9      4.8

2        27  451.1   17.4      3.4

Difference = mu (1) - mu (2)

Estimate for difference:  19.8400

95% CI for difference:  (8.3588, 31.3212)

T-Test of difference = 0 (vs not =): T-Value = 3.47  P-Value = 0.001  DF = 48

Both use Pooled StDev = 20.1241
```

**Table C.12: Two-Sample T-Test and CI ( popliteal height )**

| Sample | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| 1 | 23 | 440.5 | 17.7 | 3.7 |
| 2 | 27 | 422.2 | 18.6 | 3.6 |

Difference = mu (1) - mu (2)

Estimate for difference: 18.2850

95% CI for difference: (7.9152, 28.6548)

T-Test of difference = 0 (vs not =): T-Value = 3.55 P-Value = 0.001 DF = 48

Both use Pooled StDev = 18.1760

**Table C.13: Two-Sample T-Test and CI ( knee height )**

| Sample | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| 1 | 23 | 530.0 | 18.7 | 3.9 |
| 2 | 27 | 510.5 | 25.9 | 5.0 |

Difference = mu (1) - mu (2)

Estimate for difference: 19.4300

95% CI for difference: (6.3882, 32.4718)

T-Test of difference = 0 (vs not =): T-Value = 3.00 P-Value = 0.004 DF = 48

Both use Pooled StDev = 22.8595

**Table C. 14: Two-Sample T-Test and CI , inequality variance ( hip width )**

| Sample | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| 1 | 23 | 372.9 | 26.6 | 5.5 |
| 2 | 27 | 394.5 | 43.8 | 8.4 |

```
Difference = mu (1) - mu (2)

Estimate for difference:  -21.6055

95% CI for difference:  (-41.9316, -1.2793)

T-Test of difference = 0 (vs not =): T-Value = -2.14  P-
Value = 0.038  DF = 43
```

**Table C.15: Two-Sample T-Test and CI (Height inequality variance )**

```
Sample   N    Mean  StDev  SE Mean

1       23  175.91   5.09      1.1

2       27  165.68   7.81      1.5

Difference = mu (1) - mu (2)

Estimate for difference:  10.2350

5% CI for difference:  (10.1190, 10.3510)

T-Test of difference = 0 (vs not =): T-Value = 5.56  P-
Value = 0.000  DF = 45
```

**Table C. 16: Two-Sample T-Test and CI ( elbow sitting height)**

```
Sample   N   Mean  StDev  SE Mean

1       23  219.9   16.7      3.5

2       27  217.6   19.1      3.7

Difference = mu (1) - mu (2)

Estimate for difference:  2.28341

95% CI for difference:  (-8.01240, 12.57923)

T-Test of difference = 0 (vs not =): T-Value = 0.45  P-
Value = 0.658  DF = 48

Both use Pooled StDev = 18.0463
```

**Table C.17: Test for Equal Variances: (table height ) m, (table height ) f**

95% Bonferroni confidence intervals for standard deviations

| | N | Lower | StDev | Upper |
|---|---|---|---|---|
| (table height ) m | 23 | 22.1286 | 29.6353 | 44.2591 |
| (table height ) f | 27 | 20.7271 | 27.1959 | 39.1183 |

F-Test (normal distribution)

Test statistic = 1.19, p-value = 0.669

**Table C.18: Two-Sample T-Test and CI: (table height ) m, (table height ) f**

Two-sample T for (table height ) m vs (table height ) f

| | N | Mean | StDev | SE Mean |
|---|---|---|---|---|
| (table height ) | 23 | 660.4 | 29.6 | 6.2 |
| (table height ) | 27 | 639.8 | 27.2 | 5.2 |

Difference = mu ((table height ) m) - mu ((table height ) f)

Estimate for difference:  20.5765

95% lower bound for difference:  7.0890

T-Test of difference = 0 (vs>): T-Value = 2.56  P-Value = 0.007  DF = 48

Both use Pooled StDev = 28.3400

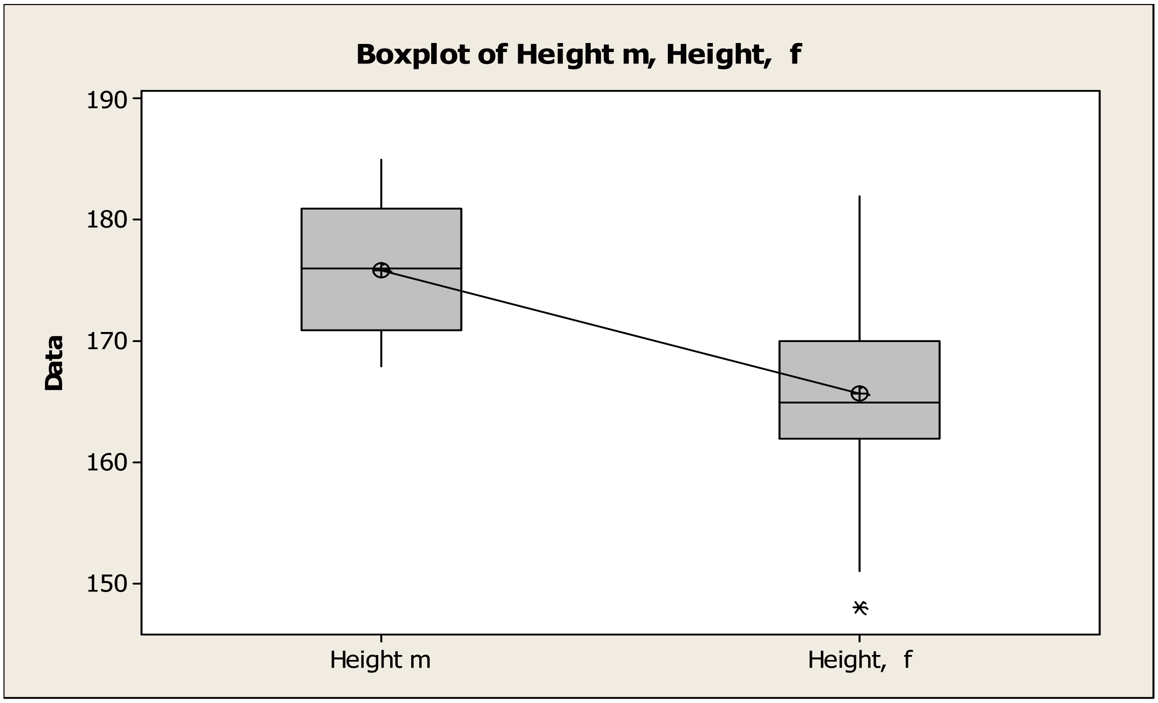

Figure C.1: Boxplot of Height for Both Male and Female

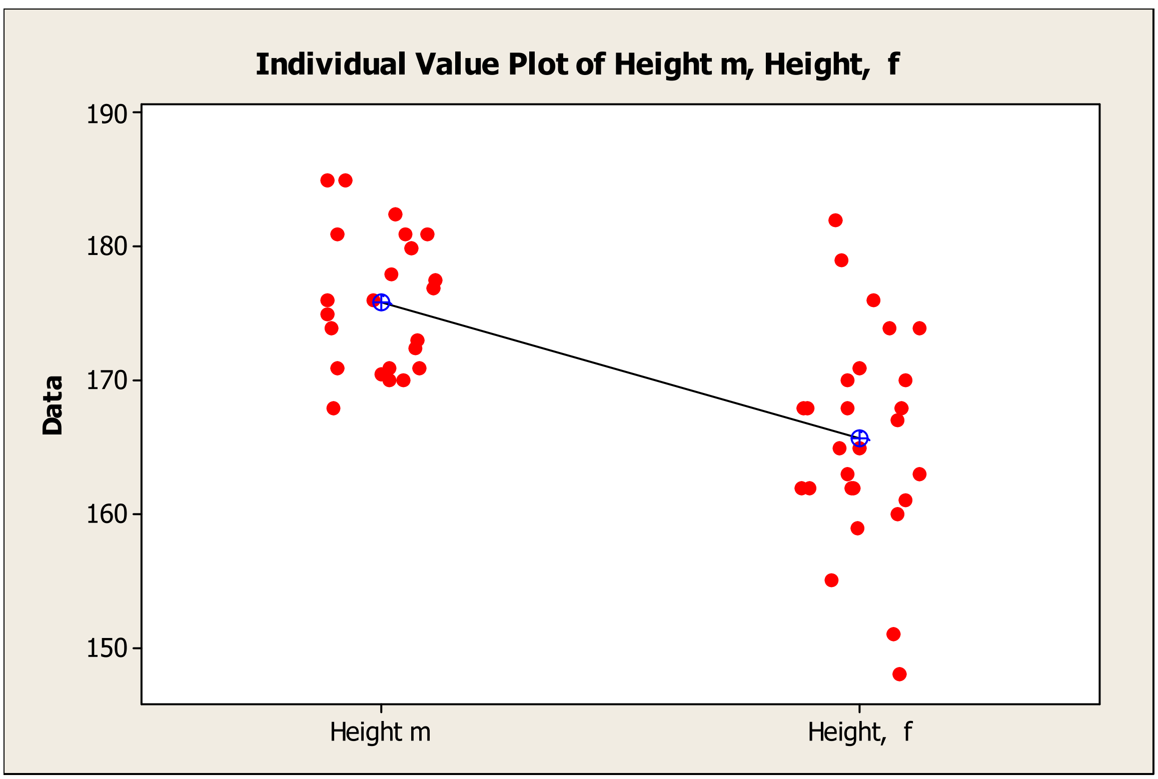

Figure C.2: Individual Value Plot of Height for Both Male and Female

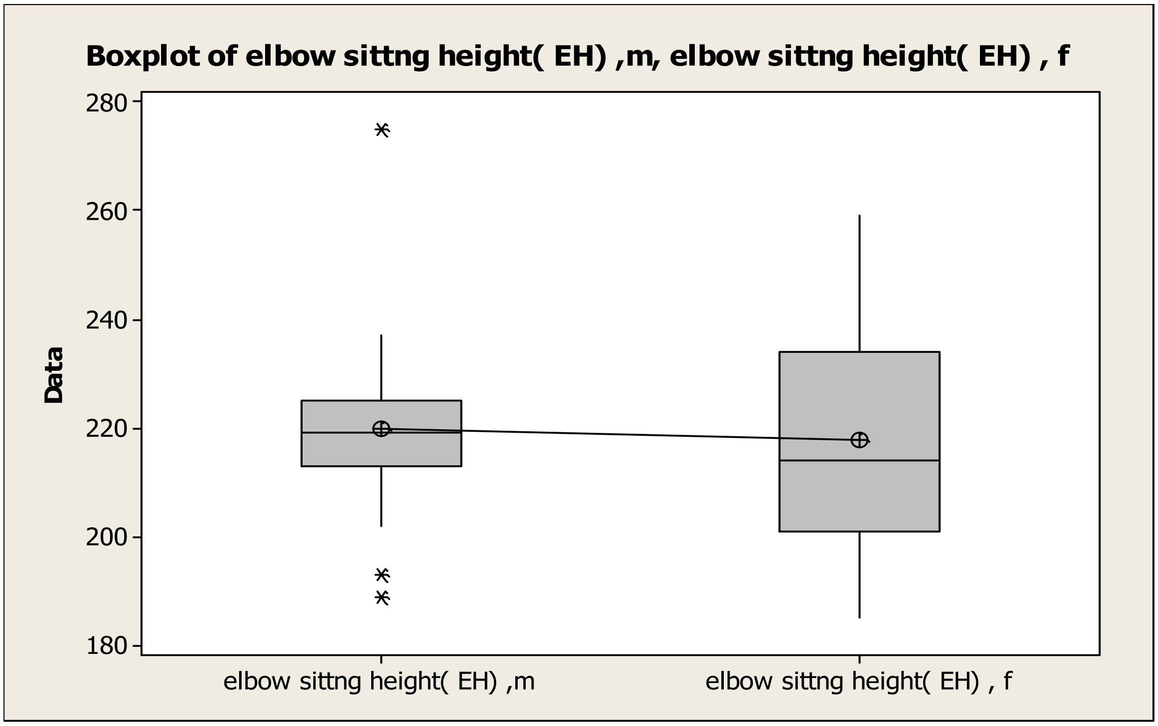

Figure C.3: Boxplot of Sitting Elbow Height for Both Male and Female

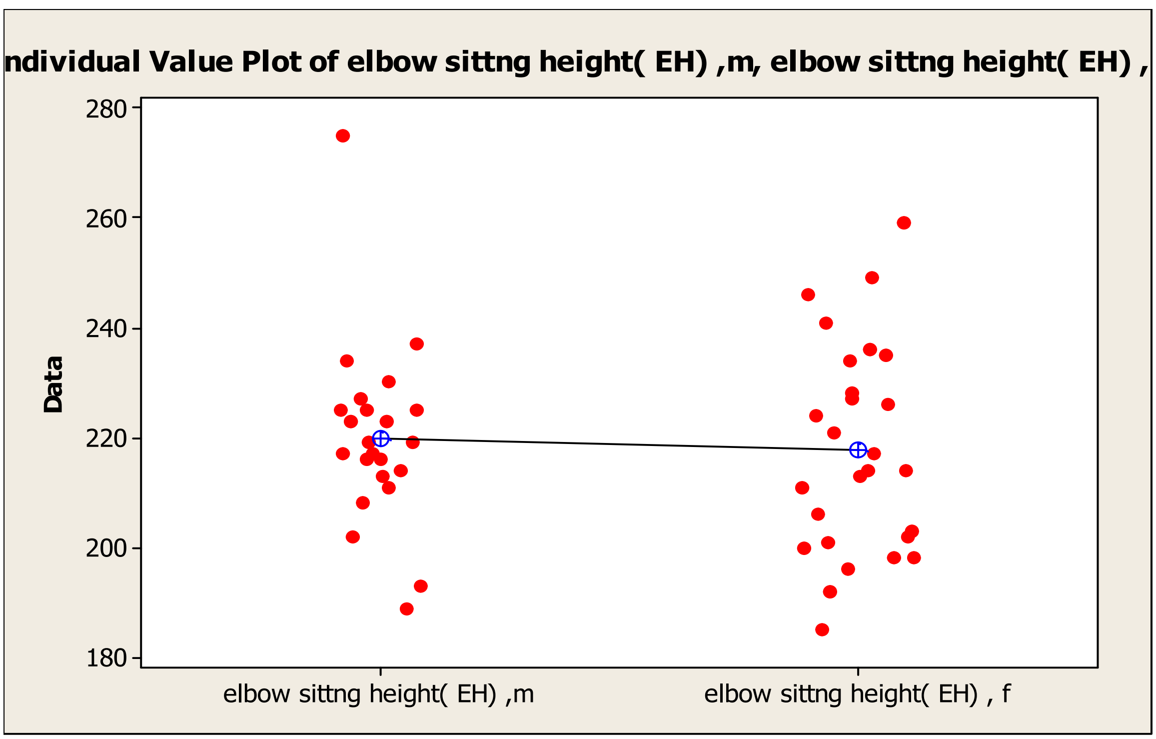

Figure C.4: Individual Value plot of Elbow Sitting Height for Both Male and Female

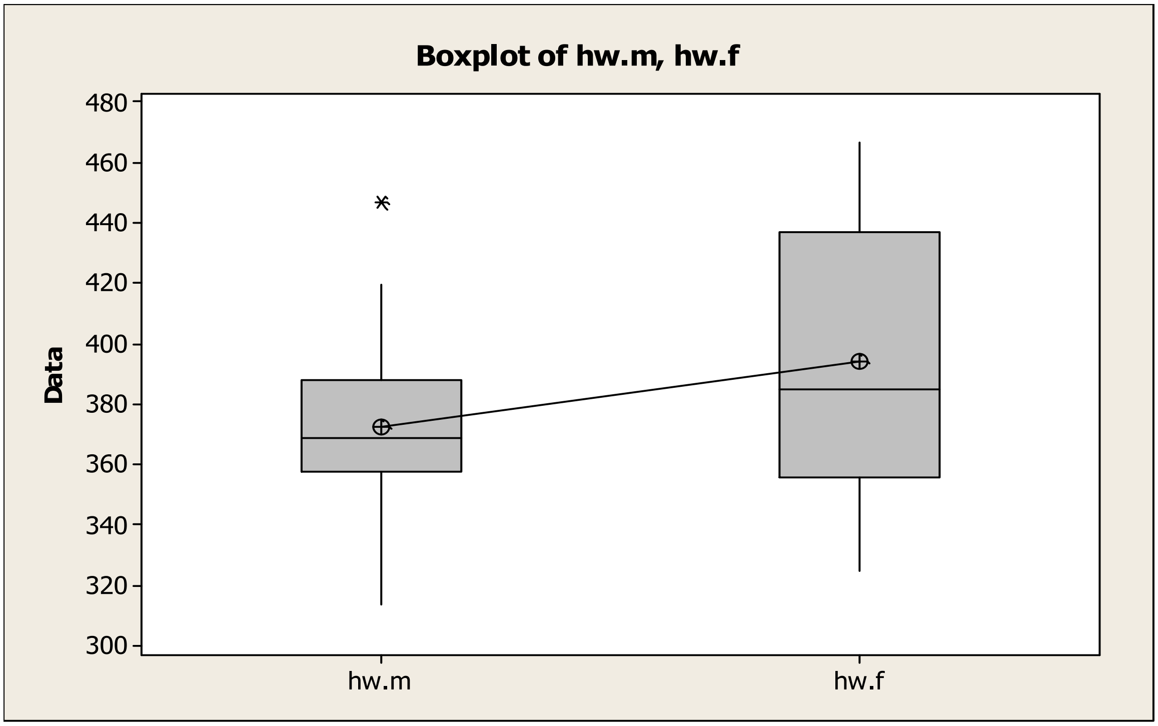

Figure C.5: Boxplot of Hip Breadth for Both Male and Female

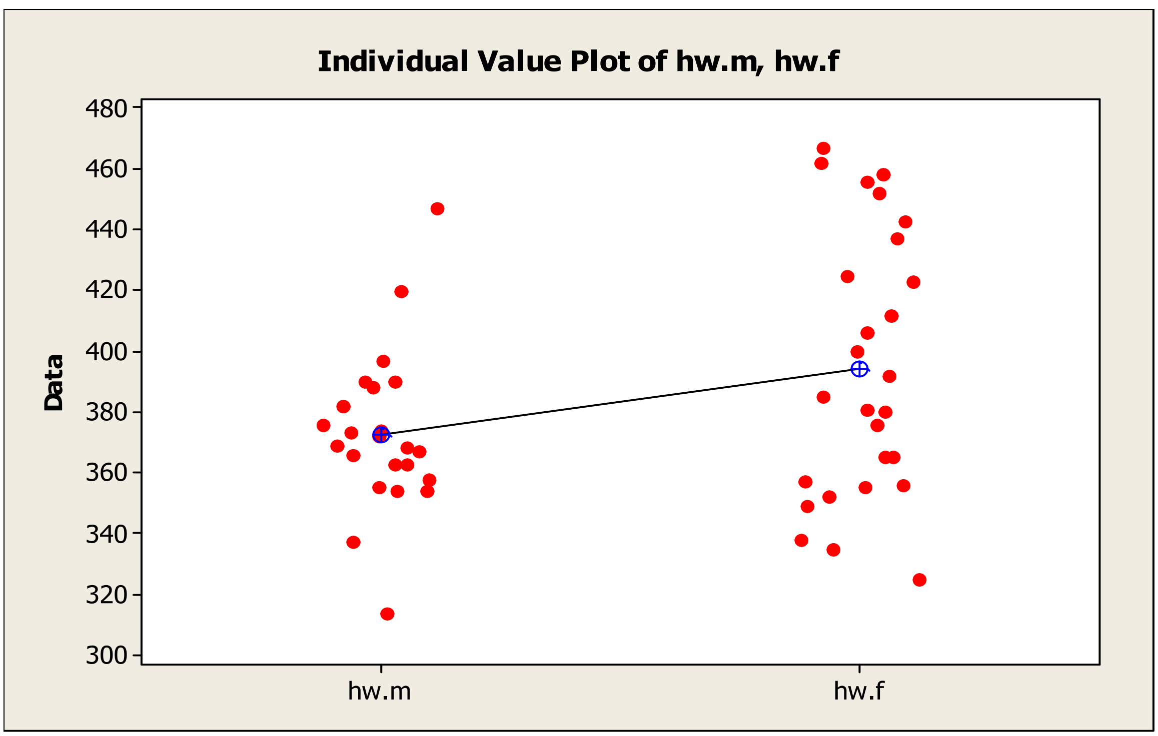

Figure C.6: Individual Value Plot Hip Breadth

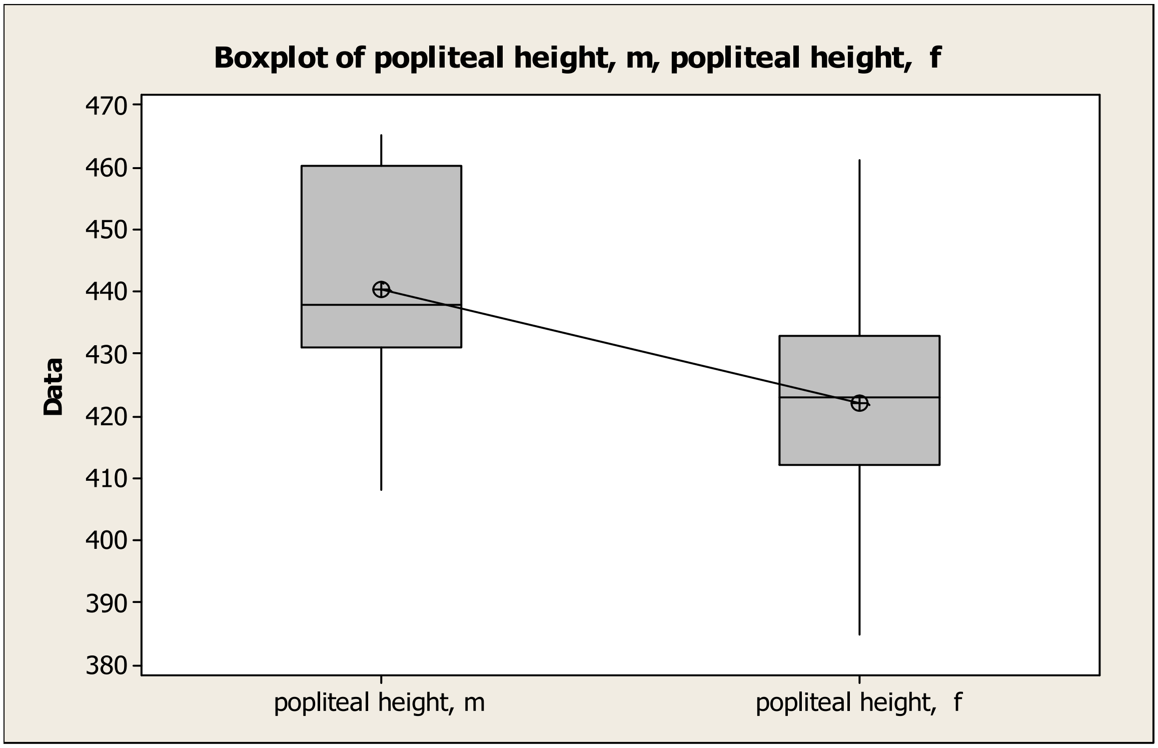

Figure C.7: Boxplot of Popliteal Height for Both Male and Female

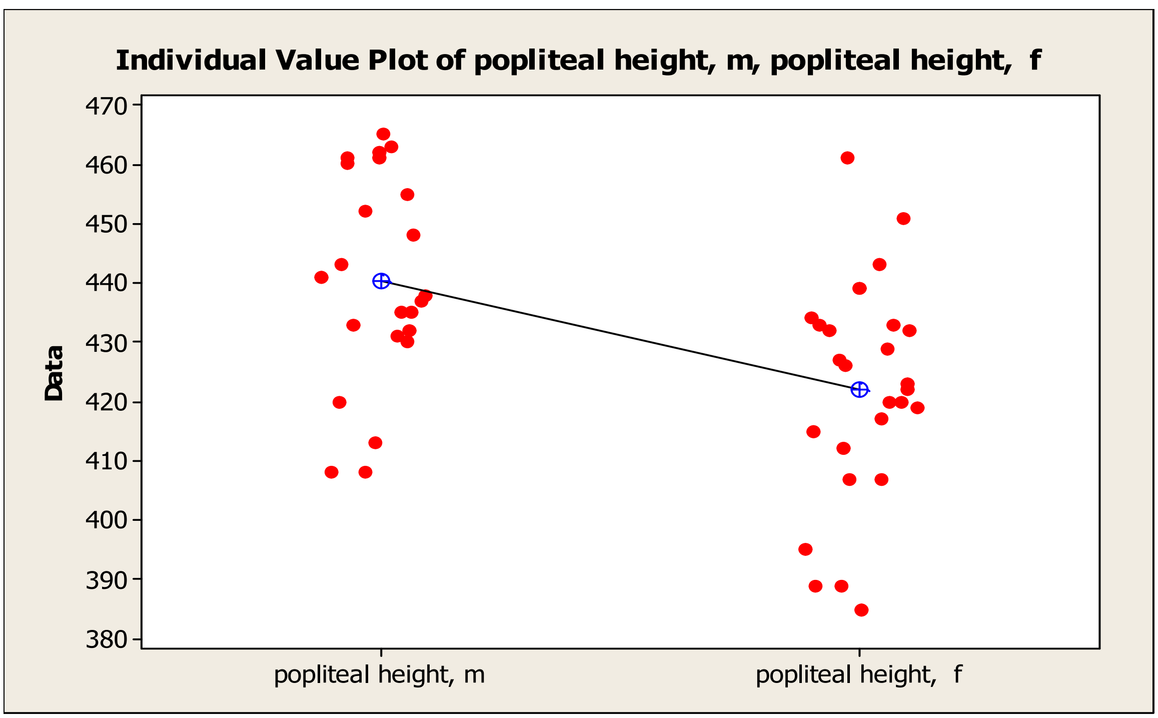

Figure C.8: Individual Value Plot of Popliteal Height

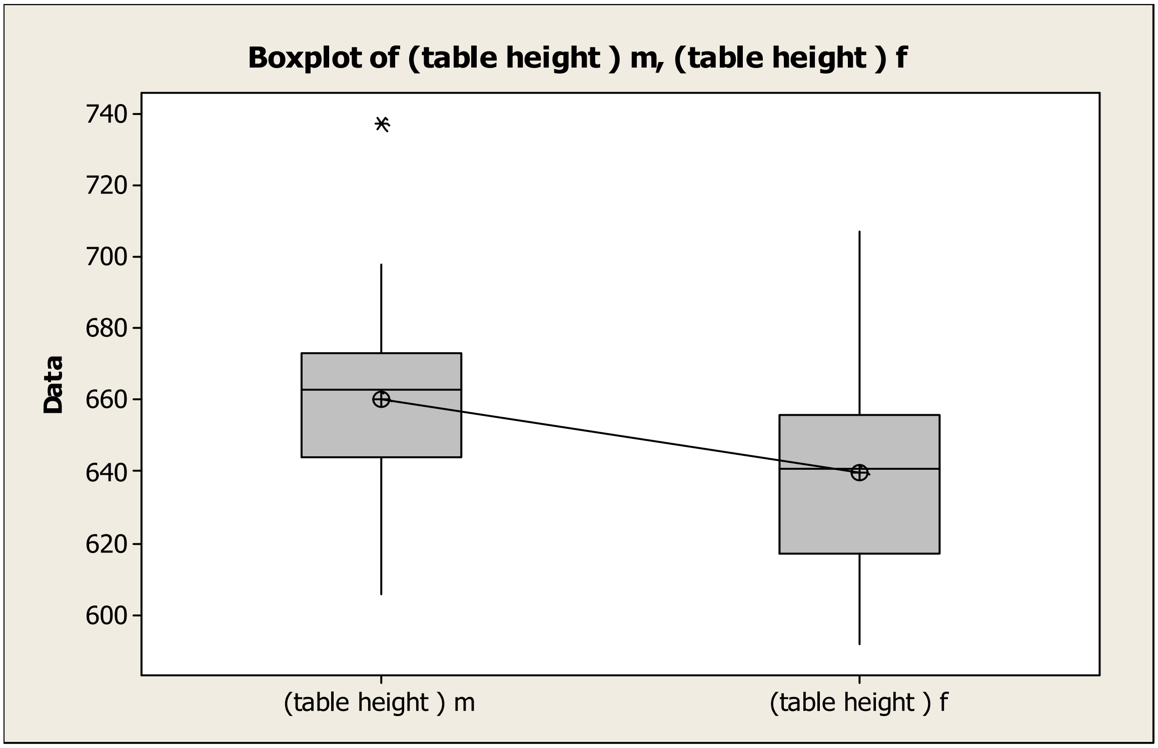

Figure C.9: Boxplot of Table Height for Both Male and Female

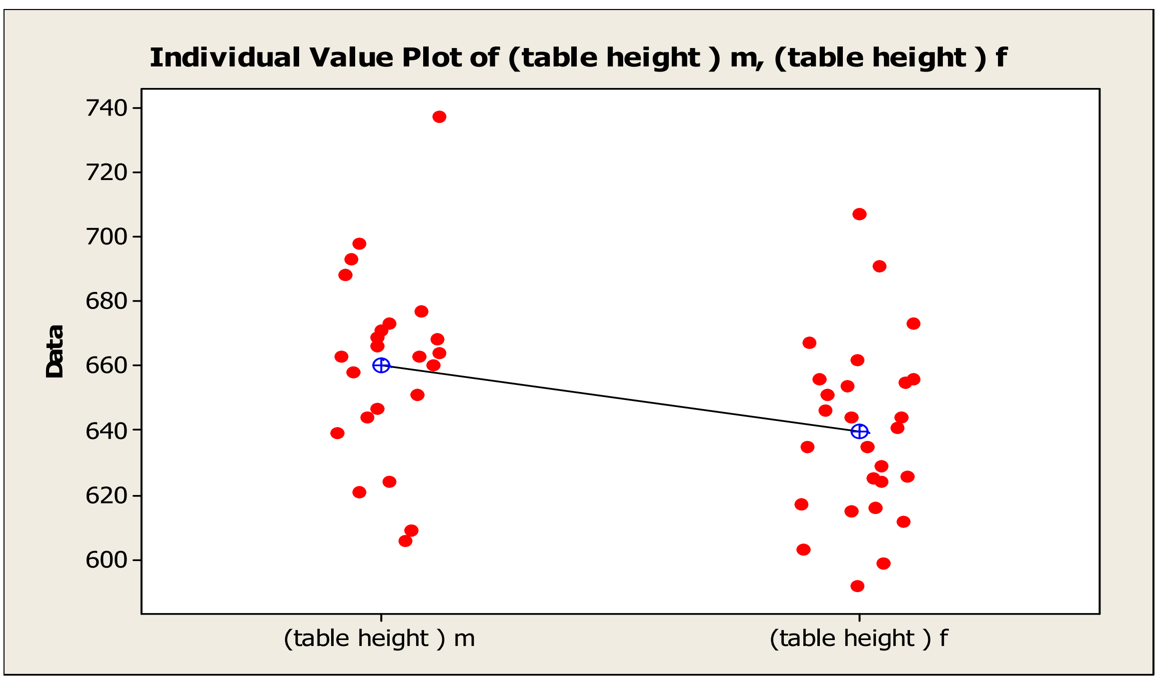

Figure C.10: Individual Value Plot of Table Height

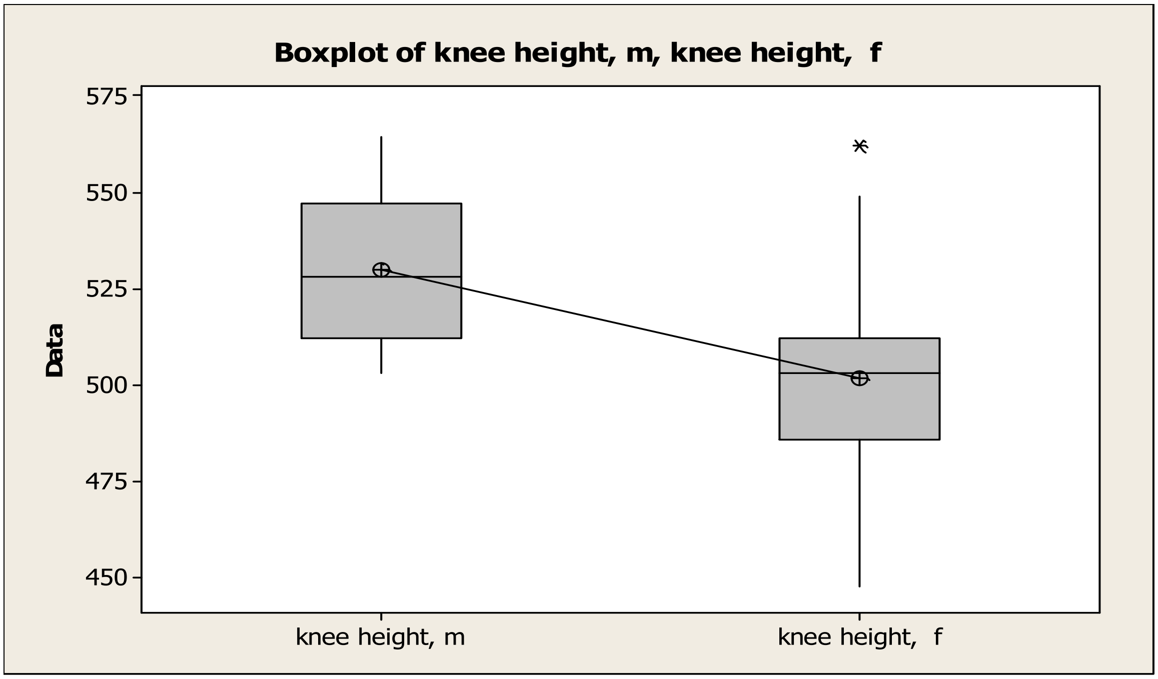


Figure C.11: Boxplot of Knee Height for both Male and Female

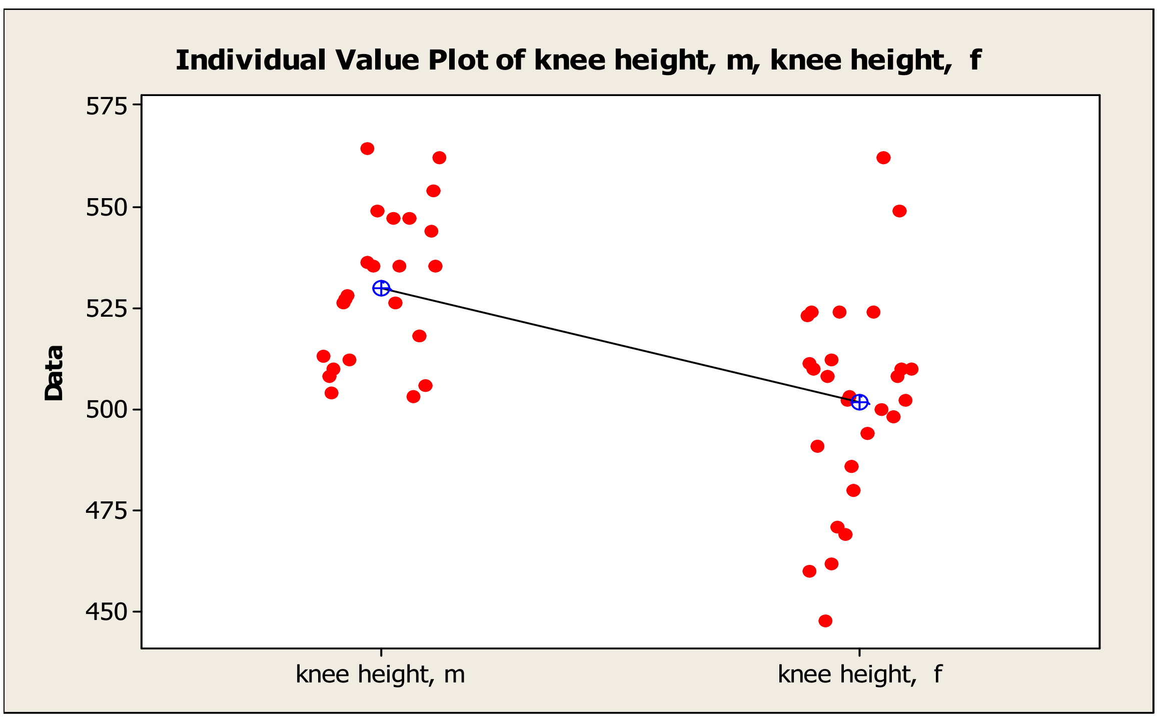


Figure C.12: Individual Value Plot of Knee height for Both Male and Female

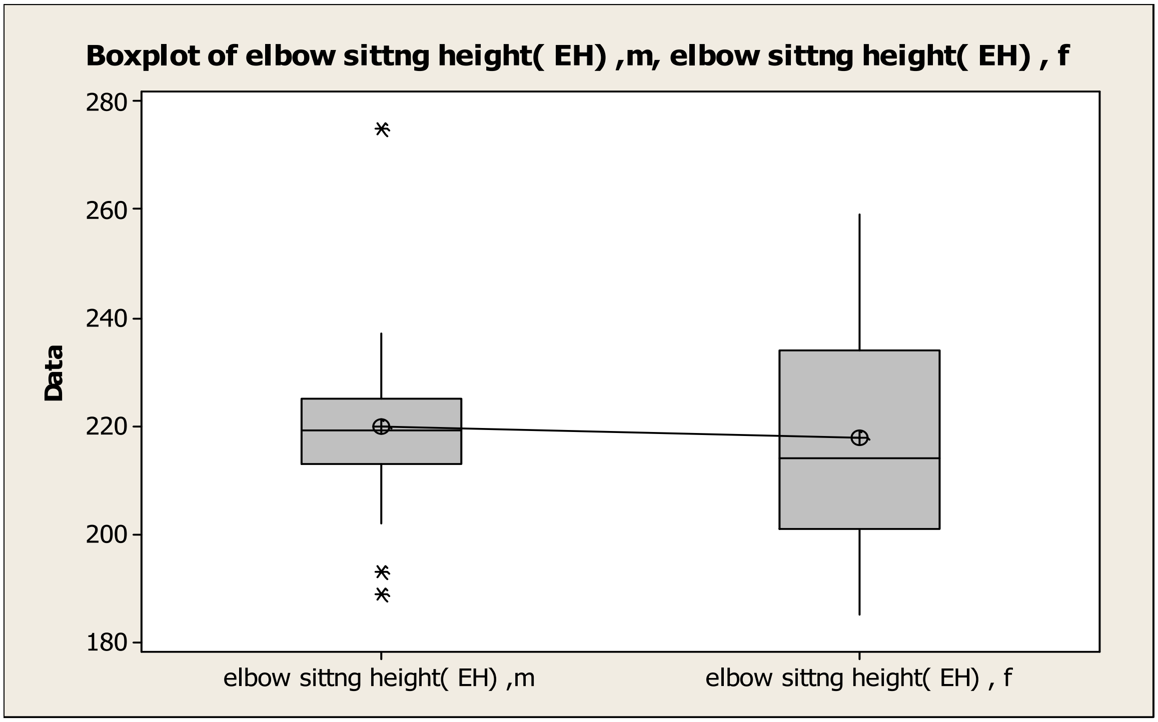

Figure C.13: Boxplot of Sitting Elbow Height for Both Male and Female

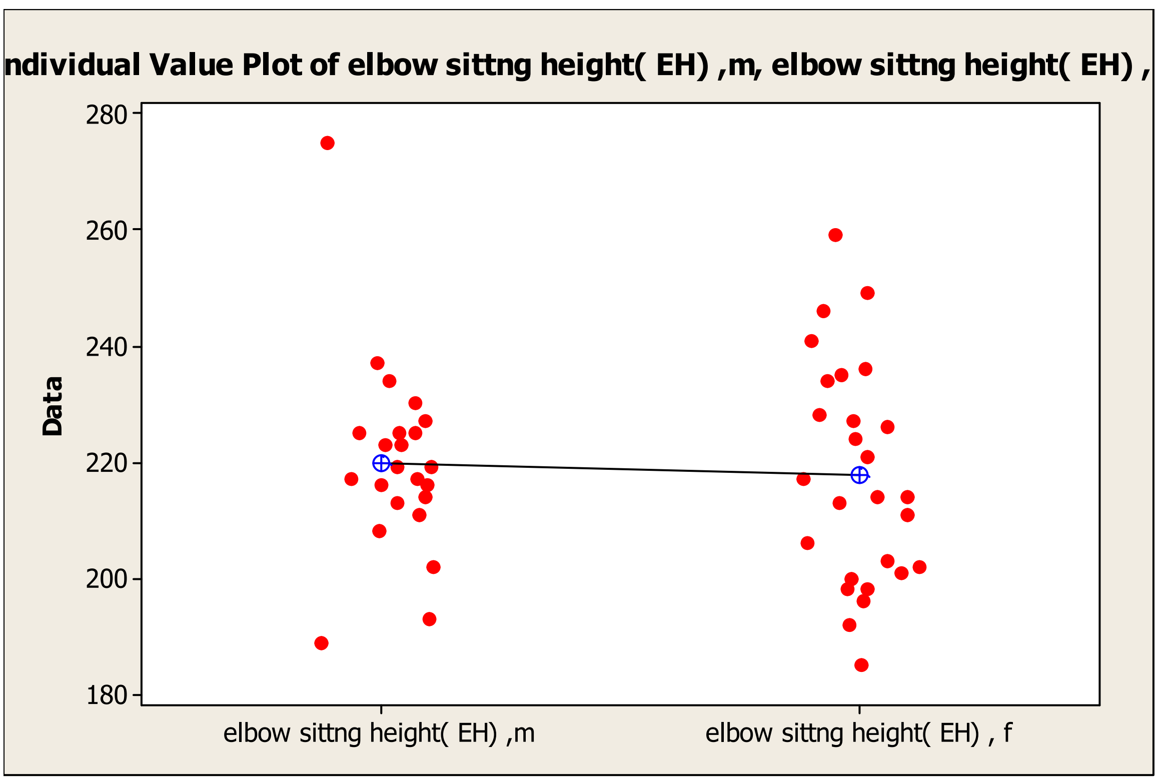

Figure C.14: Individual Value Plot of Elbow Sitting Height

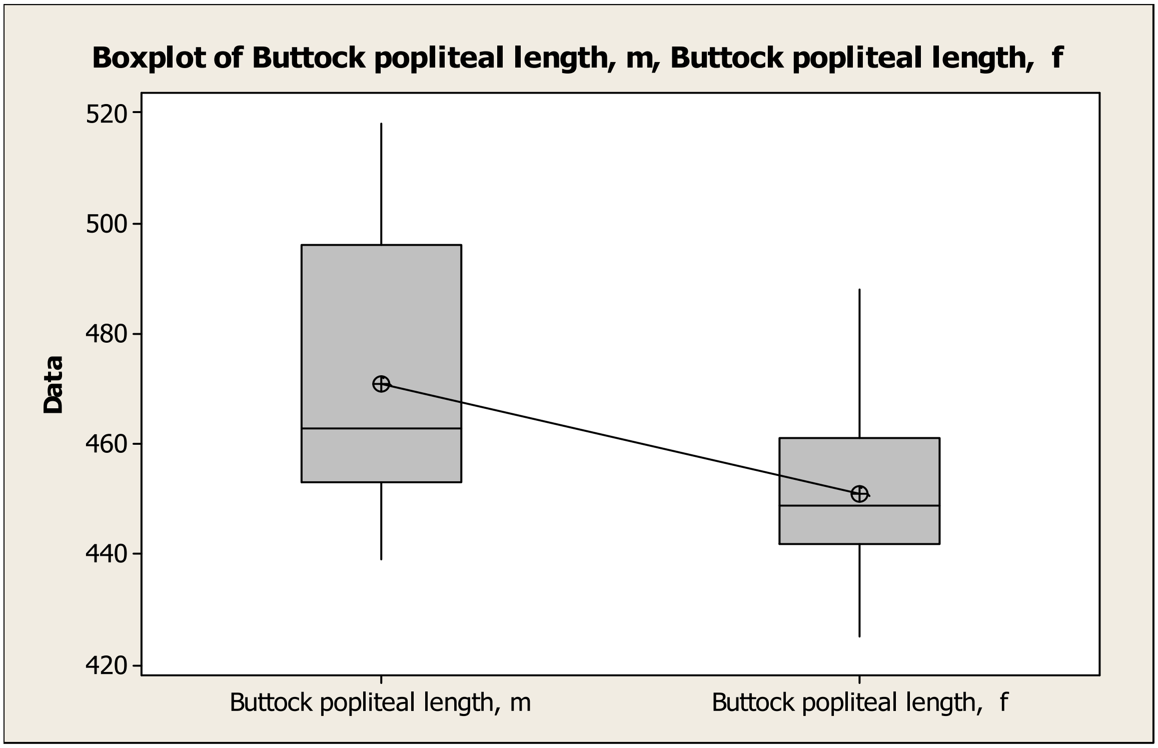


Figure C.15: Boxplot of Buttock Popliteal Length for Both Male and Female

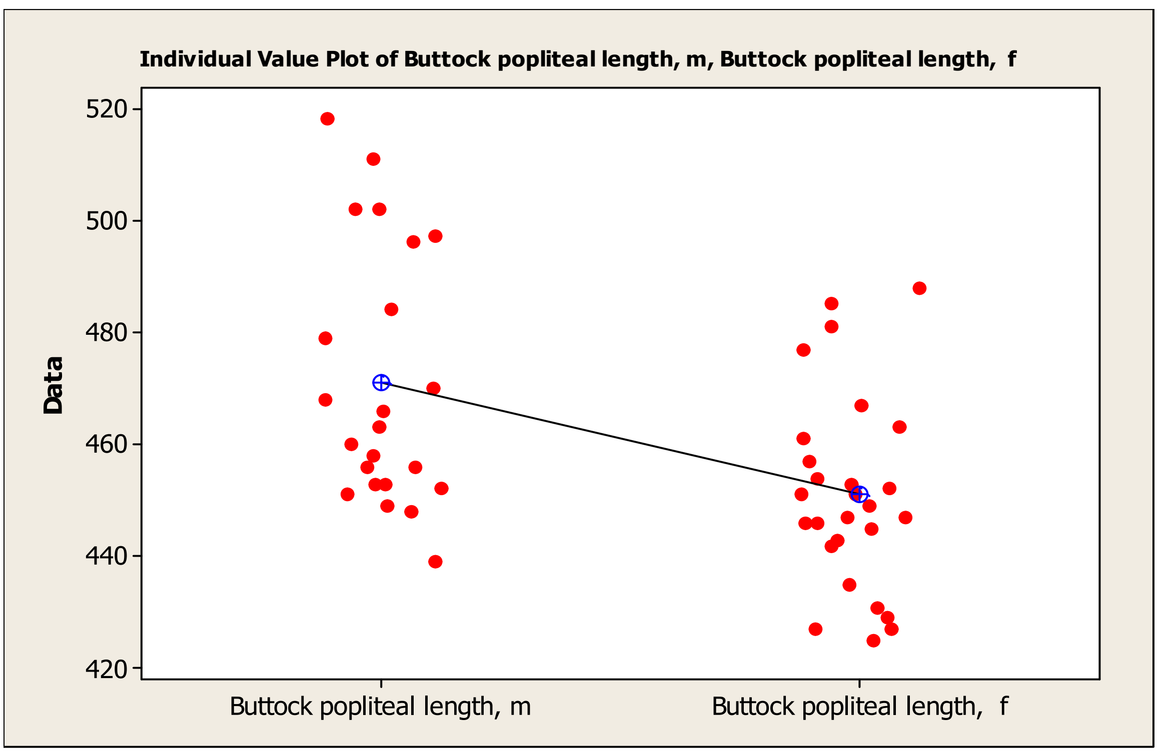


Figure C.16: Individual Value Plot of Buttock Popliteal Length

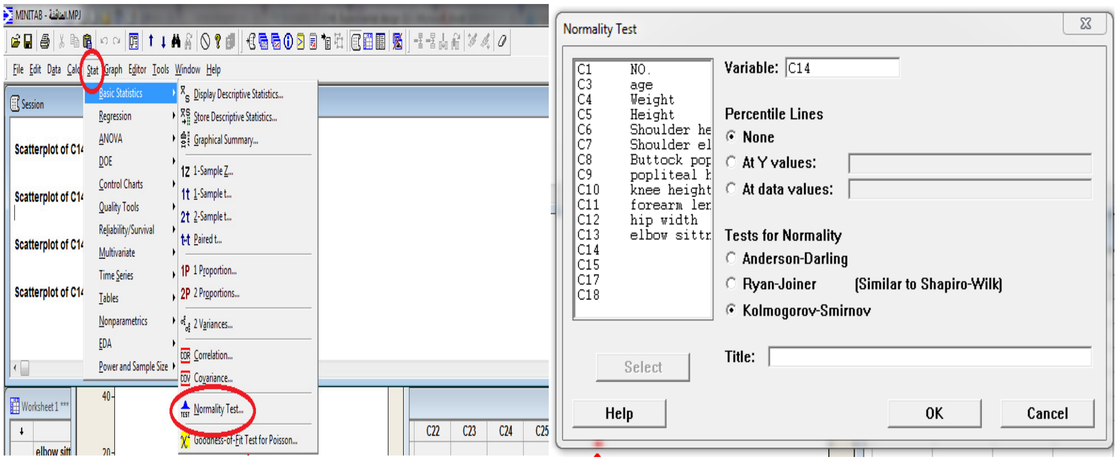

Figure C.17: The Normality Test by Minitab14

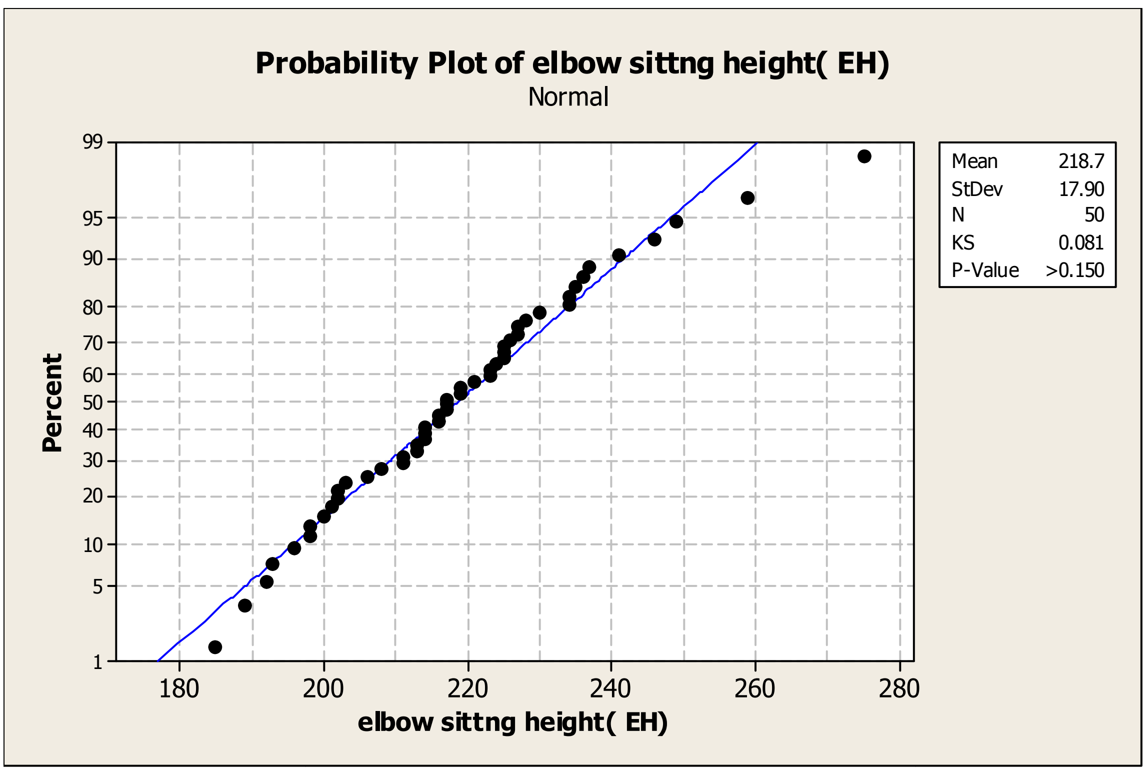


Figure C.18: Normal Probability Plot of Elbow Sitting Height

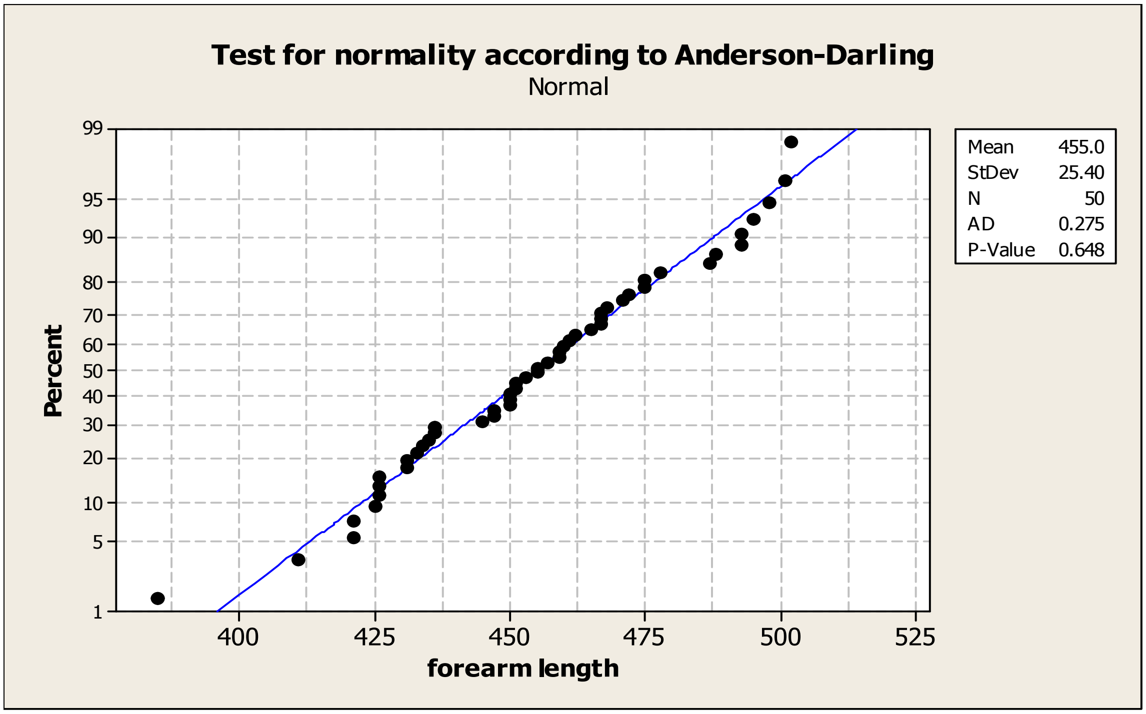


Figure C.19: Normal Probability Plot of Forearm Length

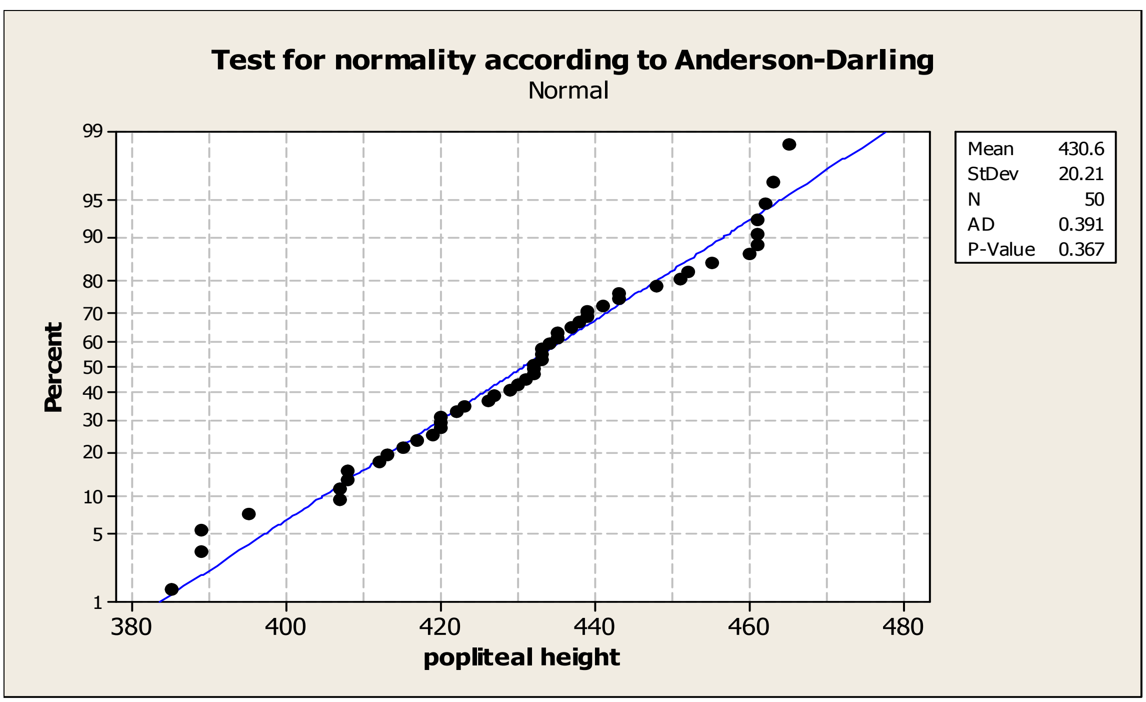


Figure C.20: Normal Probability Plot of Popliteal Height

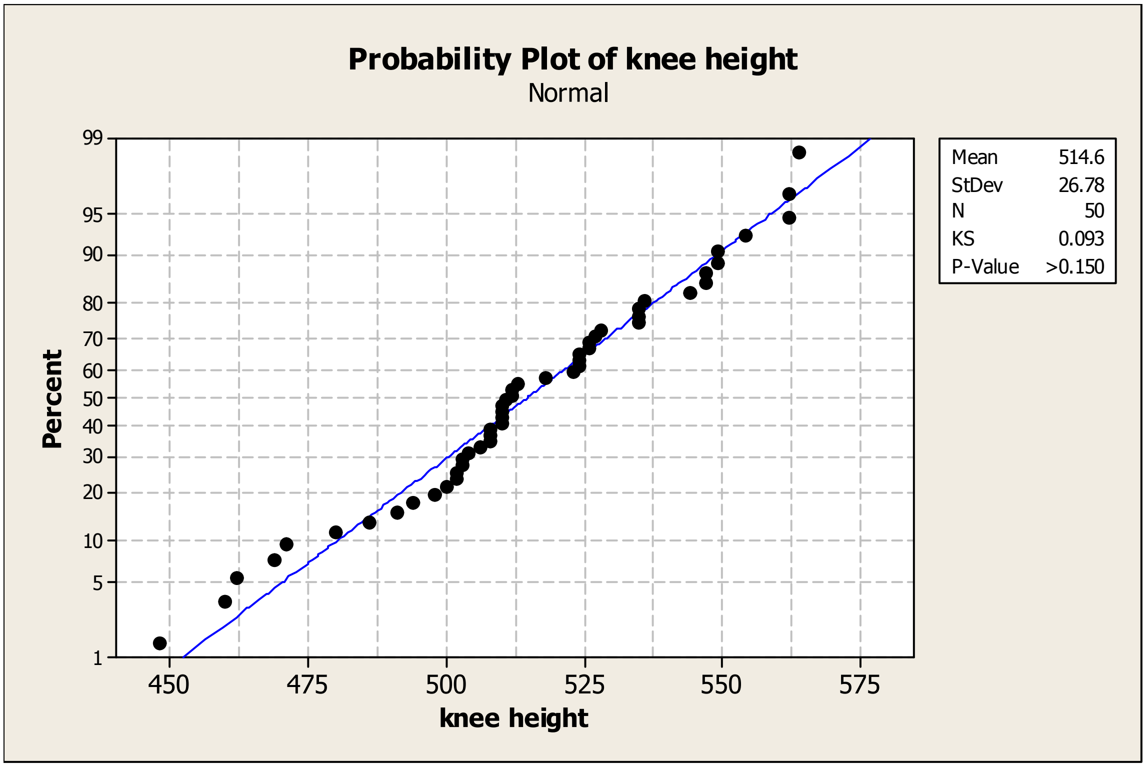


Figure C.21: Normal Probability Plot of Knee Height

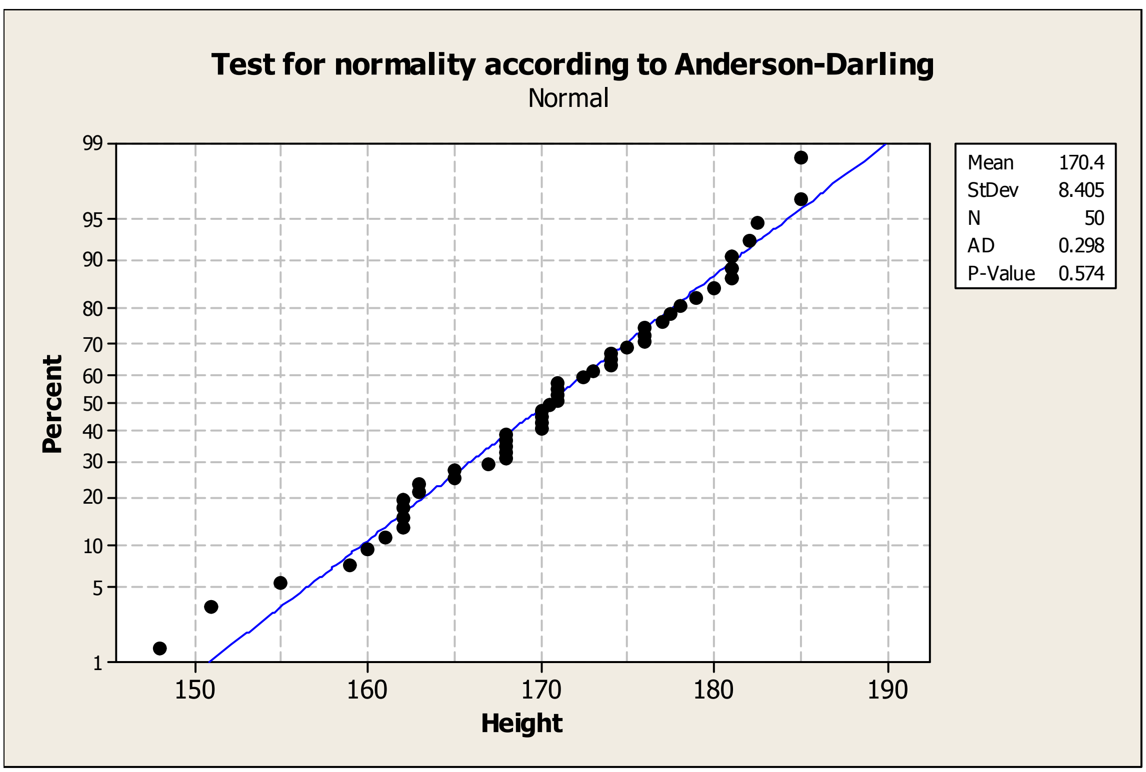


Figure C.22: Normal Probability Plot of Height

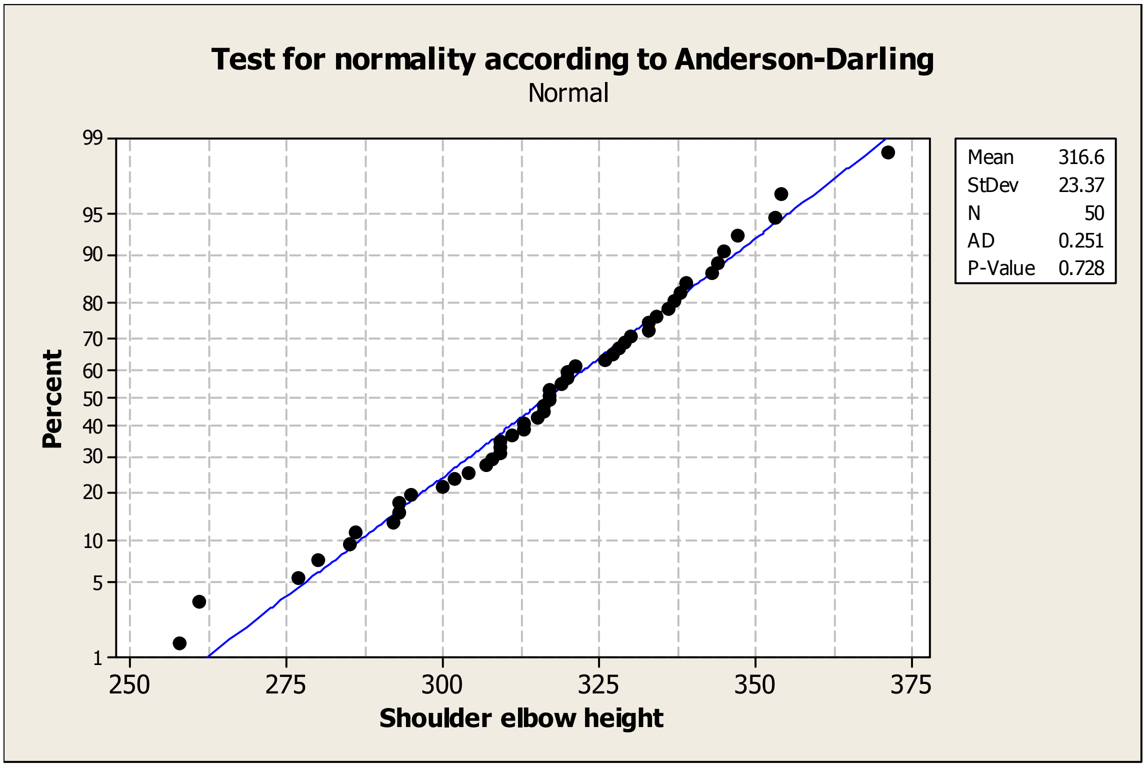

Figure C.23: Normal Probability Plot of Shoulder Elbow Height

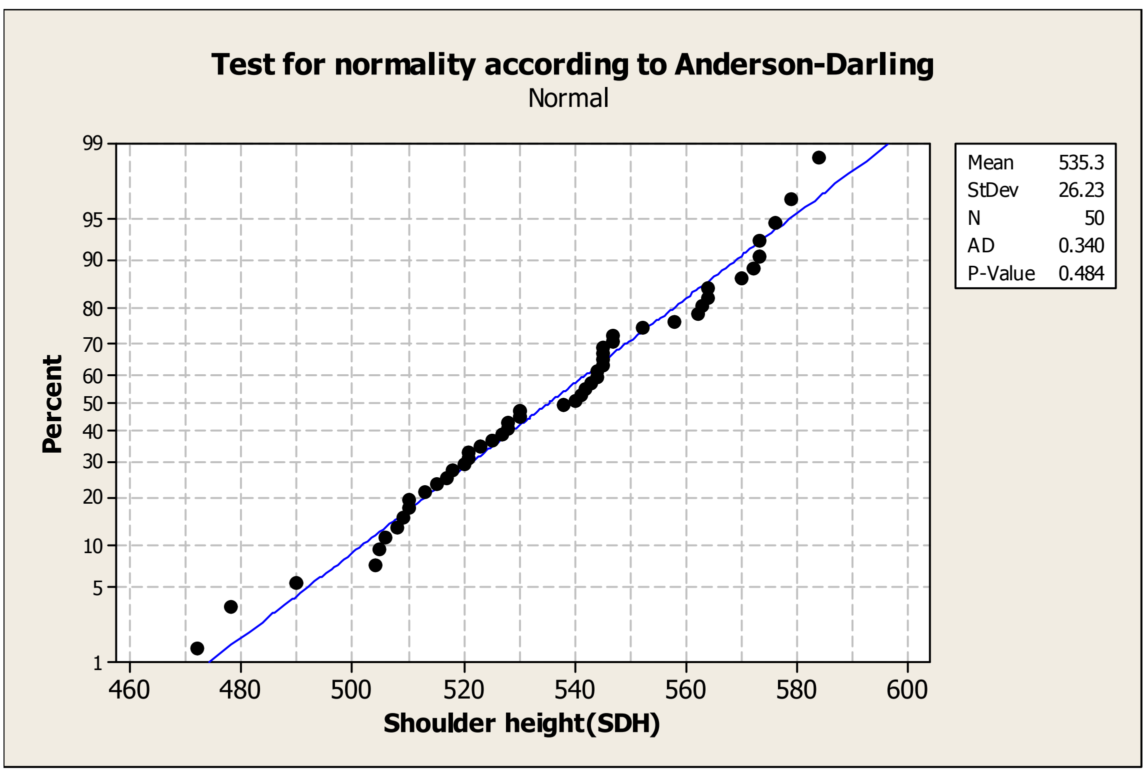

Figure C.24: Normal Probability Plot of Shoulder Height

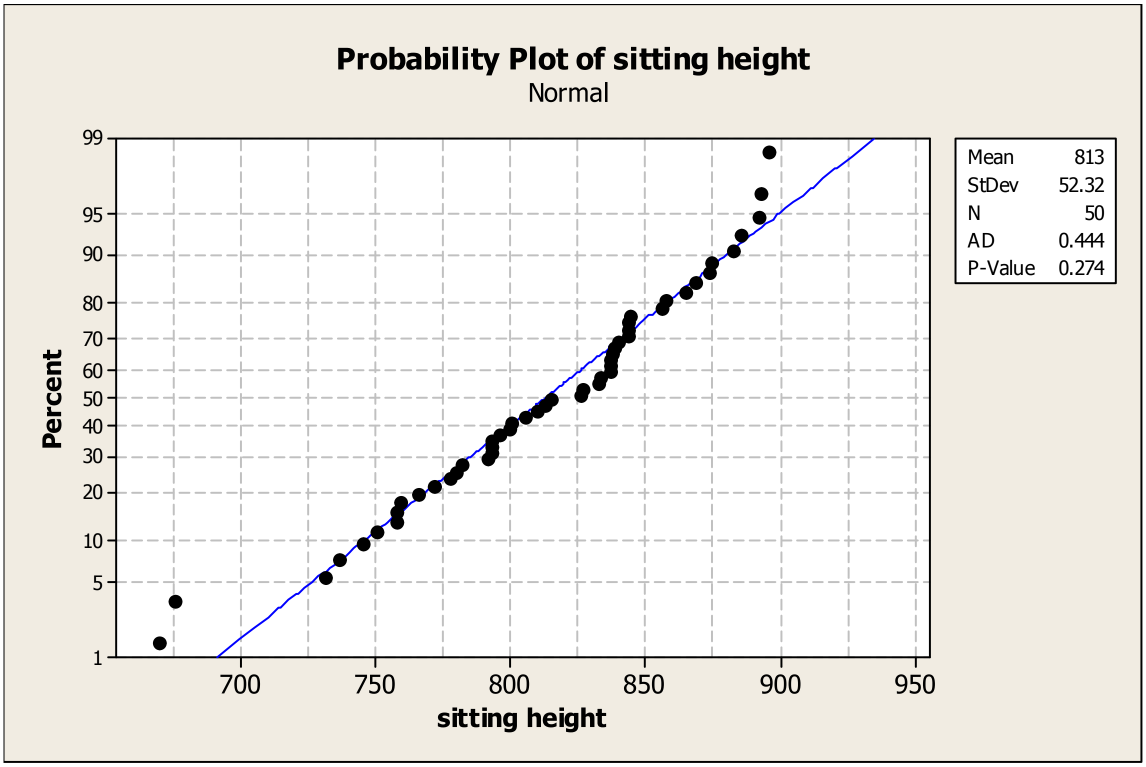


Figure C.25: Normal Probability Plot of Sitting Height

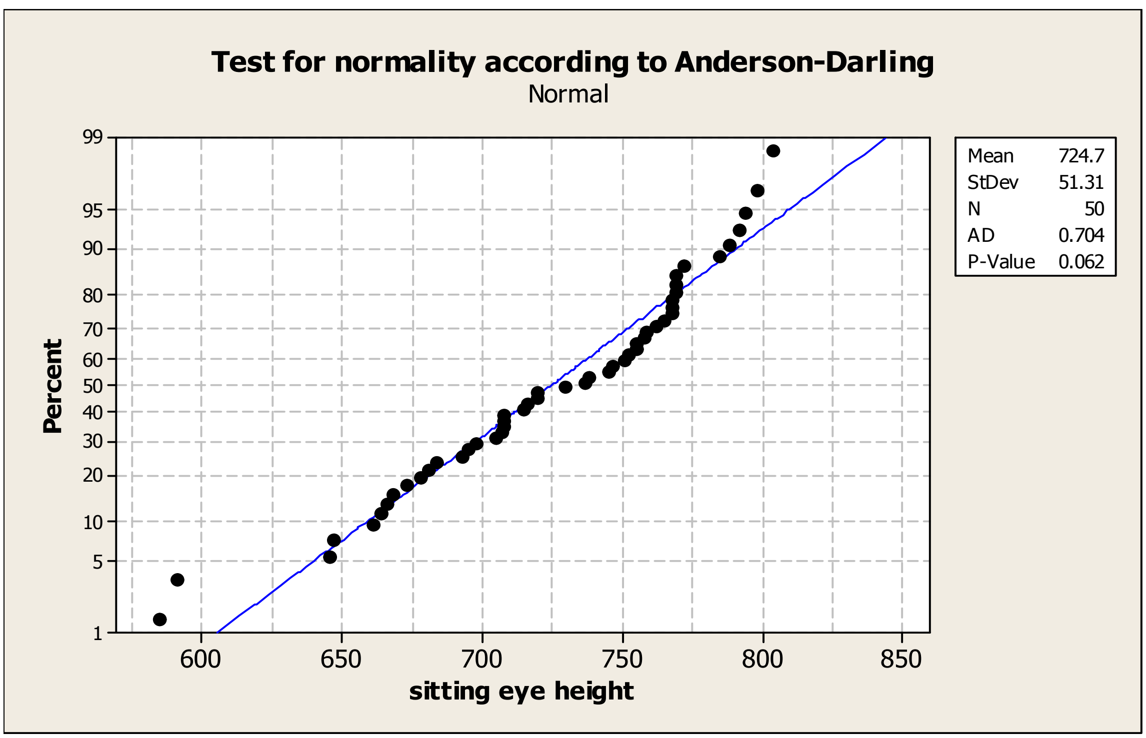


Figure C.26: Normal Probability Plot of Sitting Eye Height