ESTIMATING THE ISOMETRIC PINCH STRENGTH DISTRIBUTION OF THE POPULATION OF TURKEY

by

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ABSTRACT

ESTIMATING THE ISOMETRIC PINCH STRENGTH DISTRIBUTION OF THE POPULATION OF TURKEY

Strength norms, which show cross-national variations, are important for the design of productive and safe mechanical human work and product, and clinical purposes. Through this first-ever study, the pinch strength norms of the population of Turkey are established. The main objective of this study was to estimate the maximum voluntary isometric pinch strength distribution of healthy adult population of Turkey related to gender, age, occupation, and several anthropmetric characteristics. Another objective of the study was to investigate the effects of body posture (sitting and standing) on pinch strength. For the purpose, a sample of 223 healthy volunteer participants was recruited. The study involved both laboratory and field studies. The estimated maximum voluntary isometric pinch strength types were: lateral (key) pinch, three-jaw chuck pinch and pulp pinch for both genders and tip pinch strength for males only. In addition, maximum isometric power grip strength and a number of anthropometric measurements such as weight, height, circumference of forearm, circumference of fist and forearm-hand length were measured. The results indicate that the estimated maximum mean pinch strength values for dominant hand corresponding to seated posture for males and females, respectively in kgf are: 11 and 7.7 (lateral), 9.9 and 7 (chuck), 7.8 and 5.4 (pulp), and 7 for tip pinch for males. For all three matching pinch strengths, female strengths are about 70% of male strengths. Overall, pinch strength capacity reaches its maximum at about 40-49 year age range for males and stays stable at 18-59 year age range for females. After age 60 a dramatic decrease occurs for both genders. Manual worker group was the strongest in all age groups. Dominant hand was significantly stronger than non-dominant hand. On the other hand, the tested posture did not have any significant effect on pinch strength. Pinch strength capacity of the population of Turkey is found similar to the USA population and stronger than Chinese population.

ÖZET

TÜRKİYE NÜFUSUNUN STATİK PARMAK KAVRAMA KUVVETİ DAĞILIMININ TAHMİNLEMESİ

Ülkeler arası farklılıklar gösteren insan kas kuvveti standartları, verimli ve güvenli iş ve ürün tasarımı ve klinik amaçlar için önemlidir. Bir ilk olan bu çalışmada, Türkiye nüfusunun statik parmak kavrama kuvvet standartları belirlenmiştir. Bu çalışmanın ana amacı, sağlıklı yetişkin Türkiye nüfusunun maksimum statik parmak kavrama kuvvetini cinsiyet, yaş, meslek ve birkaç antropometrik özelliklere göre istatitiksel olarak hesaplamaktı. Çalışmanın bir başka amacı da, vücut pozisyonunun (oturarak veya ayakta) parmak kavrama kuvveti üzerindeki etkisini araştırmaktı. Bu amaçla, çalışmada 223 sağlıklı gönüllü katılımcı yer aldı. Çalışma hem laboratuvar hem de saha çalışmalarını içerdi. Hesaplanan maksimum statik parmak kavrama kuvveti türleri şunlardı: her iki cinsiyet için yanal parmak kavrama, üçlü parmak kavrama ve yassı parmak ucu kavrama; ve sadece erkekler için parmak ucu kavrama kuvveti. Buna ek olarak, maksimum statik el kavrama kuvveti, kilo, boy, önkol çevresi, yumruk çevresi ve önkol-el uzunluğu ölçüldü. Sonuçlara göre, hesaplanan maksimum parmak kavrama kuvvetleri (oturma pozisyonda baskın el için) erkek ve bayanlarda kg-kuvet olarak sırasıyla şöyledir: 11 ve 7.7 (yanal parmak), 9.9 ve 7 (üçlü parmak), 7.8 ve 5.4 (yassı parmak ucu), ve 7 (erkekler için parmak ucu kuvveti). Genel toplamda, parmak kavrama kuvveti erkeklerde 40-49 yaşları arasında maksimuma erişmektedir, bayanlarda ise 18-59 yaşları arasında hemen hemen sabit kalmaktadır. 60 yaşından sonra her iki cinsiyet için de keskin bir düşüş yaşanmaktadır. Ağır fiziki işlerde çalışanlar her yaş grubunda en güçlü idi. Baskın el, baskın olmayan ele göre önemli şekilde güçlüydü. Ayrıca, test edilen vücut pozisyonlarının parmak kavrama kuvvetleri üzerinde önemli bir etkisi olmadığı görüldü. Türkiye nüfusunun parmak kavrama kuvveti kapasitesi Amerika nüfusu ile benzer, Çin nüfusundan ise kuvvetli bulunmuştur.

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LIST OF SYMBOLS/ABBREVIATIONS

n	Sample size
μ	Overall response mean
α_i	Effect of i^{th} level for hand factor
χ_j	Effect of j^{th} level for posture factor
δ_k	Effect of k^{th} level for BMIP group factor
τ_l	Effect of l^{th} level for occupation group factor
φ_m	Effect of m^{th} level for age group factor
η_n	Effect of n^{th} block
ε_{ijklmn}	NID $(0,\sigma^2)$ random error component.
ANOVA	Analysis of variance
BMIP	Body mass index prime
CFI	Circumference of fist
CFO	Circumference of forearm
cm	Centimeter
CPS	Three-jaw chuck pinch strength
DCPSit	Dominant hand three-jaw chuck pinch strength while sitting
DCPStand	Dominant hand three-jaw chuck pinch strength while standing
DG	Dominant hand grip strength while sitting
DLPSit	Dominant hand lateral pinch strength while sitting
DLPStand	Dominant hand lateral pinch strength while standing
DPPSit	Dominant hand pulp pinch strength while sitting
DPPStand	Dominant hand pulp pinch strength while standing
DTPSit	Dominant hand tip pinch strength while sitting (for male subjects)
DTPStand	Dominant hand tip pinch strength while standing (for male subjects)
GS	Grip strength
kgf	Kilogram force
LF	Forearm-hand length
LPS	Lateral pinch strength

MANOVA	Multiple analysis of variance
MW	Manual Workers.
NDCPSit	Don-dominant hand three-jaw chuck pinch strength while sitting
NDCPStand	Non-dominant hand three-jaw chuck pinch strength while standing
NDG	Non-dominant hand grip strength while sitting
NDLPSit	Non-dominant hand lateral pinch strength while sitting
NDLPStand	Non-dominant hand lateral pinch strength while standing
NDPPSit	Non-dominant hand pulp pinch strength while sitting
NDPPStand	Non-dominant hand pulp pinch strength while standing
NDTPSit	Non-dominant hand tip pinch strength while sitting (for male subjects)
NDTPStand	Non-dominant hand tip pinch strength while standing (for male subjects)
NID	Normally and independently distributed
NMW	Non-Manual Workers
PPS	Pulp pinch strength
SE	Standard error
Std. Dev.	Standard deviation
TPS	Tip pinch strength
VIF	Variance inflation factor
yrs	Years

1. INTRODUCTION

Many tasks in industry involve the usage of upper extremity. Due to the excessive force exertions and repetitive tasks, awkward postures and inadequate rest times, work-related musculoskeletal disorders of the upper extremity occur. Moreover, these also lead to loss of productivity, loss of quality and safety. Hand is one of the main parts of the upper extremity that suffers from these disorders (Chaffin et al., 2006).

To reduce the harmful effects of high forces, the strength requirements of the tasks and limits of the workers must be known. In clinical aspect, strength capabilities of the population are also important for the treatment procedures for the patients who have disabilities caused by MSDs. Therefore, strength norms for the populations are needed for the design of manual tasks, hand tools, machines and and for clinical treatment purposes (Ekşioğlu and Silahlı, 2009).

One of the most difficult task types in industry is the pinching tasks. Fingers and hands are used in many tasks such as meat processing, packaging, automobile upholstering, electronics assembly, etc. Moreover, dentists also use hand tools which need high pinch force application. Because of high pinch forces required, these types of jobs usually lead to cumulative trauma disorders. Powerful or repetitive hand and finger activities are linked to the incidence of cumulative trauma disorders of the hand such as carpal tunnel syndrome, trigger finger, etc. Therefore, to reduce the harmful effect of high forces, the strength requirements of the tasks and the limits of the workers should be known (Imrhan, 2008).

Muscular hand strength norms are required for designing safer hand tools or machines that are controlled manually. Strength norms are also important for the clinical purposes. The effectiveness of treatment procedures are tied to the valid and reliable strength norms (Eksioglu and Silahlı, 2009). To determine which level of force is excessive, the strength norms of the population must be known. People have different strength levels. Therefore, the distribution of strength data is important in designs to cover the most of the population.

In literature, types of pinch are generally classified as tip pinch, pulp pinch, three-jaw chuck pinch and lateral (key) pinch. In tip pinch, the tip of thumb opposes the tip of another finger of the same hand. The pad of the thumb opposes the pad of another finger in pulp pinch. Chuck pinch is similar to pulp pinch except that thumb opposes the pads of index and middle fingers together. In lateral pinch strength, the thumb opposes the radial lateral aspect of index finger in the clenched fist (Imrhan, 2008; Mathiowetz et al., 1985).

Pinch strength capacity can be affected by a number of factors such as type of pinch, position of the wrist, position of upper arm and shoulder, support of forearm, repetition of the task, age, gender, occupation, geographical region, race, anthropometric measures, etc. There are many studies in literature which investigate the effects of these factors on pinch strength.

In order to compare the results with the other researchers in literature, a standard test procedure was followed in all of the measurements. The experiments were mainly conducted at Boğaziçi University Ergonomics Laboratory. Some were conducted at different places which are organized to have similar testing conditions as the laboratory.

The main aim of this study is to obtain normative pinch strength data for the population of Turkey. In addition, the effects of gender, age, occupation, dominant/non-dominant hand, sitting/standing posture, and some anthropometric measurements on pinch strength are investigated.

The thesis is organized as the following: Chapter 2 includes a literature review of previous studies that are conducted on pinch strength. In chapter 3, rationale behind the study is mentioned. Chapter 4 contains the objectives of the study. In Chapter 5, the methodology of the study is explained in detail. Chapter 6 presents the general and statistical results of the study in detail. In Chapter 7, the discussion on the results is included. Moreover, comparisons with other studies in literature are involved. In the last chapter, the conclusions of the study are mentioned.

2. LITERATURE REVIEW

Strength measurement is a widely researched area in ergonomics field. The determination of strength norms for populations is an important part of this area and many researchers conducted normative data studies on sample populations.

In this section, general information on muscle strength, strength types, pinch strength are mentioned. In addition, the studies that are conducted on hand strength and pinch strength are included.

2.1. Strength

Strength capacity of a population is very important in designing the tasks and equipments. It can be defined as the application of force or torque by a body segment to an outside object and it is usually interpreted in Newton unit (Kroemer, 1999).

Strength assessment can provide a method for managers to decide whether a person is capable of performing a job without having an injury (Chaffin 1975). Also, the assessment of strength is important for clinical treatment methods. Therefore, strength assessments of populations are needed for designing tasks, tools, machines and for clinical purposes.

In order to understand strength, one has to learn about the mechanism and physiology of muscles and muscle strength.

2.1.1. Physiology and Working Mechanism of Muscles

Engineers are interested in skeletal muscles because one of the main functions of skeletal muscles is to move body segments. These muscles connect two or more body links across their joints. When the muscles are activated they pull on the bones and as a result movement or exertion of force to an object happens (Kroemer 1999).

The only action that a muscle can take is to contract (Kroemer 1999). When nerve impulses come to the muscle by the motor units, the muscle starts to contract. As a result of this contraction a tension in the muscle is created. This tension can be active or passive. Active tension occurs when the muscle contracts concentrically and a muscle can shorten to at most 60% of its resting length. However passive tension occurs when muscle is lengthened beyond its resting length. This can happen by external forces such as gravity or the action of an antagonist muscle. The tension of the muscle depends only on its active contraction when it's below its resting length whereas the total tension of the muscle is the active contraction plus passive strain when the muscle is above its resting length (Kroemer 1999).

Muscles need energy to be able to work properly and this energy is supplied by blood vessels. When muscles contract they make a pressure on these blood vessels and this pressure interrupts the blood circulation. A strong pressure (strong contraction) means a higher interruption in circulation thus leading to muscle fatigue (Chaffin et al., 2006).

Fatigue can be defined as the inability of a muscle to maintain its contraction and it is caused by the interruption of blood circulation during muscle contraction. The more the pressure is, the quicker the fatigue occurs. Therefore, a maximal contraction can be maintained only for a few seconds whereas sustained force exertion is possible when muscle tension is at low level (Kroemer 1999).

The factors that influence the ability of a muscle to produce tension are described as the following (Chaffin *et al*., 2006):

(i) Number of muscle fibers that contract: Each fiber in the muscle contracts with a certain force and the total force of all fibers in the muscle creates the muscle strength. The more the number of muscle fiber the more the strength.

(ii) Length and size of the muscle: A muscle produces the maximum active strength when it is near its resting length. The ability to produce force declines as the muscle gets shortened. Moreover beyond the 120-130% of resting length, the active strength is also reduced.

(iii) Frequency of exciting signals: The signals reaching the motor units provide the muscle tension. A single twitch or frequent twitches affect the tension generated by the muscle.

(iv) Muscle fatigue: When fatigue occurs in a muscle, the strength capability decreases.

2.1.2. Types of Muscle Strength

Muscle strength can be divided into two groups according to the type of force being applied and the movement of the body parts which the force is applied.

<u>2.1.2.1. Static (Isometric) Muscle Strength.</u> Isometric muscle strength is the capacity of muscles to produce force or torque by a single maximal voluntary exertion. The body segments remain motionless and muscle length doesn’t change in static strength. Therefore, measuring static strength is rather easy and controllable. (Mital and Kumar, 1998).

There are a number of factors which influence the isometric muscle strength (Eastman Kodak Company, 1983; Mital and Kumar, 1998). Some of these factors can be listed as the following:

- Body posture
- Duration of force exertion
- Rest periods between exertions
- The measurement device
- Test conditions and subject type (gender, age, fitness level etc).
- Anthropometry
- Protocols and procedures

In measuring static strength, the experimenter must be aware of the fact that there is a small time delay between the command to exert force and the development of peak force. This delay is due to some biomechanical, physiological and psychomotor factors. Studies show that maximum contraction is reached after 1 second of force application and the average value between the 1st and 4th seconds give a good estimate of the peak force (Eastman Kodak Company, 1983).

2.1.2.2. Dynamic Muscle Strength. The length of muscles change and the body segments move or rotate in dynamic force exertion. The difference between static and dynamic strength is that dynamic strength involves the movement of the objects being held. From the biomechanical perspective, motion of body segments requires more muscle force to overcome inertia and accelerate the body segment masses (Chaffin, 2006).

From industrial perspective, the tasks that include dynamic force application are more common. Dynamic strength can be mainly classified to three types (Chaffin, 2006):

- Isoinertial strength: In this type of strength, constant external loads are moved.
- Isokinetic strength: In this type of strength, the velocity ot the movement at the joint is held constant.
- Isotonic strength: In this type of strength, muscle tension is held constant while velocity is changed.

The measurement of dynamic strength has many difficulties. The main problems are the change in muscle length and acceleration of load (Eastman Kodak Company, 1983). Because of these difficulties, static strength tests are mostly used instead of dynamic strength tests.

2.2. Pinch Strength

In many tasks in industry hands are actively used. One kind of action that is used in these manual tasks is the usage of fingers in opposition to the thumb. This action is defined as the application of pinch force (Imrhan, 2008).

Pinch strength was widely investigated by the clinical field for assessing hand functions. Ergonomic studies on pinch strength are also published which investigate the relationship between pinch strength and work-related cumulative trauma disorders (Imrhan and Rahman, 1995).

Voluntary contraction for pinch force is influenced by many factors. Some of the significant factors can be listed as the following:

- Type of pinch
- Gender
- Age
- Occupation
- Anthropometry (height, weight, hand-arm dimensions)
- Hand dominance
- Arm posture (upper arm, forearm, wrist and hand postures)
- Pinch width
- The protocols and instructions that are used

Using a standard protocol is very important in the strength measurement studies. Because a standard protocol provides researchers to determine the method of measurement, the characteristics of sample, the instructions given to the subjects, etc. Moreover, it also helps the experimenter to obtain reliable results and gives the ability to compare results with other researchers who have also used the same protocol.

American Society of Hand Therapists introduced a standard testing position for measuring static hand strength and many researchers in literature have used this position in their experiments (Innes, 1999). This testing position is described below:

- Sitting in a straight-backed chair
- Shoulder adducted and neutrally rotated
- Elbow flexed at 90 degrees
- Forearm in neutral posture and not supported
- Wrist at 0 – 30 degrees extension and 0 – 15 degrees ulnar deviation.

Caldwell *et al*. (1974) proposed a standard procedure for static muscle strength testing. According to this protocol, at the beginning of a testing session, the subject should be informed about the objectives of the study and the procedures. Instructions should be given to the subjects during the experimentation period. The subject should start with the instructor’s “increase to maximum exertion (without jerking) in about one second and maintain the maximum effort for four seconds” command. During the experiments no feedback should be given to the subjects and competition or other factors which can affect the subject’s performance should be avoided. There should be at least a two minute break between the trials and when the trials are not within 10% variation, the test should be repeated until it meets this condition. After the experiments are completed, the results should include the data about the sample size, the subjects’ characteristics and the testing conditions. Moreover the statistical results such as mean, standard deviation, minimum and maximum values and skewness of the data should also be included.

Another ergonomics guide for human static strength measurements was mentioned by Chaffin (1975). His recommendations for static strength assessment procedure included mainly eight steps and these steps are defined as below:

- Exertion Duration: A person should maintain his/her exertion for at least three seconds to reach a steady state maximum voluntary exertion.

- Strength Measuring Device: The measurement device should not cause discomfort when applying force because discomfort during force exertion can affect the person’s performance. Moreover, a good instrument should give the average of the applied force or torque during steady state.

- Rest Periods: A two minute rest period is adequate when 15 measures are taken and a minimum of 30 seconds is necessary if only a few measures are taken.

- Body Position: To obtain valid strength estimates, body posture during the experimentation must be specified and controlled.

- Subject Instructions: Subjects must be informed about the intent of the study, the risks and the procedure. To minimize variations due to motivational effects, the subjects must be instructed in an objective tone, and anything that affects the subject emotionally must be forbidden.

- Reporting Test Conditions: In order to obtain comparable results, the testing conditions must be well defined.

- Reporting Subject Biographic Data: A strength assessment study should contain the characteristics of the sample chosen. Age, sex, relevant anthropometric data, health status, sample size, etc. should be covered in the study.

- Reporting of Strength Data: Some statistical results such as mean, median, standard deviation, skewness, minimum and maximum values of the data should be included in the results of the study.

2.3. Pinch Strength Studies

Mathiowetz *et al*. (1985) made a normative data research for grip and pinch strength. They used a very large sample (310 males, 328 females) and measured tip, chuck and key pinch strengths. Subjects were divided into age groups and according to the results the average pinch strength was relatively stable between 20 – 59 years and decreased after 60 years old.

One of the earliest studies in static pinch strength is made by Imrhan and Loo (1989). Their study consisted of 182 subjects whose ages ranged from 5 to 89. Lateral pinch, chuck pinch and pulp 2, pulp 3, pulp 4, pulp 5 pinch forces were measured. Results indicated that lateral pinch strength was highest, which was followed with chuck strength and the weakest was the pulp pinch strength in all of the age and gender groups with small exceptions. In general, pinch strength was found to be highest in adults and lowest in children. Moreover, females found to be weaker than males.

Young *et al*. (1989) also analyzed the distribution of key pinch strength in a sample that includes 95 subjects. The subjects were aged between 18 – 67 and the highest strength values were obtained from the group of 18 – 27 years. Pinch strength decreased with age. In addition, there was a significant difference between the female and male results that males were stronger than females.

Another normative data study was made by Crosby and Wehbe. (1994). Key and pulp pinch measurements were taken from a sample of 214 subjects. Key pinch strength was found to be stronger than pulp pinch strength in their study. Moreover, males were found to be stronger than females.

The effect of wrist and arm postures on pinch strength was investigated widely in literature. In one of these studies the effect of wrist posture on pinch strength was examined (Imrhan, 1991). The results showed that deviated wrist postures decreased the pinch strength and maximum pinch strength was maintained when wrist was in neutral posture.

Wrist posture effect was also investigated by Fernandez et al. (1991). A limited sample of 15 male subjects was used in the experiments and the measured pinch strengths were tip, pulp, chuck and key pinches. Results implied that pinch strength was decreased under deviated wrist postures.

In another research (Halpern and Fernandez, 1996); lateral, chuck and tip pinch measurements were taken from twenty male subjects. Many different forearm, wrist and elbow postures were used in the experiments and results indicated that deviated wrist or forearm postures decreased the pinch strength. Maximum strength was maintained when the elbow was 90 degree flexed.

Forearm position was found to be effective in maximum voluntary pinch strength by Jansen et al. (2003). Their results indicated that key and tip pinch strengths were affected by forearm position but the effect in chuck pinch was not found significant.

Lau and Ip (2006) investigated the difference between non-manual workers and manual workers for lateral pinch strength. They found out that there wasn’t a significant difference between these groups for the dominant hand.

Many studies in literature investigated the effect of dominant and non-dominant hand (Young, *et al*., 1989; Lau and Ip, 2006; Jansen, *et al*., 2003). The results revealed that using dominant hand results in higher pinch strength.

Standardized pinch tests are done under restricted conditions so sometimes they may not reflect the real working conditions. For example the testing equipments usually have a limited surface and a standard pinch width. Some researchers (Dempsey and Ayoub, 1996; Imrhan and Rahman, 1995) have investigated this issue and they found that pinch width had an important effect on pinch strength. Imrhan and Rahman (1995) concluded that large pinch widths reduce pinch strength sharply but small-to-moderate widths do not have a strong effect on pinch strength.

A summary of pinch strength studies and some of their results are given in Table 2.1 and Table 2.2.

Table 2.1. Summary of studies in literature

Source	Population	Sample type (Size, Gender, Age)	Measure used	Instrument	Posture	Measured strength	Anthropometric measures taken	Rest/Squeeze
Dukelow (1996)	USA	88 female,17 male Age: 75 – 96	Mean of three trials	▪ Jamar dynamometer ▪ Pinch meter	▪ Shoulder and forearm neutral, elbow 90◦ ▪ Seated, without support ▪ Both dominant and non dominant hand.	▪ Hand grip ▪ Three-jaw chuck pinch ▪ Lateral pinch ▪ Tip pinch	None	Not mentioned.
Medley (1991)	USA	40 females 20-homebound 20-normal Age: 70 - 79	Mean of three trials	▪ Jamar dynamometer ▪ B & L pinch gauge	▪ Seated, ▪ Shoulder adducted and neutrally rotated, ▪ Elbow flexed at 90 degrees, ▪ Forearm neutral, ▪ Wrist between 0-30 extension and 0-15 ulnar deviation ▪ Only dominant hand	▪ Hand grip ▪ Grip strength ▪ Palmar(chuck) pinch	None	30 sec rest between trials
Lau and Ip (2006)	China	64 males (Non-manual and manual workers)	Mean of three trials	▪ Jamar dynamometer ▪ Pinch meter	▪ Seated, ▪ Shoulder adducted and neutrally rotated, ▪ Elbow flexed at 90 degrees, ▪ Forearm neutral, ▪ Wrist between 0-30 extension ▪ Both dominant and non dominant hand	▪ Power grip ▪ Lateral pinch	None	Squeeze 3 sec., Rest 3 sec.
Mathiowetz et al. (1985)	USA	628 subjects (310 men – 318 women) 20 to 94 years of age 12 age groups of 5 year intervals (except 75+)	Average of 3 successive trials	▪ Jamar dynamometer ▪ B & L pinch gauge	▪ Seated ▪ Shoulder adducted and neutrally rotated ▪ Elbow flexed at 90 degree ▪ Forearm in neutral posture ▪ Wrist between 0 and 30 degree dorsiflexion and between 0 and 15 degree ulnar deviation ▪ Both dominant and non-dominant ▪ Forearm was not supported	▪ Hand grip ▪ Tip pinch ▪ Key (lateral) pinch ▪ Three-jaw chuck (palmar) pinch	None	Not mentioned.
Jansen et al. (2003)	USA	135 subjects (44 males, 91 females) Aged between 20 and 88 3 age groups (20-39, 40-59, 60+)	▪ First of three trials ▪ Mean of three trials ▪ Highest of three trials	▪ B & L pinch gauge	▪ Seated ▪ Shoulder adducted and neutrally rotated ▪ Elbow flexed at 90 degree ▪ Wrist between 0 and 20 degree dorsiflexion ▪ Forearm: Neutral, supinated, pronated ▪ Forearm was not supported ▪ Both hands	▪ Key pinch ▪ Pulp pinch ▪ Three-jaw chuck pinch	None	Rest:30 sec.

Table 2.1. Cont'd

Yuh-Chuan Shih and Yu-Chin Ou (2005)	Taiwan	30 subjects (15 males – 15 females) Students were participated	Using the first 10 points a confidence interval is calculated. Then 5 consecutive trials which exceeded the upper bound of interval was obtained and the first of them was chosen as MVC.	▪ Fabricated pinch gauge	▪ Sitting ▪ Upper arm extended with an angle of about 25 degrees ▪ Elbow angle was near 110-120 degree ▪ Palm was toward medial position ▪ Forearm is supported by the table ▪ Dominant hand	▪ Chuck pinch	▪ Age ▪ Weight ▪ Height ▪ Hand length ▪ Palm length ▪ Palm breadth ▪ Circumference of forearm(relax) ▪ Circumference of wrist ▪ Circumference of palm ▪ Thumb index distance ▪ Thumb middle distance	Squeeze:3-5 sec Rest:2 min.
Imrhan (1991)	USA	30 male subjects Age: 18 – 50	One contraction per measurement	▪ Best models pinch gauge ▪ LaFayette handgrip dynamometer	▪ Sitting ▪ Only dominant hand ▪ 5 different wrist positions: ▪ Natural, radial deviation, ulnar deviation, dorsi-flexion, palmar flexion ▪ Arm in sagittal plane, ▪ Hand is at shoulder height ▪ Elbow is about mid-range	▪ Hand grip ▪ Lateral pinch ▪ Three-jaw chuck pinch ▪ Pulp-2 pinch ▪ Pulp-3 pinch	▪ Stature ▪ Weight ▪ Hand length ▪ Hand breadth ▪ Wrist circumference	Rest: 3 min.
Imrhan and Loo (1989)	USA	182 subjects 5-12 years (62) 18-40 years(70) 60-89 years(50)	Peak value of each contraction	▪ Preston pinch meter ▪ Stoelting handgrip dynamometer	▪ Sitting ▪ Only dominant hand ▪ Elbow flexed at 90 degree ▪ Forearm in midpronated/supinated ▪ Wrist undeviated ▪ Shoulder flexed at about 30 degree with humerus close to sagittal plane but slightly abducted	▪ Handgrip ▪ Lateral pinch ▪ Three-jaw chuck pinch ▪ Pulp pinch(for each digit)	▪ Age ▪ Gender ▪ Stature ▪ Body weight ▪ Hand length ▪ Hand breadth	Rest: 1,5 - 3 min.
Hallbeck and McMullin (1993)	USA	15 M, 15 F Ages: 20-25 40-45 60-65		▪ Vital Signs hand dynamometer ▪ B&L pinch gauge	▪ Standing ▪ Shoulder adducted ▪ Elbow 90 degree ▪ Forearm at neutral posture ▪ Wrist : neutral/ 45° extension/ 45° flexion/ 65° extension/ 65° flexion ▪ Both hands	▪ Power grasp ▪ Chuck pinch	None	Squeeze: 4 sec Rest: 1 min.

Table 2.1. Cont'd

Fernandez et al. (1991)	USA	15 male students	Not mentioned.	▪ Jamar hydraulic handgrip dynamometer ▪ ENG pinch strength gauge	▪ Sitting ▪ Elbow adducted and 90 degree flexed ▪ Wrist: neutral, ½ of max flexion, ½ of max extension, max flexion, max extension ▪ For pulp pinch, other fingers were extended; for tip, lateral and chuck pinch, other fingers were flexed.	▪ Hand grip ▪ Tip pinch ▪ Pulp pinch(for each digit) ▪ Chuck pinch ▪ Lateral pinch	▪ Age ▪ Hand length ▪ Breadth at metacarpal ▪ Breadth at thumb ▪ Thickness at metacarpal ▪ Circumference at wrist ▪ Maximum flexion ▪ Maximum extension	Not mentioned.
Crosby and Wehbe (1994)	USA	214 subjects 105 male 109 female Age: 16 – 63	One trial	▪ Jamar dynamometer ▪ Pinch gauge	▪ Both hands ▪ Shoulder adducted and naturally rotated ▪ Elbow at 90 degree flexion ▪ Forearm in neutral posture	▪ Hand grip ▪ Pulp pinch ▪ Key pinch	None	Not mentioned.
Young et al. (1989)	USA	95 subjects 61 women 34 men Age: 18 – 67	Mean of three successive trials	▪ Jamar dynamometer ▪ Preston Pinch gauge	▪ Sitting ▪ Shoulder adducted ▪ Elbow at 90 degree flexion ▪ Wrist in neutral posture ▪ Both hands	▪ Hand grip ▪ Key pinch	None	Not mentioned.
Mathiowetz et al. (1985)	USA	29 college women	Mean of three successive trials	▪ Jamar dynamometer ▪ B&L Pinch gauge	▪ Sitting ▪ Shoulder adducted ▪ Elbow at 90 degree flexion and full extension ▪ Wrist between 0 and 30 degree dorsiflexion and between 0 and 15 degree ulnar deviation ▪ Both hands ▪ Pinch gauge and dynamometer was held by the experimenter ▪ Forearm not supported	▪ Hand grip ▪ Key pinch	None	Not mentioned.
Catovic et al. (1989)	Yugoslavia	46 males Age:20-26	Mean of 5 sec. trial period	Gripping device with strain gauges	▪ Sitting / standing ▪ Foream supported / unsupported ▪ Elbow 90 degree	Pinch grip (all fingers/ 1st and 2nd fingers /1st and 3rd fingers)	None	Squeeze: 5 sec.
Catovic et al. (1991)	Yugoslavia	77 female dentists Age: 25-50	Mean of 5 sec. trial period	▪ Gripping device with strain gauges	▪ Standing / Sitting ▪ Elbow 90 degree ▪ Forearm supported/ unsupported ▪ Wrist neutral	Pinch grip (all fingers/ 1st and 2nd fingers /1st and 3rd fingers)	None	Squeeze: 5 sec.

Table 2.1. Cont'd

Woody and Mathiowetz (1988)	USA	50 college women	Mean of three successive trials	▪ B&L pinch gauge	▪ Sitting ▪ Shoulder adducted ▪ Elbow at 90 degree flexion ▪ Wrist between 0 and 30 degree dorsiflexion and between 0 and 15 degree ulnar deviation ▪ Both hands ▪ Pinch gauge was held by the experimenter ▪ Forearm not supported	▪ Key pinch ▪ Chuck(palmar) pinch	None	Rest: 5 min.
Palanisami et al. (1994)	USA	20 male student	Max. of two trials	▪ Jamar dynamometer ▪ ENG pinch gauge	▪ Sitting / Standing ▪ Only dominant hand ▪ Forearm supported/unsupported ▪ Forearm in mid pronated/ pronated/supinated postures ▪ Elbow adducted/ at maximum abduction/ half of min. abduction	▪ Hand grip ▪ Chuck pinch ▪ Pulp pinch ▪ Lateral pinch	▪ Age ▪ Weight ▪ Standing height ▪ Acromial height ▪ Forearm length ▪ Upperarm length ▪ Hand length ▪ Breadth at metacarpal ▪ Breadth at thumb ▪ Thickness at metacarpal ▪ Circumference at wrist ▪ Thickness at wrist ▪ Finger lengths	Squeeze:4-5 sec
Halpern and Fernandez (1996)	USA	20 male Age: 20 - 34	Two peak trials are recorded.	▪ Jamar dynamometer ▪ ENG mechanical pinch strength gauge	▪ Standing ▪ Only dominant hand ▪ Experiment 1: 7 shoulder postures, 5 elbow postures,Wrist and forearm in neutral posture, only for chuck pinch ▪ Experiment 2: 3 forearm postures, 3 wrist postures, chuck, lateral and tip pinch is measured.	▪ Hand grip ▪ Three-jaw tip chuck pinch ▪ Lateral pinch ▪ Tip pinch	▪ Age ▪ Stature ▪ Body weight ▪ Link lengths(upper arm, forearm) ▪ Hand length ▪ Breadth at metacarpal ▪ Breadth at thumb ▪ Thickness at metacarpal ▪ Thickness at wrist ▪ Circumference of wrist ▪ Finger lengths ▪ Range of motion(wrist flexion, wrist extension)	Squeeze: 2 sec.

Table 2.2. Results of some studies in literature (kgf)

	Sample Type	DG	NDG	DLP Sit	NDLP Sit	DLP Stand	NDLP Stand	DCP Sit	NDCP Sit	DCP Stand	NDCP Stand	DPP Sit	NDPP Sit	DPP Stand	NDPP Stand	DTP Sit	NDTP Sit	DTP Stand	NDTP Stand
Mathiowetz, et. al (USA, 1985)	310 M	47.3 (12.8)	42.2 (12.5)	11.11 (2.09)	10.71 (2.09)			10.61 (2.27)	10.43 (2.4)							7.71 (1.86)	7.44 (1.81)		
	318 F	28.5 (7.71)	24.5 (7.12)	7.35 (1.36)	6.94 (1.41)			7.39 (1.72)	7.12 (1.63)							5.13 (1.18)	4.9 (1.09)		
Jansen, et.al. (USA, 2003)	44 M			10.5 (2.42)	10.14 (2.33)			9.38 (2.34)	9.14 (2.24)			7.01 (1.62)	6.78 (1.77)						
	91 F			7.27 (1.51)	6.68 (1.55)			6.92 (1.62)	6.35 (1.52)			4.89 (1.16)	4.55 (1.15)						
Young et al. (USA, 1989)	34 M	43.7 (6.49)	41.8 (7.29)	11.52 (1.67)	11.02 (1.6)														
	61 F	25.5 (4.4)	21.9 84.27)	7.26 (1.11)	6.71 (0.96)														
Crosby and Wehbe (USA, 1994)	105 M	62.14 (10.89)	58.51 (9.98)	12.25 (2.27)	11.79 (2.27)							8.62 (1.81)	8.17 (1.81)						
	109 F	36.74 (7.26)	34.02 (7.26)	9.07 (2.27)	8.62 (1.81)							6.35 (1.81)	5.9 (1.36)						
Halpern (USA, 1996)	20 M					8.8 (1.4)				8.3 (1.8)								6.2 (1.4)	
Lau V., Wing-Yuk Ip (China, 2006)	64 M			10.65 (1.55)	9.7 (1.5)														

(M= Males, F=Females)

Table 2.2. Cont'd

	Sample Type		DG	NDG	DLP Sit	NDLP Sit	DLP Stand	NDLP Stand	DCP Sit	NDCP Sit	DCP Stand	NDCP Stand	DPP Sit	NDPP Sit	DPP Stand	NDPP Stand	DTP Sit	NDTP Sit	DTP Stand	NDTP Stand
Imrhan S, Loo C. H. (USA, 1989)	Children	32 M			4.2 (0.2)				4 (0.24)				2.7 (0.15)							
		30 F			3.6 (0.18)				3.6 (0.22)				2.4 (0.17)							
	Adult	40 M			9.4 (0.35)				9.4 (0.22)				7.3 (0.29)							
		30 F			6.5 (0.17)				7 (0.23)				4.7 (0.17)							
	Elderly	16 M			6.7 (0.35)				5.9 (0.45)				4.3 (0.27)							
		34 F			4.9 (0.31)				4.6 (0.27)				3 (0.2)							
Palanisami et al. (USA,1994)	20 M								7.69 (1.55)		8.2 (1.61)									
Mathiowetz, et. al (USA, 1985)	29 F		31.39 (4.26)	27.8 (4.72)	7.71 (1.23)	7.21 (1.13)														

(M= Males, F=Females)

3. OBJECTIVES OF THE STUDY

Strength norms are needed for work and product design and clinical purposes. Due to the cross-national variations, strength norms should be developed for various geographical regions and nationalities. This study is the first attempt to establish pinch strength norms of healthy adult population of Turkey. Therefore, the main objectives of this study are to:

(i) estimate the maximum voluntary isometric (static) pinch (tip, pulp, lateral and three-jaw chuck) strength distributions of healthy (normal) adult population of Turkey from a sample data specific to gender, age and occupation;

(ii) investigate the effects of body posture, handedness, gender, age, height, weight, occupation and hand/arm dimensions on pinch strength; and

(iii) compare the developed pinch strength norms of the population of Turkey with the pinch norms of the population of several other countries.

4. METHODS

4.1. Subjects

The main aim of the study is to obtain normative pinch strength data for the population of Turkey. To meet the requirements of a normative study, the sample is chosen randomly to be representative of the whole population.

Subjects were recruited voluntarily from a metropolitan city of Turkey (İstanbul) and its surrounding areas. The population of this city is composed of people whose family origins are from every region of Turkey. Therefore, due to its demographic characteristics, the population of İstanbul approximately represents the population of Turkey.

To examine the regional effects, the subjects were asked about their birthplace, family origin city, father and mother's birthplace. The regional distribution of the family origins of the subjects is shown in Table 4.1 and Figure 4.1.

Table 4.1. Distribution of family origin regions of the subjects

REGION	**FEMALE**	**MALE**	**ALL**
Aegean	8	19	27
Black Sea	18	26	44
Central Anatolia	14	21	35
Eastern Anatolia	13	10	23
Marmara	22	24	46
Mediterranean	12	11	23
Southeastern Anatolia	5	6	11
Foreign Countries	10	4	14
TOTAL	102	121	223

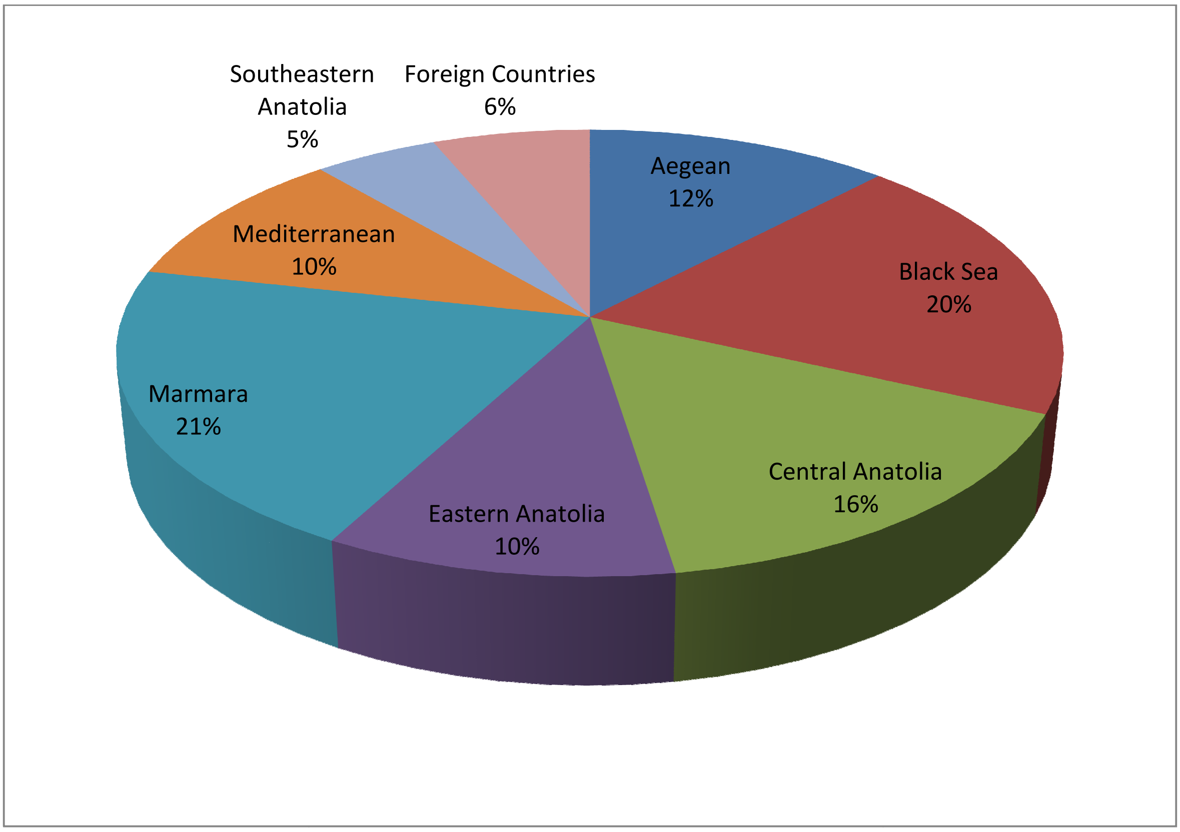

Figure 4.1. Distribution of family origins of the subjects

A medical history form was applied to the subjects before the experiments. The purpose of this form was to discover if the subjects had serious health problems which can lead to experimental errors. The subjects, which had health problems, were excluded from the experiments and the experimentation period was conducted with the healthy subjects.

The subjects were stratified into 5 age groups as following (in years): (18 – 29), (30 – 39), (40 – 49), (50 – 59) and (60 – 69).

To investigate the effects of work conditions on strength, the subjects were divided into three occupation groups: manual workers, non-manual workers and students. This categorization was partly made by the help of the “Regulation of Heavy and Dangerous Labors” which was published in the “Turkish Official Newspaper” on 16 June 2004.

A total of 223 (102 female and 121 male) subjects were volunteered for the study. Among them, seven female and seven male subjects were left hand-dominant.

Table 4.2, shows the number of subjects categorized by gender, age and occupation groups.

Table 4.2. Number of subjects by gender, occupation and age groups

GENDER	OCCUPATION GROUP	AGE GROUP					ALL
		18-29	30-39	40-49	50-59	60 and above	
Male	Non-Manual	13	10	5	14	10	52
	Manual	13	19	12	0	0	44
	Student	25	0	0	0	0	25
	ALL	51	29	17	14	10	**121**
Female	Non-Manual	12	9	12	16	13	62
	Manual	4	7	4	0	0	15
	Student	25	0	0	0	0	25
	ALL	41	16	16	16	13	**102**
TOTAL		92	45	33	30	23	**223**

Moreover, the subjects were categorized according their body mass index prime value. Body Mass Index Prime is a value which is obtained by the following formula (apps.who.int):

$$\text{BMI Prime} = \text{Weight(kg)} / (25 \times \text{Height(m)}^2) \qquad (4.1)$$

The results of BMIP categorization can be found in Table 4.3.

Table 4.3. Number of subjects according to their BMIP value

Category	BMIP Range	Female	Male	All
Underweight	<0.74	9	0	9
Normal	$0.74 \leq x < 1$	58	56	114
Overweight	≥ 1	35	65	100
TOTAL		102	121	**223**

4.2. Equipment

Both hand grip strength and pinch strength measurements were taken during the experiments. Jamar hand grip dynamometer (Figure 4.2) was used for measuring hand grip strength and Jamar hydraulic pinch gauge (Figure 4.3) was used for measuring pinch strength.

Figure 4.2. Hydraulic hand grip dynamometer

Figure 4.3. Hydraulic pinch gauge

The equipment was calibrated before starting the experiments. The calibration of the pinch gauge was done in the following manner: Firstly the pinch gauge was fastened on the edge of a table with only the measuring pad being free. Then previously determined weights were hanged from the measuring pad by the help of a rope. Then the result was read from the scale and compared with the determined real weights of the objects being held. The weights that were used in calibration were 2.5 kg, 3 kg, 5.5 kg, 6 kg, 7 kg, 8 kg, 9.5 kg, 11 kg, and 12 kg. The readings from the scale were the same as the actual weights of the objects. Therefore the equipment was accurate and needed no further calibration.

A similar calibration test was applied to the hand grip dynamometer and as a result it was also found accurate enough to be used in the experiments.

Some anthropometric measurements were taken before the experiments. The weight of the subjects was measured by a mechanical scale. A wall-mounted meter was used to measure the height of the subjects. Other anthropometric measurements such as circumference of forearm, circumference of fist and forearm-hand length were measured by using a measuring tape. An adjustable chair was used for the tests where sitting posture is needed.

4.3. Procedure

All the candidate subjects filled a “Medical History Form” (Appendix A.1) and the ones who were free from diseases such as diabetes, heart diseases, rheumatoid arthritis, hypertension and musculoskeletal disorders were accepted to participate in the study. The participants then signed the “Personal Consent Form” (Appendix A.3). The “Personal Consent Form” and “Medical History Form” were prepared both in English and Turkish.

Before starting the tests, the subjects filled a “Personal Data Form” (Appendix A.5), which included questions like age, occupation, the city the subject lives now, family origin, and mother and father’s birthplace. Part of the information related to this form (e.g., height, weight, circumference of forearm, fist circumference, forearm-hand length) is filled by the investigator after the measurements.

Height was measured by a wall-mounted meter while the subject with shoes-off stood still with his/her shoulders and hip touching the wall and eyes looking forward. Weight of the subjects was measured by a mechanical scale. The subjects wore light clothes and did not wear any accessories which cause extra weight.

Circumference of forearm was measured while the elbow was flexed at 90 degree and wrist in neutral posture. To be able to measure the widest part of forearm, the subject was asked to squeeze his/her fist moderately and then the measurement was taken by a tape measure (Figure 4.4). Circumference of fist was measured while the subject formed a fist. The measurement was taken around the fist including all the knuckles (Figure 4.5). Forearm-hand length was measured from elbow joint to the tip of middle finger (Figure 4.6). All anthropometric measurements were taken from the dominant side of the subject.

Figure 4.4. Measurement of the circumference of forearm

Figure 4.5. Measurement of the circumference of fist

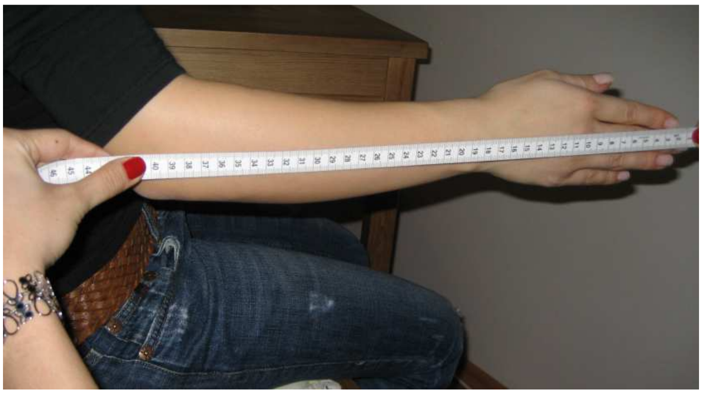

Figure 4.6. Measurement of the forearm-hand length

Once the anthropometric measurements were taken, the experimentation period began. Before the tests, subjects were given time for familiarizing with the experimental conditions and testing devices. In addition, the experimenter let the subject do some warm up exercises for hands and fingers before the experiments start in order to increase blood circulation to condition muscles.

After the explanation of the experimental procedures in detail, the experiments started. The dependent variables in the experiment were maximum voluntary pinch strength and maximum voluntary hand grip strength. Four types of pinch strength were measured for males. These were tip pinch, pulp pinch, lateral pinch and three-jaw chuck pinch. Three types of pinch strength were measured for females and these were pulp pinch, lateral pinch and three-jaw chuck pinch. Since the fingernails of most females were not short enough to measure tip pinch, it was not measured for females.

Hand grip strength was measured while the subjects were sitting, shoulder in neutral posture, elbow flexed at 90° and wrist in neutral posture following the standards of American Society of Hand Therapists (Fess & Moran, 1981; Fess, 1992). Forearm was not supported during the measurements and the dynamometer was hold by the experimenter (Figure 4.7). The measurement was taken for both the dominant and non-dominant hand in a randomized order. Sitting posture was preferred because many studies in literature have used this posture and recent studies on hand grip strength show that there is not a significant difference between the sitting and standing posture (Silahlı, 2008).

Strength measurements were performed according to Caldwell protocol (Caldwell *et al.*, 1974). This protocol suggests that the subject should start with the instructors's "Increase to maximum exertion (without jerking) in about one second and maintain the maximum effort for four seconds." command. No feedback should be given to the subject during the experiments. There should be at least a two minute break between the trials and when the trials are not within 10% variation, the test should be repeated until it meets this condition.

Figure 4.7. Measurement of hand grip strength

Pinch strength measurements were taken both when the subject was sitting and standing. In both positions shoulder was in neutral posture, elbow flexed at 90 degree and wrist in neutral posture like the measurement of hand grip strength. Arm (upper and forearm) was not-supported in the measurements. The experimenter held the pinch gauge and subject performed the strength test following the Caldwell protocol (Caldwell, *et al*., 1974). The tests were conducted in a randomized order. The testing positions for each pinch strength type are shown in Figures 4.8 to 4.15.

Figure 4.8. Measurement of lateral pinch strength while sitting

Figure 4.9. Measurement of three-jaw chuck pinch strength while sitting

Figure 4.10. Measurement of pulp pinch strength while sitting

Figure 4.11. Measurement of tip pinch strength while sitting

Figure 4.12. Measurement of lateral pinch strength while standing

Figure 4.13. Measurement of three-jaw chuck pinch strength while standing

Figure 4.14. Measurement of pulp pinch strength while standing

Figure 4.15. Measurement of tip pinch strength while standing

The subject started exerting force with the experimenter’s command, reached his / her maximum in about 1 second, held the maximum exertion for about 3-4 seconds and then released. The instructions which are given to the subjects by the experimenter are shown in Appendix A.6.

Each test was repeated at least twice. If the difference between the two measurements was more than 10%, the test was repeated as many times as needed to meet this 10% variation criterion. The maximum value of the successive two trials was recorded as the subject’s maximum voluntary strength. There was a 2-minute rest period between two consecutive tests of the same hand. The tests were done in random order but to speed up the experiments when a dominant hand measurement was taken the following measurement was a non-dominant one.

Table 4.4 provides the list of all the strength measurements that are taken from the subjects.

Table 4.4. List of strength measurements taken from the subjects

Number	Measurement
1	Dominant hand grip strength while sitting
2	Non-dominant hand grip strength while sitting
3	Dominant hand lateral pinch strength while sitting
4	Non-dominant hand lateral pinch strength while sitting
5	Dominant hand lateral pinch strength while standing
6	Non-dominant hand lateral pinch strength while standing
7	Dominant hand three-jaw chuck pinch strength while sitting
8	Non-dominant hand three-jaw chuck pinch strength while sitting
9	Dominant hand three-jaw chuck pinch strength while standing
10	Non-dominant hand three-jaw chuck pinch strength while standing
11	Dominant hand pulp pinch strength while sitting
12	Non-dominant hand pulp pinch strength while sitting
13	Dominant hand pulp pinch strength while standing
14	Non-dominant hand pulp pinch strength while standing
15	Dominant hand tip pinch strength while sitting (only for male subjects)
16	Non-dominant hand tip pinch strength while sitting (only for male subjects)
17	Dominant hand tip pinch strength while standing (only for male subjects)
18	Non-dominant hand tip pinch strength while standing (only for male subjects)

The experimental procedure can be summarized by the following flow chart (Figure 4.16):

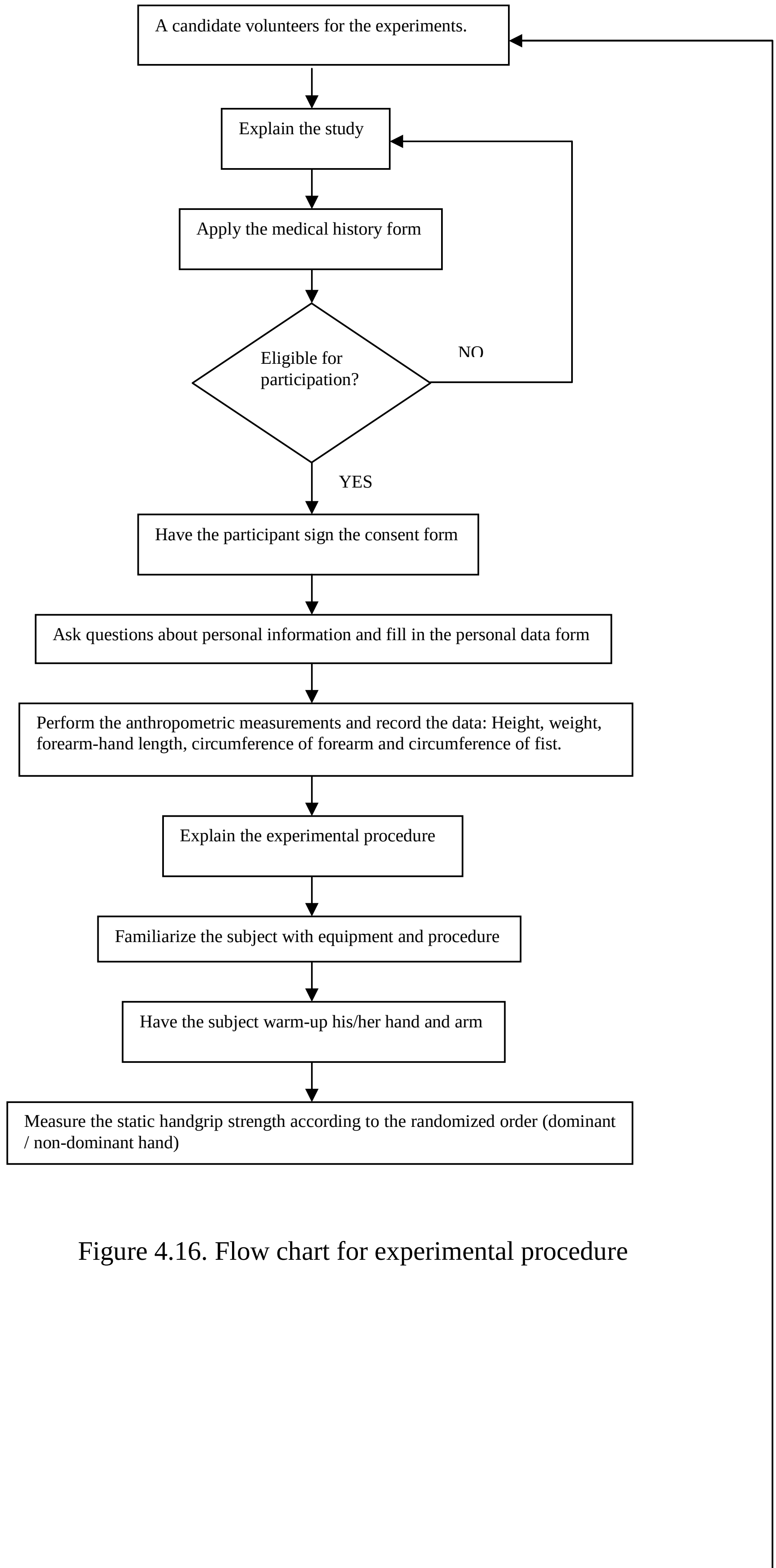

Figure 4.16. Flow chart for experimental procedure

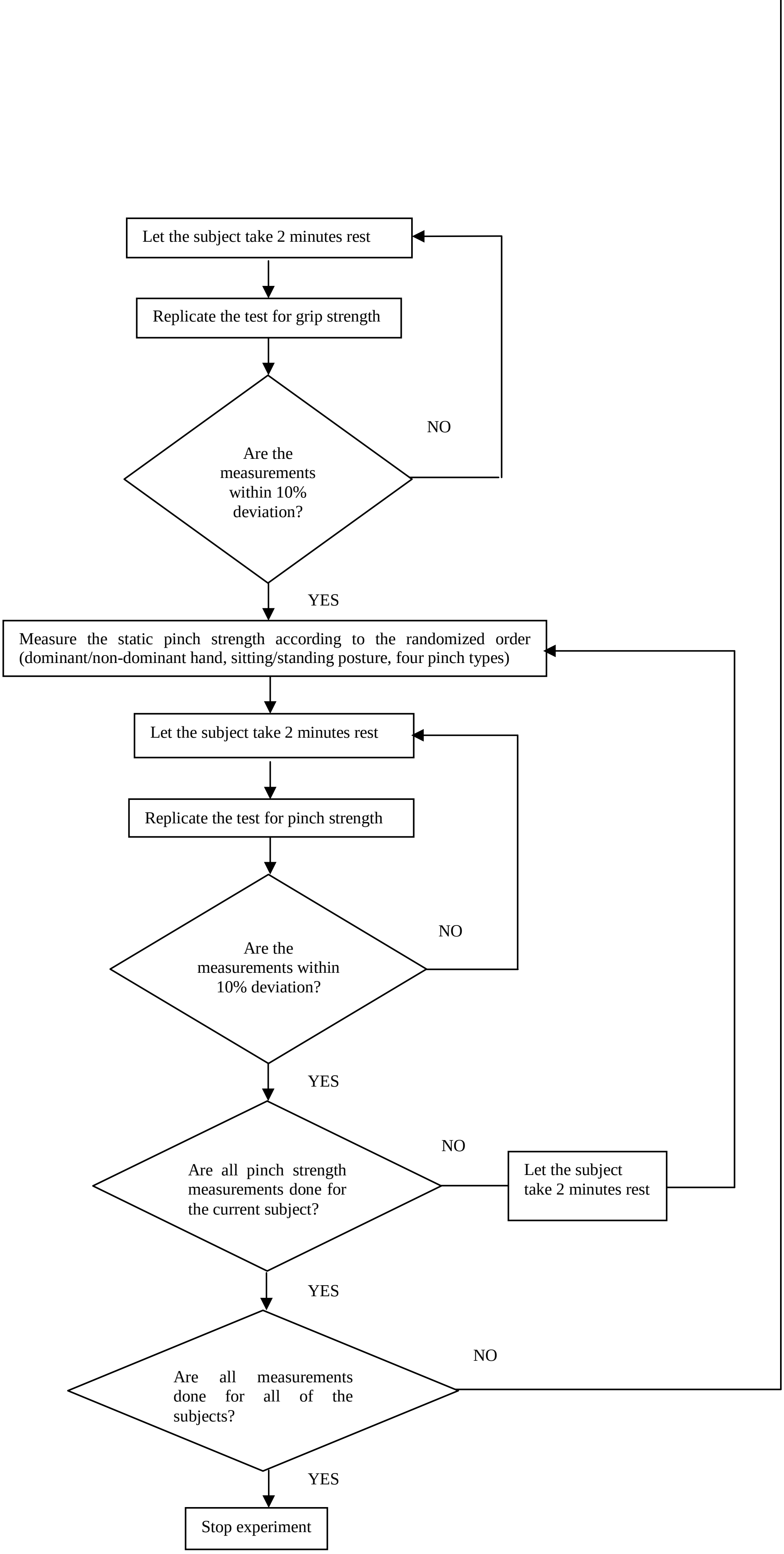

Figure 4.16. Cont’d

4.4. Experimental Design and Statistical Analysis

4.4.1. Experimental Variables

Maximum voluntary isometric lateral pinch strength, three-jaw chuck pinch strength, pulp pinch strength and tip pinch strength were the dependent variables in this study.

Independent variables for each pinch strength type are described in Table 4.5.

Table 4.5. Design factors for pinch strength

Design Factors	Levels
Hand	(1)Dominant hand (2)Non-dominant hand
Posture	(1) Sitting (2) Standing
BMIP group	(1) Underweight (for females only) (2) Normal (3) Overweight
Occupation group	(1) Non-manual worker (2) Manual worker (3) Student
Age group	(1) 18-29 yr. (2) 30-39 yr. (3) 40-49 yr. (4) 50-59 yr. (5) 60-69 yr.
Circumference of the largest part of forearm	
Circumference of fist	
Forearm-hand length	

4.4.2. Experimental Model and Experimental Conditions

Randomized complete block design with subjects serving as blocks were used as the experimental model. Randomization is necessary to avoid the effects of nuisance factors in the experiments. When nuisance source of variability is known and controllable, blocking can be used to eliminate its effect on the statistical comparisons among treatments (Montgomery, 2005).

The no-interaction statistical model for this design can be stated as the following:

$$y_{ijklmn} = \mu + \alpha_i + \chi_j + \delta_k + \tau_l + \varphi_m + \eta_n + \varepsilon_{ijklmn} \tag{4.2}$$

for

i = 1, 2 (1: Pinching with dominant hand; 2: Pinching with non-dominant hand)

j = 1, 2 (1: Pinching while sitting; 2: Pinching while standing)

k = 1, 2, 3 (1: Underweight people -for females only-; 2: Normal people; 3: Overweight people)

l = 1, 2, 3 (1: Non-manual workers; 2: Manual workers; 3: Students)

m = 1, 2, 3, 4, 5 (1: 18-29 years; 2: 30-39 years; 3: 40-49 years; 4: 50-59 years; 5: 60-69 years)

n = 1, 2,…, 102 for females (number of female subjects)

n = 1, 2,…, 121 for males (number of male subjects)

where,

y_{ijklmn}: $ijklmn^{th}$ response (pinch strength)

μ: overall response mean

α_i: effect of i^{th} level for hand factor

χ_j: effect of j^{th} level for posture factor

δ_k: effect of k^{th} level for BMIP group factor

τ_l: effect of l^{th} level for occupation group factor

φ_m: effect of m^{th} level for age group factor

η_n: effect of n^{th} block

ε_{ijklmn}: NID $(0,\sigma^2)$ random error component.

Randomization was done by using RAND( ) command in Excel. Hand grip and pinch measurements were randomized separately. For hand grip strength, randomization was done between dominant and non-dominant hand. For pinch strength, randomization for dominant hand and non-dominant measurements were done separately. Because, since a 2 minute break is needed between the consecutive trials of the same hand, a sequential order of dominant hand and non-dominant hand measurement speeds up the testing. Therefore, pinch measurements were started with the hand that hand grip measurements started and continued according to the randomized order. In randomization only one trial is taken into account and measurements are repeated in the same randomized order.

There were 18 tests to be accomplished by male subjects and 14 tests to be accomplished by female subjects. Therefore total number of strength data for the statistical analysis is (102x14) + (121x18) = 3.606. Since each test is done at least twice, the number of data collected is at least 7.212. The collected data are recorded on a form which is shown in Appendix A.5.

4.4.3. Pilot Study

A pilot study with randomly selected 20 subjects (10 males, 10 females) was conducted before the actual experiments. The aims of pilot study were twofold: (i) get familiar with experimental procedures and equipment. (ii) obtain the standard deviation for sample size determination of the actual study.

The overall mean and standard deviation of pinch strengths (lateral, chuck, pulp for both genders and tip for males only) obtained from the pilot study (16 test combinations for males: 4 pinch types x 2 postures x 2 hands; 12 test combination for females: 3 pinch types x 2 postures x 2 hands) in kgf. were 8.9 and 1.1 for males; 6.3 and 0.6 for females.

4.4.4. Sample Size Determination

Sample size calculation is an important part of the statistical analysis. Because sample size calculation is concerned with how much data we need to make a correct decision on the study. It must be large enough to give accurate results and small enough to be collected in feasible time.

Sample size calculation formula for normative data studies is given in the ISO standards for establishing anthropometric databases as the following (ISO 15535:2006):

$$N = \left(\frac{1.96 \times CV}{a}\right)^2 \times (1.534)^2 \tag{4.3}$$

Where, 1.96 is the critical Z value from a standard normal distribution for a 95% confidence interval; CV is the coefficient of variation; a is the percentage of relative accuracy desired (CI is to be no larger than ± some percentage of the mean). Furthermore; CV is defined as the following:

$$CV = \frac{SD}{\bar{x}} \times 100 \tag{4.4}$$

Where,

$\bar{x}$: sample mean

SD: sample standard deviation.

In current study, true mean and standard deviation of the population are unknown, so these values are estimated by using the results of the pilot study. Relative accuracy is decided to be at least 5%. Therefore, sample sizes for males and females were calculated as;

$$N = \left(\frac{1.96 \times 9.8}{5}\right)^2 \times (1.534)^2 = 35 \quad \text{for females,}$$

$$N = \left(\frac{1.96 \times 12.2}{5}\right)^2 \times (1.534)^2 = 54 \quad \text{for males.}$$

4.4.5. Statistical Analysis

Statistical Analysis was performed using SPSS 16.0 and Minitab 15.0. In the analysis, p-values ≤ 0.05 were accepted as significant and $0.05 <$ p-values ≤ 0.1 were accepted as marginal.

The data was categorized by gender and then descriptive statistics such as mean, standard deviation, 95% confidence interval of means, range and percentiles were calculated. Pearson's correlation coefficient was used to investigate the linear relationship between factors.

Multiple Analysis of Variance (MANOVA) was used to investigate the effects of independent factors on pinch strength. Dependent variables were lateral pinch strength, three-jaw chuck pinch strength, pulp pinch strength and tip pinch strength for males and lateral pinch strength, three-jaw chuck pinch strength and pulp pinch strength for females. Independent factors were age group, occupation group, BMIP group, posture and hand group.

The purpose of an ANOVA is to test whether the means for two or more groups are taken from the same sampling whereas the purpose of MANOVA is to test whether the vectors of means for the two or more groups are sampled from the same sampling distribution. The MANOVA gives one overall test of the equality of mean vectors for several groups (Carey, 1988).

MANOVA has the advantage of testing the effects of several independent variables and several dependent variables within a single analysis. It is more powerful than univariate tests and reduces the error rate.

Before conducting a MANOVA analysis, its assumptions must be satisfied. These are described as the following (ncsu.edu., 2009):

(i) The sampling must be random and observations must be independent of one another. The sample in each cell must be greater than the number of independent variables.

(ii) The dependent variables must be continuous and independent variables must be categorical.

(iii) Dependent variables should be moderately correlated with each other.

(iv) Multivariate normality must be established and residuals of the dependent variables must follow normal distribution.

(v) Homogeneity of variances within groups must be ensured.

Data was stratified into gender first. Both male and female subjects were stratified into three occupation groups: 1(non-manual), 2(manual), 3(student); five age groups: 1(18-29), 2(30-39), 3(40-49), 4(50-59), 5(60-69). Male subjects were classified into two groups according to their Body Mass Index Value: 1(normal), 2(overweight); and female subjects into three: 1(underweight), 2(normal), 3(overweight).

MANOVA was performed for each gender separately. Interaction effects were not found significant in the models so they were neglected and only main effects were taken into account. Wilk's Lambda statistic was used to test the significance across groups because it was the most commonly used statistic for overall significance (canberra.edu.au, 2010). Due to the significant factor effects, MANOVA was followed by univariate analysis of variance for each dependent variable. Once the existence of significant factors were found, post hoc range tests and pairwise multiple comparisons were used to determine which levels of factor means differ. Tukey's test was used as the range test for factors which have more than two levels. Tukey's tests give narrower confidence levels, therefore it was chosen for the analyses (Toothaker, 1993). Pairwise multiple comparisons test the difference between each pair of means and t-test was used to test the differences of means for factors which have two levels (SPSS Inc, 2010).

The hypothesis for Tukey's test is as the following (Montgomery, 2005):

$$H_0: \mu_i = \mu_j$$
$$H_1: \mu_i \neq \mu_j \tag{4.5}$$

where i and j are treatment levels($i \neq j$).

This procedure uses studentized range statistic which is:

$$q = \frac{\bar{y}_{\max} - \bar{y}_{\min}}{\sqrt{MS_E / n}} \tag{4.6}$$

where

$\bar{y}_{\max}$ is the largest sample mean,

$\bar{y}_{\min}$ is the smallest sample mean,

MS_E is mean squares due to error,

n is the sample size.

Using the q value, T value of the statistic can be calculated as:

$$T_\alpha = \frac{q_\alpha(p, f)}{\sqrt{2}} \sqrt{MS_E \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \tag{4.7}$$

where q_α *(p,f)* is the upper α percentage points of *q* (studentized range statistic), *p* is the number of groups will be compared, n_i and n_j are the sample sizes of the groups, *f* is the number of degrees of freedom associated with the MS_E.

The 100(1- α) confidence intervals for all pairs of means can be constructed as the following (Montgomery, 2005):

$$\bar{y}_{i.} - \bar{y}_{j.} - \frac{q_\alpha(p, f)}{\sqrt{2}} \sqrt{MS_E \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \le \mu_i - \mu_j \le \bar{y}_{i.} - \bar{y}_{j.} - \frac{q_\alpha(p, f)}{\sqrt{2}} \sqrt{MS_E \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \tag{4.8}$$

where

$\bar{y}_{i.}$ and $\bar{y}_{j.}$ are sample means of i^{th} and j^{th} groups,

μ_i and μ_j are population means of i^{th} and j^{th} groups ($i \ne j$).

For factors with two levels, t-tests were used to compare the means of groups. For comparing the gender differences, since we don't know if the variances of male and female strengths are equal, general t-test is used. For BMIP comparisons in males, since we know that all data comes from same distribution, pooled t-test is used. For comparisons of hand and posture effects paired t-tests are used.

The hypothesis of a general t-test is stated as (Montgomery, 2005):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2 \qquad (4.9)$$

where μ_1 and μ_2 are means of group 1 and 2.

The test statistic is calculated as:

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \qquad (4.10)$$

where $\bar{y}_1 - \bar{y}_2$ are the sample means, n1 and n2 are the sample sizes, S_1^2 and S_2^2 are the sample variances. The distribution of t_0 is well approximated by t if we use;

$$v = \frac{\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}\right)^2}{\frac{\left(\frac{S_1^2}{n_1}\right)^2}{n_1 - 1} + \frac{\left(\frac{S_2^2}{n_2}\right)^2}{n_2 - 1}} \qquad (4.11)$$

The hypothesis of pooled t-test is stated as (Montgomery, 2005):

$$H_0: \mu_1 = \mu_2$$
$$H_1: \mu_1 \neq \mu_2 \qquad (4.12)$$

where μ_1 and μ_2 are means of group 1 and 2.

The test statistic is calculated as:

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{S_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \quad (4.13)$$

where $\bar{y}_1 - \bar{y}_2$ are the sample means, n1 and n2 are the sample sizes, S_p^2 is an estimate of the common variance.

Furthermore, S_p^2 is calculated as:

$$S_p^2 = \frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2} \quad (4.14)$$

where S_1^2 and S_2^2 are sample variances.

The hypotheses of paired t-test are (Montgomery, 2005):

$$H_0: \mu_d = 0$$
$$H_1: \mu_d \neq 0 \quad (4.15)$$

where μ_d is the difference of the mean between two groups. The test statistic for this hypothesis is

$$t_0 = \frac{\bar{d}}{S_d/\sqrt{n}} \quad (4.16)$$

where $\bar{d}$

$$\bar{d} = \frac{1}{n}\sum_{j=1}^{n} d_j \quad (4.17)$$

is the sample mean of the differences, S_d

$$S_d = \left[\frac{\sum_{j=1}^{n}(d_j - \bar{d})^2}{n-1}\right]^{1/2} \quad (4.18)$$

is the sample standard deviation of the differences, n is the sample size, and d_j is the j^{th} paired difference.

Regression analysis was made to develop prediction equations for pinch strength of males and females. Since the interactions between independent variables were not found significant in the MANOVA analysis, a no-interaction multiple linear regression model was determined as a suitable model for the analysis. Stepwise regression approach was adopted in the analysis. It is a method which systematically adds the most significant variable to the model and removes the least significant variable in each step. 0.05 was selected for the level of significance.

The general form of the multiple regression equation is as the following (Montgomery, 2005):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon \quad (4.19)$$

where

β_0 : Constant

$\beta_1, \beta_2, \ldots$: Regression coefficients for independent variables,

$x_1, x_2, \ldots$: Regressor variables,

ε : Error term (normally distributed).

Before starting the regression analysis, the following assumptions must be met (Kalaycı, 2006):

- Linearity: The relationship between the dependent and independent variables should be linear. Multiple regression procedures are not greatly affected by minor deviations from this assumption.
- Normality: The residuals of the independent variables must be normally distributed. This assumption can be checked by looking at the normal probability plots of residuals.

- Multicollinearity must not exist: If it exists, it means that there are redundant variables in the regression. This can be checked by looking at the variance inflation factor (VIF). VIF is desired to be smaller than 5.
- Variance homogeneity: The variances within groups must be equal. Bartlett's test can be used to check this assumption.
- Autocorrelation: there must not be correlation between the errors because correlation affects the estimation of coefficients for the regression. Durbin-Watson statistic is used to verify this assumption. It is desired to be between 1,5 and 2,5.

After regression models were determined, a test for significance of regression was performed to check the goodness of model (Montgomery, 2005).

The model utility test is performed for checking the significance of the model. The hypothesis of this test is:

$$H_0:\ \beta_1 = \beta_2 = ... = \beta_n = 0$$

$$H_1:\ \beta_j \neq 0 \text{ for at least one } j \text{ (j=1,…, n).} \qquad (4.20)$$

Rejection of H_0 in the above hypothesis implies that at least one of the regressor variables contributes significantly to the model. An ANOVA table, which considers the total sum of squares, sum of squares due to regression model and sum of squares due to residual, is used for checking the significance of regression model. If the p-value is less than α significance level, the null hypothesis H_0 is rejected, which implies that at least one of the regressor variables contributes significantly to the model (Montgomery, 2005).

Moreover R^2 and R^2_{adj} values were examined to see the goodness of fit of the regression model. R^2 is the proportion of variance in the dependent variable, which can be explained by the independent variables and R^2_{adj} is used to penalize the addition of extraneous predictors to the model. The higher R^2_{adj} values indicate that the included independent variables describe the dependent variable better, thus the fit of the model is better (ucla.edu, 2010).

5. RESULTS

5.1. Descriptive Statistics

The demographic profile and anthropometric characteristics of subjects are summarized in Table 5.1.

Table 5.1. Characteristics of participants

	Female		Male	
Measurement	Mean±Std. Dev.	Min-Max	Mean±Std. Dev.	Min-Max
Age (yrs)	38.3 ± 14.6	18.8 - 68.2	36.0 ± 13.2	18.3 - 66.7
Height (cm)	162.9 ± 5.6	148 - 177	174.2 ± 6.7	160 - 193
Weight (kgf)	63.2 ± 10.6	46 - 93	78.1 ± 13.4	55 - 150
Circumference of Forearm (cm)	24.7 ± 2.1	20.5 - 30	28.4 ± 1.9	24.5 - 36
Circumference of Fist (cm)	24.8 ± 1.3	21 - 28.5	29.1 ± 1.7	26 - 34
Forearm-Hand Length (cm)	42.1 ± 1.4	39 - 46	45.6 ± 2.2	41 - 53.5

Table 5.2 and 5.3 present the maximum isometric grip and pinch strength values of males and females (mean, standard deviation (std. dev.), range (min – max) and 95% confidence interval for the mean in kgf) for dominant and non-dominant hands by gender, age and occupation.

Results indicate that mean pinch strength of females was 68% of males. Lateral pinch strength was found the strongest, followed by chuck pinch and pulp pinch strength for both genders. Tip pinch was the weakest of all for males.

Moreover pinch strength was maximum at ages between 40-49 years. After age 50, a gradual decrease began for both genders.

Manual workers were found to be the strongest in all age groups. The weakest groups were students for males and non-manual workers for females.

Dominant hand was significantly stronger than non-dominant hand (The difference was 7.5 % in males and 8.5 %t in females).

Moreover, the results showed that sitting or standing posture did not have any effect on pinch strength.

Table 5.2. Male grip and pinch strength (*)

Age	N	DG	NDG	DLP Sit	NDLP Sit	DLP Stand	NDLP Stand	DCP Sit	NDCP Sit	DCP Stand	NDCP Stand	DPP Sit	NDPP Sit	DPP Stand	NDPP Stand	DTP Sit	NDTP Sit	DTP Stand	NDTP Stand
Male	112	43.7 (±6.8) 26.5-58 42.5-45	40.7 (±6.8) 23.5-56 39.5-41.9	11 (±1.2) 8-14.5 10.8-11.2	10.3 (±1.2) 7.1-13 10.1-10.5	11.1 (±1.3) 8.1-14.5 10.9-11.4	10.4 (±1.2) 7.2-13.5 10.2-10.7	9.9 (±1.3) 7.3-13 9.7-10.1	9.1 (±1.2) 6.6-12.3 8.9-9.4	10 (±1.3) 7.4-13 9.7-10.2	9.2 (±1.2) 6.8-12.3 9-9.4	7.8 (±1.1) 5.5-10 7.6-8	7.3 (±1.1) 4.9-9.6 7.1-7.4	7.9 (±1.1) 5.5-10.5 7.7-8.1	7.3 (±1.1) 5-10 7.1-7.5	7 (±1.1) 4.5-9.7 6.8-7.1	6.3 (±1) 4.3-9 6.2-6.5	7 (±1.1) 4.6-10 6.8-7.2	6.4 (±1.1) 4.2-9.7 6.3-6.6
NMW	52	41.1 (±6.1) 26.5-54 39.4-42.8	38.2 (±6.3) 23.5-52 36.4-39.9	10.9 (±1.1) 8.4-13.1 10.6-11.2	10.2 (±1.1) 8-12.3 9.9-10.5	11 (±1.1) 8.5-13.2 10.7-11.3	10.3 (±1.1) 8.1-13 10-10.7	9.9 (±1.2) 7.5-12.9 9.6-10.3	9.1 (±1.1) 6.6-11.6 8.8-9.4	10 (±1.2) 7.4-13 9.6-10.3	9.1 (±1.1) 6.8-12 8.8-9.4	7.8 (±1.1) 5.5-10 7.4-8.1	7.1 (±1.1) 4.9-9.6 6.8-7.5	7.8 (±1.1) 5.5-10.1 7.5-8.1	7.2 (±1.1) 5-9.5 6.8-7.5	7 (±1) 4.5-9.7 6.7-7.3	6.3 (±1) 4.3-9 6.1-6.6	7 (±1.1) 4.6-10 6.7-7.3	6.4 (±1.2) 4.2-9.7 6.1-6.8
18-29 years	13	44.4 (±5.5) 36.5-54 41-47.7	41.5 (±5.8) 34.5-52 38-45	11.2 (±1) 8.8-12.8 10.5-11.8	10.4 (±1.1) 8.3-12 9.7-11	11.6 (±1.1) 10-13.1 10.9-12.2	10.8 (±1.2) 9.6-13 10.1-11.5	10.1 (±1.4) 7.5-12.6 9.3-11	9.1 (±1.4) 6.6-11.5 8.3-9.9	10.4 (±1.3) 7.8-13 9.7-11.2	9.3 (±1.4) 6.8-12 8.4-10	7.7 (±0.9) 6-9.3 7.1-8.3	7.2 (±0.9) 5.5-9 6.7-7.8	7.8 (±0.9) 6.5-9.2 7.3-8.4	7.3 (±0.9) 5.6-8.9 6.7-7.9	6.8 (±0.9) 5-8.5 6.3-7.4	6.2 (±1) 4.5-8.1 5.6-6.7	6.8 (±0.9) 5.2-8.4 6.3-7.4	6.3 (±1) 4.6-8.1 5.7-7
30-39 years	10	45.5 (±4.1) 35.5-50.5 42.5-48.4	43 (±4.1) 33-49 40.1-46	11.1 (±1.1) 9.6-13 10.3-11.9	10.7 (±1.1) 8.3-12.3 9.9-11.5	11.1 (±1.1) 9.7-12.9 10.3-11.9	10.6 (±1.4) 8.1-12.5 9.6-11.6	10.2 (±1.3) 8.1-12.9 9.3-11.1	9.6 (±1) 7.6-11 8.9-10.3	10.2 (±1.4) 7.8-12.6 9.2-11.2	9.4 (±1.3) 7-11.6 8.4-10.3	8.2 (±1.2) 6.5-10 7.4-9.1	7.5 (±1.4) 4.9-9.6 6.5-8.5	8.1 (±1.3) 6.1-10.1 7.2-9	7.3 (±1.3) 5-9.5 6.4-8.3	7.2 (±1.7) 4.5-9.7 6-8.4	6.7 (±1.4) 4.3-9 5.7-7.7	7.3 (±1.9) 4.6-10 5.9-8.6	6.9 (±1.9) 4.2-9.7 5.6-8.3
40-49 years	5	39 (±2.4) 35.5-41.5 36-42	35.4 (±3) 31-38 31.7-39.1	10.8 (±0.9) 9.2-11.6 9.6-11.9	10.2 (±1.1) 8.2-11 8.8-11.6	10.9 (±0.9) 9.4-11.5 9.8-12	11.3 (±1) 8.5-11 9-11.5	9.7 (±2.1) 7.5-12.5 7-12.3	9.1 (±2) 7-11.6 6.6-11.7	9.7 (±1.8) 7.7-11.8 7.5-12	9.1 (±1.7) 7.1-10.9 7-11.1	8 (±1.4) 6.5-9.6 6.3-9.7	7.2 (±1.2) 6-9 5.7-8.7	8.2 (±1.4) 6.7-9.7 6.5-9.9	7.3 (±1.2) 6.1-9.1 5.8-8.9	6.8 (±0.7) 6.1-7.5 5.9-7.6	6 (±0.7) 5.4-7 5.2-6.9	6.9 (±0.9) 6-8.1 5.8-8	6.1 (±0.8) 5.3-7.1 5-7.1
50-59 years	14	39.8 (±6.7) 26.5-48 35.9-43.6	36.7 (±6.4) 23.5-44 33-40.4	10.8 (±1.4) 8.4-13.1 10-11.6	10.1 (±1.3) 8-12.2 9.4-10.8	10.8 (±1.4) 8.5-13.2 10-11.6	10.1 (±1.2) 8.1-12.3 9.4-10.8	9.9 (±1.1) 7.5-12 9.3-10.5	8.9 (±0.9) 7.1-10.8 8.4-9.4	9.8 (±1) 7.4-11.9 9.2-10.4	9 (±0.8) 7-10.7 8.5-9.5	7.9 (±1.2) 5.9-9.8 7.2-8.6	7.2 (±1.2) 5-9.1 6.5-7.9	7.9 (±1.3) 5.6-10 7.2-8.6	7.3 (±1.2) 5.2-9.2 6.6-8	7.3 (±0.8) 5.5-8.3 6.8-7.8	6.7 (±0.8) 5-8 6.2-7.2	7.2 (±0.8) 5.7-8.2 6.8-7.8	6.7 (±0.8) 5.1-7.9 6.2-7.1
60-69 years	10	35.3 (±2.8) 32-41 33.3-37.3	32.4 (±3.4) 29-40 30-34.8	10.6 (±0.6) 10.1-12 10.1-11	9.7 (±0.7) 9.2-11.5 9.2-10.2	10.5 (±0.5) 9.8-11.6 10.2-11	9.8 (±0.6) 9.4-11.3 9.4-10.2	9.5 (±0.5) 8.7-10.3 9.1-9.9	8.7 (±0.4) 8-9.6 8.4-9	9.4 (±0.6) 8.5-10.2 9-9.8	8.7 (±0.6) 7.9-9.7 8.3-9.1	7.1 (±1) 5.5-8.5 6.4-7.8	6.5 (±0.9) 5-7.6 5.9-7.1	7.2 (±0.9) 5.5-8.3 6.6-7.9	6.6 (±0.8) 5.1-7.6 6-7.1	6.7 (±0.7) 4.9-7.3 6.2-7.2	5.9 (±0.8) 4.3-6.5 5.4-6.5	6.7 (±0.8) 5-7.5 6.2-7.3	6 (±0.8) 4.5-6.7 5.4-6.5

* (Numbers in each cell indicate mean; standard deviation; range and 95% confidence interval of the mean respectively in kgf)

Table 5.2. Cont'd

MW	44	48.7 (±6.1) 32.5-58 46.8-50.5	45.2 (±6.5) 29.5-56 43.2-47.2	11.7 (±1.1) 9-14.5 11.4-12.1	10.9 (±1.1) 8.9-13 10.5-11.2	11.8 (±1.2) 9.1-14.5 11.4-12.2	11.1 (±1.1) 9-13.5 10.7-11.4	10.3 (±1.3) 7.3-13 9.9-10.6	9.5 (±1.3) 7-12.3 9.1-9.9	10.4 (±1.3) 7.6-13 10-10.8	9.6 (±1.3) 6.9-12.3 9.2-10	7.9 (±1.1) 5.6-10 7.6-8.3	7.4 (±1.1) 5-9.5 7-7.7	8.1 (±1.2) 5.5-10.5 7.7-8.5	7.5 (±1.2) 5-10 7.2-7.9	7.1 (±1.2) 5-9.2 6.7-7.4	6.5 (±1.2) 4.3-8.9 6.1-6.8	7.1 (±1.2) 4.9-10 6.7-7.5	6.6 (±1.2) 4.2-9 6.2-6.9
18-29 years	13	48.5 (±5.1) 36-55.5 45.5-51.6	46.2 (±5) 34-53.5 43.2-49.3	11.5 (±0.8) 10.5-13 11-12	10.7 (±0.7) 9.7-11.8 10.3-11.1	11.8 (±0.7) 10.9-13.5 11.4-12.3	11.1 (±1) 9.5-12.5 10.5-11.7	10.2 (±1.3) 7.3-12 9.5-11	9.4 (±1.3) 7-11.5 8.6-10.1	10.4 (±1.3) 7.6-12.5 9.6-11.2	9.6 (±1.1) 7.2-11.6 8.9-10.3	8.1 (±1.2) 6.3-10 7.4-8.8	7.6 (±1.1) 5.8-9.5 6.9-8.3	8.2 (±1.1) 6.2-9.6 7.5-8.8	7.7 (±1.1) 5.8-9.4 7-8.3	7.2 (±1.2) 5.1-9.1 6.5-7.9	6.5 (±1.1) 4.9-8.1 5.8-7.2	7.4 (±1.4) 5-10 6.6-8.2	6.8 (±1.1) 4.7-8.2 6.2-7.5
30-39 years	19	48 (±7.6) 32.5-58 44.4-51.6	44.7 (±7.5) 30-56 41.1-48.3	11.7 (±1.2) 9-13.5 11.1-12.3	10.9 (±1.1) 8.9-13 10.3-11.4	11.7 (±1.4) 9.1-14.5 11-12.4	11 (±1.2) 9-13.5 10.5-11.6	10 (±1.1) 7.7-11.5 9.5-10.5	9.3 (±1.1) 7-11.2 8.8-9.9	10.3 (±1.3) 7.8-13 9.7-11	9.4 (±1.3) 6.9-11.5 8.8-10	7.6 (±1.1) 5.6-9.2 7.1-8.1	7 (±1) 5-9 6.5-7.5	7.8 (±1.3) 5.5-10 7.1-8.4	7.2 (±1.2) 5-9.5 6.6-7.8	6.7 (±1.2) 5-9.2 6.2-7.3	6.2 (±1.2) 4.3-8.8 5.6-6.8	6.8 (±1.3) 4.9-9.4 6.2-7.4	6.3 (±1.3) 4.2-9 5.7-6.9
40-49 years	12	49.9 (±4.8) 42-58 46.8-52.9	44.8 (±6.5) 29.5-54 40.7-49	12 (±1.2) 10.5-14.5 11.2-12.8	11 (±1.3) 9.5-13 10.2-11.9	11.9 (±1.3) 10-14 11.1-12.7	11 (±1.3) 9.2-12.9 10.2-11.9	10.7 (±1.5) 8.5-13 9.7-11.7	10 (±1.5) 8-12.3 9.1-11	10.6 (±1.5) 8.2-12.6 9.7-11.6	9.9 (±1.6) 7.2-12.3 8.9-10.9	8.2 (±1) 6.9-9.6 7.6-8.9	7.7 (±1.1) 6.2-9.4 7.1-8.4	8.6 (±1.3) 7-10.5 7.8-9.3	7.9 (±1.2) 6.1-10 7.2-8.6	7.4 (±1.1) 5.4-9.2 6.7-8.1	6.9 (±1.1) 5.1-8.9 6.2-7.6	7.4 (±1) 5.5-9.4 6.7-8	6.8 (±1) 4.9-9 6.2-7.5
Students	25	40.5 (±3.8) 32-48 38.9-42.1	38.1 (±3.8) 30-46 36.5-39.7	10.1 (±1) 8-12 9.7-10.5	9.4 (±1) 7.1-11.4 9-9.8	10.2 (±1) 8.1-12.1 9.8-10.6	9.6 (±1) 7.2-11.6 9.2-10	9.1 (±0.9) 7.5-11.2 8.8-9.6	8.6 (±1) 7.1-11 8.2-9	9.2 (±1) 7.6-11 8.8-9.6	8.6 (±1) 7-10.8 8.2-9	7.8 (±0.8) 6.2-8.9 7.5-8.1	7.3 (±0.8) 5.7-8.5 7-7.6	7.9 (±0.8) 5.8-9.1 7.6-8.2	7.3 (±0.8) 5.2-8.9 7-7.6	6.7 (±0.8) 4.9-7.8 6.4-7	6.1 (±0.8) 4.4-7.2 5.8-6.5	6.9 (±0.8) 4.8-8 6.5-7.2	6.2 (±0.8) 4.5-7.3 5.9-6.6
18-29 years	25	40.5 (±3.8) 32-48 38.9-42.1	38.1 (±3.8) 30-46 36.5-39.7	10.1 (±1) 8-12 9.7-10.5	9.4 (±1) 7.1-11.4 9-9.8	10.2 (±1) 8.1-12.1 9.8-10.6	9.6 (±1) 7.2-11.6 9.2-10	9.1 (±0.9) 7.5-11.2 8.8-9.6	8.6 (±1) 7.1-11 8.2-9	9.2 (±1) 7.6-11 8.8-9.6	8.6 (±1) 7-10.8 8.2-9	7.8 (±0.8) 6.2-8.9 7.5-8.1	7.3 (±0.8) 5.7-8.5 7-7.6	7.9 (±0.8) 5.8-9.1 7.6-8.2	7.3 (±0.8) 5.2-8.9 7-7.6	6.7 (±0.8) 4.9-7.8 6.4-7	6.1 (±0.8) 4.4-7.2 5.8-6.5	6.9 (±0.8) 4.8-8 6.5-7.2	6.2 (±0.8) 4.5-7.3 5.9-6.6

Table 5.3. Female grip and pinch strength (*)

Age	N	DG	NDG	DLP Sit	NDLP Sit	DLP Stand	NDLP Stand	DCP Sit	NCLP Sit	DCP Stand	NDCP Stand	DPP Sit	NDPP Sit	DPP Stand	NDPP Stand
Female	102	27.5(±5.7) 10.5-42 26.4-28.7	25(±5.7) 9.6-38 23.9-26	7.7(±1.2) 4.9-11.1 7.5-7.9	7.1(±1.1) 4.3-9.5 6.9-7.3	7.8(±1.2) 5.1-11 7.5-8	7.2(±1.1) 4.2-9.6 7-7.4	7(±1.1) 4.3-10.5 6.8-7.2	6.4(±1.1) 3.6-9 6.2-6.6	7(±1.1) 3.8-10.2 6.8-7.2	6.4(±1) 4-8.8 6.2-6.6	5.4(±1) 3.3-7.7 5.2-5.6	4.9(±0.9) 2.8-7 4.7-5.1	5.5(±1) 3.4-7.8 5.3-5.7	4.9(±0.9) 2.7-7 4.8-5.1
NMW	62	26.6(±6) 14.5-42 25.1-28.1	24.2(±6.1) 11-38 22.6-25.7	7.6(±1.2) 5.1-11.1 7.3-7.9	6.8(±1.1) 4.3-9.5 6.6-7.1	7.6(±1.2) 5.1-11 7.3-7.9	6.9(±1.1) 4.2-9.6 6.6-7.2	6.7(±1.1) 4.5-10.5 6.5-7	6.1(±1.1) 4-9 5.8-6.4	6.8(±1.1) 4.6-10.2 6.5-7.1	6.2(±1) 4-8.8 5.9-6.4	5.1(±0.8) 3.3-7.1 4.9-5.4	4.7(±0.8) 2.8-6.5 4.5-4.9	5.2(±0.9) 3.4-7.1 5-5.4	4.7(±0.8) 2.7-6.5 4.5-4.9
18-29 years	12	28.9(±5) 21-34 25.7-32.1	27.3(±5.8) 19-36 23.6-30.9	7.8(±1.4) 6.3-10.5 6.9-8.7	7.1(±1.2) 5.5-9.5 6.3-7.9	7.8(±1.2) 6.5-10.4 7.1-8.6	7.2(±1.2) 5.9-9.6 6.4-7.9	6.9(±1.1) 5.4-8.5 6.3-7.6	6.3(±1) 4.8-7.7 5.7-6.9	6.9(±1) 5.4-8.6 6.3-7.6	6.4(±1) 4.7-7.9 5.8-7	5.1(±0.8) 4.2-6.7 4.6-5.6	4.6(±0.8) 3.8-6.3 4.1-5.1	5.3(±0.9) 4.3-7.1 4.7-5.8	4.8(±0.8) 3.8-6.5 4.2-5.3
30-39 years	9	30.2(±6) 22.5-42 25.6-34.8	26.9(±5.6) 20-38 22.6-31.2	7.7(±0.6) 6.8-8.7 7.2-8.2	7.1(±0.6) 6-8 6.6-7.6	7.9(±0.7) 6.7-8.8 7.4-8.4	7.3(±0.6) 6.4-8.5 6.9-7.8	7(±0.4) 6.5-7.8 6.6-7.3	6.4(±0.6) 5.5-7.5 6-6.9	7.2(±0.4) 6.6-7.6 6.9-7.5	6.5(±0.5) 5.6-7.3 6.1-6.9	5.5(±0.5) 5.1-6.6 5.1-5.9	5.1(±0.5) 4.6-6.2 4.7-5.5	5.6(±0.6) 4.9-6.8 5.1-6.1	5(±0.6) 4.3-6.3 4.6-5.5
40-49 years	12	28.6(±4.1) 23.5-36 26-31.2	26.1(±4.9) 19-33 22.9-29.2	7.9(±0.8) 6.3-9 7.4-8.4	7(±0.8) 5.4-8.2 6.4-7.5	7.9(±0.9) 6.4-9.2 7.3-8.5	7(±0.7) 5.8-8 6.5-7.4	7(±0.8) 5.5-8.5 6.4-7.5	6.3(±0.9) 4.6-7.8 5.7-6.8	7(±0.8) 5.7-8.6 6.5-7.5	6.3(±0.7) 5.2-7.7 5.9-6.8	5.3(±0.8) 3.8-7.1 4.8-5.8	4.8(±0.7) 3.5-6.5 4.4-5.3	5.3(±0.7) 3.6-6.5 4.8-5.7	4.8(±0.7) 3.3-6.3 4.4-5.3
50-59 years	16	25.6(±6.1) 17-39 23.4-29.8	24(±5.6) 15.5-35 21-27	8(±1.4) 5.6-11.1 7.2-8.8	7.2(±1.2) 5-9.5 6.6-7.9	8.1(±1.5) 5.5-11 7.3-8.8	7.4(±1.2) 5.1-9.6 6.7-8	7.2(±1.3) 4.6-10.5 6.5-7.9	6.7(±1.2) 4.5-9 6-7.3	7.3(±1.3) 4.6-10.2 6.6-8	6.6(±1.2) 4.4-8.8 6-7.3	5.4(±0.9) 3.9-6.8 4.9-5.9	4.9(±0.8) 3.7-6.1 4.5-5.3	5.4(±1) 3.8-7 4.9-5.9	4.9(±0.9) 3.6-6.4 4.4-5.3
60-69 years	13	20.2(±3.4) 14.5-25 18.2-22.3	17.8(±3.6) 11-23 15.6-20	6.4(±0.7) 5.1-7.5 6-6.9	5.8(±0.8) 4.3-7.4 5.3-6.3	6.5(±0.7) 5.1-7.6 6-6.9	5.8(±0.9) 4.2-7.3 5.3-6.4	5.6(±0.6) 4.5-6.5 5.2-6	4.9(±0.6) 4-6 4.5-5.3	5.7(±0.6) 4.6-6.5 5.3-6	5(±0.6) 4-6.1 4.7-5.4	4.5(±0.8) 3.3-6 4-4.9	4(±0.8) 2.8-5.5 3.6-4.5	4.6(±0.7) 3.4-5.8 4.1-5	4.1(±0.8) 2.7-5.4 3.6-4.5
MW	15	32(±2.6) 26.5-36 30.5-33.5	29.2(±3) 24.5-34 27.6-30.9	8.6(±0.8) 7.4-10.1 8.1-9	7.9(±0.8) 6.6-9.4 7.4-8.4	8.6(±0.8) 7.1-10.2 8.1-9.1	7.9(±0.8) 6.5-9.5 7.5-8.4	8(±1) 6.5-9.5 7.4-8.5	7.2(±0.9) 6-8.8 6.7-7.7	7.9(±0.9) 6.5-9.3 7.4-8.4	7.2(±0.9) 5.9-8.7 6.7-7.7	6.4(±0.8) 5.1-7.7 6-6.8	5.8(±0.8) 4.6-7 5.3-6.2	6.4(±0.9) 4.9-7.8 6-6.9	5.8(±0.8) 4.5-7 5.3-6.2
18-29 years	4	33.1(±3) 29-36 28.3-37.9	31(±2.2) 28-33 27.6-34.4	9.2(±1.2) 7.5-10.1 7.4-11	8.8(±0.8) 7.6-9.4 7.5-10	9.3(±0.9) 8-10.2 7.8-10.8	8.8(±0.7) 7.9-9.5 7.7-9.9	8.6(±0.8) 7.5-9.2 7.4-9.8	8.1(±0.7) 7.1-8.8 6.9-9.2	8.5(±0.8) 7.6-9.3 7.3-9.8	8.1(±0.6) 7.3-8.7 7.1-9	7.2(±0.5) 6.6-7.7 6.5-8	6.6(±0.7) 5.5-7 5.4-7.7	7.3(±0.6) 6.5-7.8 6.4-8.2	6.7(±0.7) 5.7-7 5.6-7.7
30-39 years	7	32.3(±2.1) 28-34.5 30.3-34.2	29.4(±2.9) 25-34 26.8-32.1	8.1(±0.6) 7.4-9.3 7.5-8.6	7.4(±0.7) 6.6-8.6 6.8-8	8(±0.6) 7.1-9.2 7.4-8.6	7.5(±0.6) 6.5-8.5 6.9-8	7.1(±0.7) 6.5-8.4 6.5-7.8	6.5(±0.7) 6-7.9 5.9-7.1	7.3(±0.7) 6.5-8.5 6.6-7.9	6.6(±0.7) 5.9-8 5.9-7.2	5.9(±0.7) 5.1-7.1 5.3-6.5	5.3(±0.7) 4.6-6.6 4.6-6	5.9(±0.8) 4.9-7.2 5.2-6.6	5.4(±0.6) 4.5-6.5 4.8-5.9
40-49 years	4	30.4(±3) 26.5-33.5 25.7-35.1	27.1(±3) 24.5-30 22.3-32	8.7(±0.4) 8.2-9.1 8.1-9.4	8(±0.3) 7.5-8.1 7.5-8.4	8.9(±0.4) 8.3-9.2 8.2-9.5	8(±0.3) 7.6-8.2 7.5-8.4	8.8(±0.7) 7.9-9.5 7.7-9.8	7.7(±0.3) 7.5-8.1 7.2-8.1	8.5(±0.5) 7.8-8.9 7.7-9.3	7.5(±0.3) 7.3-7.9 7.1-7.9	6.5(±0.4) 6.1-6.8 5.9-7.1	5.7(±0.5) 5.1-6.3 4.9-6.5	6.3(±0.6) 5.8-7.1 5.4-7.2	5.6(±0.5) 5.1-6.2 4.8-6.5
Students	25	27.1(±5) 10.5-34 25.1-29.2	24.6(±4.8) 9.6-32 22.6-26.6	7.5(±1) 4.9-9.5 7.1-7.9	7.2(±0.9) 6-9 6.9-7.6	7.7(±1) 5.1-9.7 7.2-8.1	7.3(±0.8) 6.1-8.9 7-7.7	7(±0.9) 4.3-8.9 6.7-7.4	6.5(±0.9) 3.6-7.8 6.1-6.9	7(±1) 3.8-8.8 6.6-7.4	6.6(±0.9) 4.2-8.1 6.2-7	5.4(±0.9) 3.5-7.2 5-5.8	4.9(±0.9) 3-6.7 4.6-5.3	5.5(±1) 3.6-7.3 5.1-5.9	5(±0.9) 3-6.9 4.7-5.4
18-29 years	25	27.1(±5) 10.5-34 25.1-29.2	24.6(±4.8) 9.6-32 22.6-26.6	7.5(±1) 4.9-9.5 7.1-7.9	7.2(±0.9) 6-9 6.9-7.6	7.7(±1) 5.1-9.7 7.2-8.1	7.3(±0.8) 6.1-8.9 7-7.7	7(±0.9) 4.3-8.9 6.7-7.4	6.5(±0.9) 3.6-7.8 6.1-6.9	7(±1) 3.8-8.8 6.6-7.4	6.6(±0.9) 4.2-8.1 6.2-7	5.4(±0.9) 3.5-7.2 5-5.8	4.9(±0.9) 3-6.7 4.6-5.3	5.5(±1) 3.6-7.3 5.1-5.9	5(±0.9) 3-6.9 4.7-5.4

* (Numbers in each cell indicate mean (standard deviation); range and 95% confidence interval of the mean, respectively in kgf)

5.2. Percentiles

For reference purposes, percentile values were calculated. The 5th, 50th and 95th percentile values for each pinch strength measurement are stated in Table 5.4 for males and females. The notations that are used in the table are the same as in the descriptive statistics tables.

Table 5.4. Percentiles for males and females in each test position

	MALES				FEMALES			
STRENGTH TYPE	**Std. Dev.**	**5,0**	**50,0**	**95,0**	**Std. Dev.**	**5,0**	**50,0**	**95,0**
DG	6.8	32.5	43.7	54.9	5.7	18.2	27.5	36.9
NDG	6.8	29.5	40.7	51.9	5.7	15.7	25.0	34.4
DLPSit	1.2	9.0	11.0	13.0	1.2	5.8	7.7	9.6
NDLPSit	1.2	8.3	10.3	12.2	1.1	5.3	7.1	8.8
DLPStand	1.3	9.1	11.1	13.2	1.2	5.9	7.8	9.7
NDLPStand	1.2	8.4	10.4	12.4	1.1	5.5	7.2	8.9
DCPSit	1.3	7.8	9.9	11.9	1.1	5.1	7.0	8.8
NDCPSit	1.2	7.2	9.1	11.1	1.1	4.6	6.4	8.2
DCPStand	1.3	7.9	10.0	12.1	1.1	5.2	7.0	8.8
NDCPStand	1.2	7.2	9.2	11.2	1.0	4.7	6.4	8.1
DPPSit	1.1	6.1	7.8	9.6	1.0	3.8	5.4	6.9
NDPPSit	1.1	5.5	7.2	9.0	0.9	3.4	4.9	6.4
DPPStand	1.1	6.1	7.9	9.8	1.0	3.9	5.5	7.1
NDPPStand	1.1	5.5	7.3	9.1	0.9	3.4	4.9	6.4
DTPSit	1.1	5.2	7.0	8.7				
NDTPSit	1.0	4.7	6.3	8.0				
DTPStand	1.1	5.2	7.0	8.8				
NDTPStand	1.1	4.6	6.4	8.2				

The percentile values of dominant hand pinch strength for different age and occupation groups in sitting posture are displayed in Table 5.5 and 5.6 for males and females. The notations that are used in the tables are as the following:

GS for Grip Strength
LPS for Lateral Pinch Strength
CPS for Three-Jaw Chuck Pinch Strength
PPS for Pulp Pinch Strength
TPS for Tip Pinch Strength

Table 5.5. Percentiles for male and female dominant hand pinch strength according to age groups in sitting posture

MALES							FEMALES			
AGE GROUPS	**Std.dev. and percentiles**	**GS**	**LPS**	**CPS**	**PPS**	**TPS**	**GS**	**LPS**	**CPS**	**PPS**
18 – 29	std.dev.	5.66	1.13	1.19	0.95	0.97	5.09	1.21	1.06	1.03
	5	34.21	8.84	7.71	6.29	5.27	19.87	5.76	5.42	3.80
	50	43.53	10.71	9.66	7.84	6.86	28.24	7.76	7.16	5.49
	95	52.85	12.57	11.62	9.40	8.45	36.62	9.76	8.91	7.18
30 – 39	std.dev.	6.60	1.19	1.13	1.14	1.35	4.68	0.62	0.53	0.59
	5	36.28	9.53	8.24	5.94	4.69	23.39	6.84	6.17	4.71
	50	47.14	11.49	10.10	7.81	6.90	31.09	7.86	7.04	5.68
	95	57.99	13.45	11.96	9.69	9.11	38.79	8.88	7.92	6.64
40 – 49	std.dev.	6.59	1.27	1.73	1.10	1.04	3.85	0.79	1.11	0.89
	5	35.83	9.58	7.54	6.35	5.49	22.73	6.79	5.59	4.12
	50	46.68	11.66	10.38	8.15	7.20	29.06	8.09	7.41	5.58
	95	57.52	13.75	13.22	9.96	8.91	35.39	9.39	9.24	7.03
50 – 59	std.dev.	6.67	1.38	1.07	1.22	0.83	6.08	1.44	1.30	0.90
	5	28.81	8.51	8.12	5.86	5.92	16.59	5.62	5.11	3.90
	50	39.79	10.78	9.87	7.87	7.29	26.59	7.99	7.24	5.38
	95	50.76	13.05	11.63	9.88	8.65	36.60	10.37	9.37	6.86
60 – 69	std.dev.	2.80	0.57	0.54	0.96	0.73	3.38	0.73	0.64	0.75
	5	30.64	9.61	8.59	5.55	5.48	14.67	5.24	4.53	3.25
	50	35.25	10.55	9.48	7.13	6.67	20.23	6.44	5.58	4.48
	95	39.86	11.49	10.37	8.71	7.86	25.80	7.64	6.64	5.71

Table 5.6. Percentiles for male and female dominant hand pinch strength according to occupation groups in sitting posture

MALES							FEMALES			
OCCUPATION GROUPS	**Std.dev. and percentiles**	**GS**	**LPS**	**CPS**	**PPS**	**TPS**	**GS**	**LPS**	**CPS**	**PPS**
Non-Manual Workers	std.dev.	6.11	1.07	1.24	1.13	1.03	6.00	1.21	1.11	0.84
	5	31.03	9.13	7.86	5.89	5.28	16.75	5.57	4.92	3.76
	50	41.08	10.90	9.91	7.76	6.98	26.62	7.56	6.74	5.13
	95	51.12	12.66	11.95	9.63	8.68	36.49	9.56	8.56	6.51
Manual Workers	std.dev.	6.13	1.10	1.26	1.11	1.17	2.63	0.84	1.02	0.78
	5	38.59	9.90	8.20	6.08	5.13	27.68	7.17	6.28	5.11
	50	48.67	11.71	10.26	7.91	7.05	32.00	8.55	7.96	6.39
	95	58.75	13.53	12.33	9.74	8.98	36.32	9.92	9.64	7.67
Students	std.dev.	3.84	1.00	0.93	0.79	0.82	5.01	1.01	0.94	0.93
	5	34.18	8.43	7.60	6.50	5.36	18.91	5.85	5.49	3.87
	50	40.50	10.08	9.14	7.80	6.70	27.14	7.51	7.04	5.40
	95	46.82	11.72	10.68	9.09	8.05	35.37	9.17	8.58	6.94

5.3. Correlation Analysis

Correlation analyses (Pearson) were performed for both gender data seperately. The correlation coefficients between each pinch strength type and age, occupation, BMIP, hand and posture of the participants are provided in Table 5.7 through Table 5.10.

Occupation and hand were found significantly and negatively correlated with male lateral pinch strength (LPS) and BMIP was found significantly and positively correlated with male lateral pinch strength. But age and posture were not found significant. For females, age was significantly and negatively correlated with lateral pinch strength. Negative correlation of hand with LPS indicates that from dominant to non-dominant hand pinch strength decreases. Positive correlation of occupation with LPS means that from non-manual to manual workers pinch strength increases. But BMIP and posture were not found significantly correlated (Table 5.7).

Table 5.7 Correlations for lateral pinch strength

MALES		Age Group	Occupation Group	BMIP Group	Posture Group	Hand Group
Lateral Pinch strength	Coefficient	-0.02	-0.15	0.12	0.05	-0.28
	P-value	0.66	0.00	0.01	0.27	0.00
FEMALES						
Lateral Pinch strength	Coefficient	-0.27	0.12	0.00	0.04	-0.27
	P-value	0.00	0.01	0.99	0.46	0.00

The results for chuck pinch strength indicated that occupation and hand were negatively correlated with male chuck pinch strength. For females age and hand were negatively correlated whereas occupation was positively correlated with female chuck pinch strength (Table 5.8).

Table 5.8 Correlations for chuck pinch strength

MALES		Age Group	Occupation Group	BMIP Group	Posture Group	Hand Group
Chuck Pinch strength	Coefficient	0.00	-0.12	-0.05	0.02	-0.30
	P-value	0.99	0.01	0.29	0.61	0.00
FEMALES						
Chuck Pinch strength	Coefficient	-0.30	0.18	-0.04	0.02	-0.27
	P-value	0.00	0.00	0.41	0.71	0.00

Male pulp pinch strength was found to be negatively correlated with age and hand whereas female pulp pinch strength was negatively correlated with age and hand and positively correlated with occupation factors (Table 5.9).

Table 5.9 Correlations for pulp pinch strength

MALES		Age Group	Occupation Group	BMIP Group	Posture Group	Hand Group
Pulp Pinch strength	Coefficient	-0.10	0.05	-0.05	0.04	-0.27
	P-value	0.03	0.26	0.26	0.39	0.00
FEMALES						
Pulp Pinch strength	Coefficient	-0.27	0.20	-0.03	0.03	-0.27
	P-value	0.00	0.00	0.59	0.52	0.00

Tip pinch strength was only measured for males. The results indicated that only hand factor was significantly and negatively correlated with male tip pinch strength (Table 5.10).

Table 5.10 Correlations for tip pinch strength

MALES		Age Group	Occupation Group	BMIP Group	Posture Group	Hand Group
Tip Pinch strength	Coefficient	0.02	-0.05	-0.05	0.04	-0.27
	P-value	0.64	0.25	0.28	0.41	0.00

The general results from correlation analysis indicate that age is not significantly correlated with male pinch strength (except pulp pinch); but significantly and negatively correlated with female pinch strength. Occupation was negatively correlated with pinch strength for males and positively correlated with females. It was not significantly correlated with male pulp and tip pinch strength. BMIP was only positively correlated with male lateral pinch strength. Posture was not found significantly correlated in any of the pinch strength types for both genders. Hand was the only factor which was negatively correlated with each pinch strength type for both genders.

The results of correlation analysis for pinch strength types and anthropometric body dimensions are given in tables 5.11, 5.12, 5.13 and 5.14. Results indicated that circumference of forearm (CFO) and circumference of fist (CFI) were significantly and positively correlated with each pinch strength type for both genders. Forearm-hand length (LF) was found as a significant factor (positively correlated) for females but not for males.

Table 5.11 Correlations between lateral pinch strength and body dimensions

MALES		CFO	CFI	LF
Lateral Pinch strength	Coefficient	0.32	0.39	0.03
	P-value	0.00	0.00	0.51
FEMALES				
Lateral Pinch strength	Coefficient	0.20	0.26	0.32
	P-value	0.00	0.00	0.00

Table 5.12 Correlations between chuck pinch strength and body dimensions

MALES		CFO	CFI	LF
Chuck Pinch strength	Coefficient	0.21	0.29	-0.01
	P-value	0.00	0.00	0.79
FEMALES				
Chuck Pinch strength	Coefficient	0.13	0.16	0.22
	P-value	0.01	0.00	0.00

Table 5.13 Correlations between pulp pinch strength and body dimensions

MALES		CFO	CFI	LF
Pulp Pinch strength	Coefficient	0.26	0.21	-0.01
	P-value	0.00	0.00	0.89
FEMALES				
Pulp Pinch strength	Coefficient	0.21	0.14	0.16
	P-value	0.00	0.00	0.00

Table 5.14 Correlations between tip pinch strength and body dimensions

MALES		CFO	CFI	LF
Tip Pinch strength	Coefficient	0.27	0.30	-0.08
	P-value	0.00	0.00	0.09

5.4. Multiple Analysis of Variance

The assumptions of the analysis were checked at the beginning of multiple analysis of variance (MANOVA) process.

- Independent Random Sampling: There is not any pattern in choosing the sample and the number of measurements in each cell is greater than the number of dependent variables; therefore this assumption is met.

- Level and Measurement of the Variables: The independent variables (age-group, occupation-group, BMIP-group, posture-group and hand-group) are categorical and the dependent variable (pinch strength) is continuous, therefore this assumption is also met.

- Linearity of dependent variables: The pinch strength types as dependent variables are moderately correlated as shown in table 5.15 and 5.16. This assumption is met for both males and females.

Table 5.15. Linearity of dependent variables assumption table for males

MALES		Lateral	Chuck	Pulp	Tip
Lateral	Pearson Correlation	1.00	0.71	0.52	0.50
	P-value		0.00	0.00	0.00
Chuck	Pearson Correlation	0.71	1.00	0.66	0.64
	P-value	0.00		0.00	0.00
Pulp	Pearson Correlation	0.52	0.66	1.00	0.76
	P-value	0.00	0.00		0.00
Tip	Pearson Correlation	0.50	0.64	0.76	1.00
	P-value	0.00	0.00	0.00	

Table 5.16. Linearity of dependent variables assumption table for females

FEMALES		Lateral	Chuck	Pulp
Lateral	Pearson Correlation	1.00	0.80	0.78
	P-value		0.00	0.00
Chuck	Pearson Correlation	0.80	1.00	0.79
	P-value	0.00		0.00
Pulp	Pearson Correlation	0.78	0.79	1.00
	P-value	0.00	0.00	

- Multivariate Normality: Normality check can be done by looking at the distribution of residuals. Figure 5.1 to 5.7 show the normality plots of residuals for every pinch type and for each gender. By looking at the figures, it can be said that normality is checked.

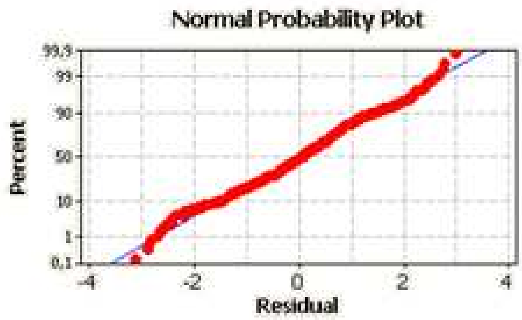

Figure 5.1. Normal probability plot for male lateral pinch strength

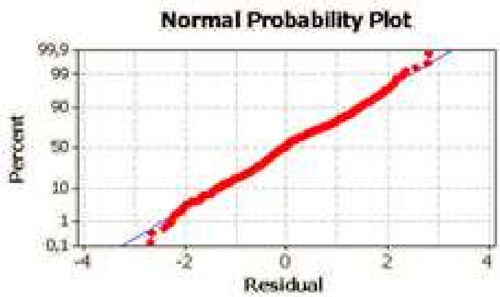

Figure 5.2. Normal probability plot for male chuck pinch strength

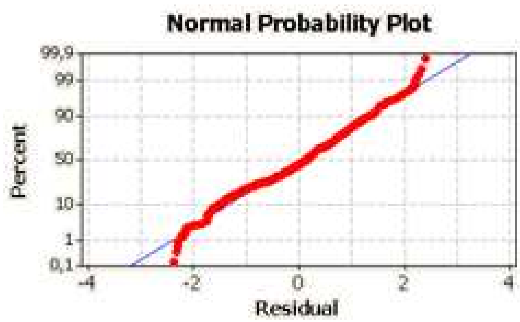

Figure 5.3. Normal probability plot for male pulp pinch strength

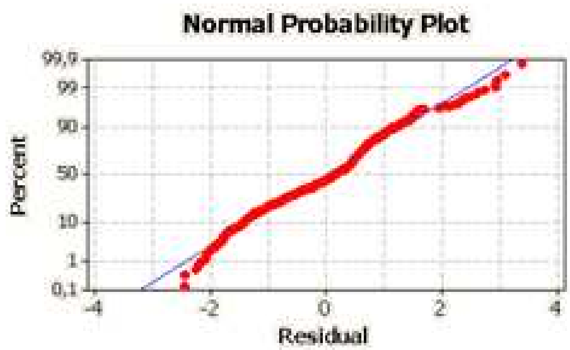

Figure 5.4. Normal probability plot for male tip pinch strength

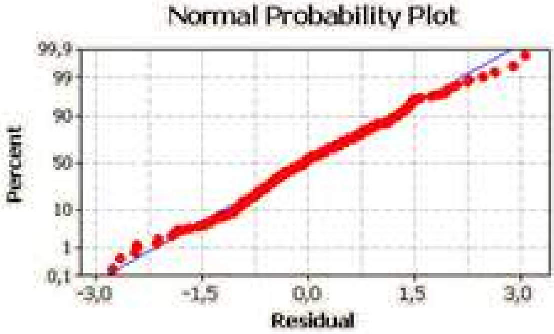

Figure 5.5. Normal probability plot for female lateral pinch strength

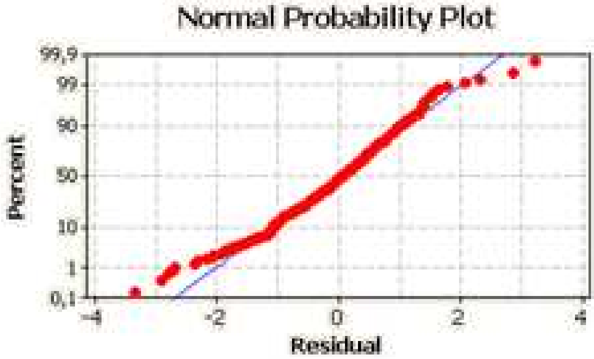

Figure 5.6. Normal probability plot for female chuck pinch strength

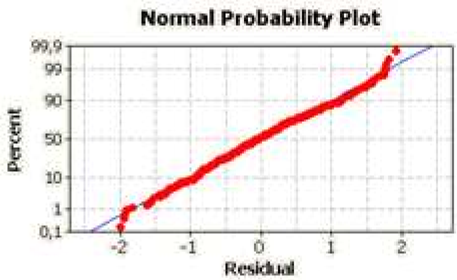

Figure 5.7. Normal probability plot for female pulp pinch strength

- Multivariate Homogeneity of Variance: Bartlett's test results (Table 5.17) show that the variances accross groups are equal except female lateral pinch strength. It is accepted that variances across groups are equal.

Table 5.17. Homogeneity of variance table for males and females

MALE			
Variable name	**Criterion**	**Test-Statistic**	**P-value**
Lateral Pinch	Bartlett's Test	72.36	0.43
Chuck Pinch	Bartlett's Test	76.92	0.30
Pulp Pinch	Bartlett's Test	70.43	0.50
Tip Pinch	Bartlett's Test	84.31	0.13
FEMALE			
Variable name	**Criterion**	**Test-Statistic**	**P-value**
Lateral Pinch	Bartlett's Test	87.51	0.01
Chuck Pinch	Bartlett's Test	69.76	0.12
Pulp Pinch	Bartlett's Test	29.96	0.99

MANOVA results for males and females are shown in Table 5.18 Wilks' lambda test is used to check the overall significance of the model. It is the widely used test for checking the significance of the model. When the overall model is significant, then we can predict the individual significance of the variable. Results of MANOVA indicate that age, occupation, BMIP and used hand have a significant effect on pinch strength. But body posture (sitting or standing) is proved to have no effect on pinch strength. The results are the same for both males and females.

Table 5.18. Manova results for males and females

MALES				
Variable name	**Criterion**	**Test-Statistic**	**F-Value**	**P-Value**
Age	Wilks' Lambda	0.90	3.19	0.00
Occupation	Wilks' Lambda	0.80	13.67	0.00
BMIP	Wilks' Lambda	0.96	5.31	0.00
Posture	Wilks' Lambda	1.00	0.54	0.71
Hand	Wilks' Lambda	0.87	17.22	0.00
FEMALES				
Variable name	**Criterion**	**Test-Statistic**	**F-Value**	**P-Value**
Age	Wilks' Lambda	0.70	12.61	0.00
Occupation	Wilks' Lambda	0.82	13.44	0.00
BMIP	Wilks' Lambda	0.94	4.47	0.00
Posture	Wilks' Lambda	1.00	0.33	0.81
Hand	Wilks' Lambda	0.88	18.47	0.00

After running the MANOVA, the effects of factors for each dependent variable are tested using univariate ANOVA technique.

Tables 5.19 through Table 5.22 present the ANOVA results for lateral, chuck, pulp and tip pinch strength of males. The results of MANOVA analysis indicate that only posture effect was not a significant factor in affecting pinch strength and all the other factors were significantly effective. The univariate analysis provides the significance values of factors in each pinch strength type.

In general, posture (sitting or standing) was a non-significant factor in each pinch strength type. Age and hand factors were found as significant factors for each of the pinch strength types. Tip pinch strength did not change according to occupation groups therefore the significant values of MANOVA results comes from lateral and chuck pinch strength. BMIP was only found significant in the lateral pinch strength results. The details of the results are given below.

Results indicate that male lateral pinch is significantly affected by age, occupation and hand factors whereas BMIP and posture has an effect which is not significant (Table 5.19).

Table 5.19. Analysis of variance results for lateral pinch strength of males

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F value**	**P value**
Age	4	68.92	17.26	4.32	3.80	0.01
Occupation	2	103.76	102.08	51.04	44.99	0.00
BMIP	1	1.64	1.64	1.64	1.45	0.23
Posture	1	1.96	1.96	1.96	1.73	0.19
Hand	1	62.27	62.27	62.27	54.89	0.00
Error	474	537.70	537.70	1.13		
Total	483	776.25				

It is seen from table 5.20 that except posture effect, all factors significantly affect male chuck pinch strength. This result is the same as the general MANOVA results.

Table 5.20. Analysis of variance results for chuck pinch strength of males

Source	DF	Seq SS	Adj SS	Adj MS	F value	P value
Age	4	41.31	16.08	4.02	3.01	0.02
Occupation	2	47.54	50.30	25.15	18.80	0.00
BMIP	1	9.35	9.35	9.35	6.99	0.01
Posture	1	0.45	0.45	0.45	0.33	0.56
Hand	1	70.33	70.33	70.33	52.58	0.00
Error	474	634.03	634.03	1.34		
Total	483	803.00				

The ANOVA results for male pulp pinch strength indicate that only age and hand has a significant effect. Occupation, BMIP and posture were not found as significant factors affecting male pulp pinch strength (Table 5.21).

Table 5.21. Analysis of variance results for pulp pinch strength of males

Source	DF	Seq SS	Adj SS	Adj MS	F value	P value
Age	4	32.80	27.86	6.97	6.38	0.00
Occupation	2	1.28	1.40	0.70	0.64	0.53
BMIP	1	1.48	1.48	1.48	1.35	0.25
Posture	1	0.93	0.93	0.93	0.85	0.36
Hand	1	43.32	43.32	43.32	39.67	0.00
Error	474	517.65	517.65	1.09		
Total	483	597.45				

Table 5.22 provides the ANOVA results for male tip pinch strength. Results indicate that age and hand has a significant effect on tip pinch strength whereas occupation, BMIP and posture effects were not significant.

Table 5.22. Analysis of variance results for tip pinch strength of males

Source	DF	Seq SS	Adj SS	Adj MS	F value	P value
Age	4	13.94	11.88	2.97	2.68	0.03
Occupation	2	4.70	5.09	2.54	2.30	0.10
BMIP	1	2.62	2.62	2.62	2.37	0.13
Posture	1	0.82	0.82	0.82	0.74	0.39
Hand	1	42.30	42.30	42.30	38.22	0.00
Error	474	524.57	524.57	1.11		
Total	483	588.95				

Tables 5.23, 5.24 and 5.25 present the ANOVA results for females. Age, occupation and hand factors were found significant in each pinch strength type. Moreover posture was not a significant factor in any of the pinch strength types. It is seen from the tables that the significant values in MANOVA results for BMIP came from the differences in lateral and pulp pinch strength. The details of the results are stated below.

Results for female lateral pinch strength indicate that age, occupation, BMIP and hand has a significant effect on lateral pinch strength whereas posture is not a significant factor (Table 5.23).

Table 5.23. Analysis of variance results for lateral pinch strength of females

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F value**	**P value**
Age	4	101.56	93.92	23.48	26.74	0.00
Occupation	2	34.83	39.19	19.60	22.31	0.00
BMIP	2	12.29	12.29	6.14	7.00	0.00
Posture	1	0.71	0.71	0.71	0.81	0.37
Hand	1	37.69	37.69	37.69	42.92	0.00
Error	397	348.62	348.62	0.88		
Total	407	535.68				

Table 5.24 presents the analysis of variance results for female chuck pinch strength. According to the results BMIP and posture does not affect chuck pinch strength significantly. But age, occupation and hand factors have a significant effect.

Table 5.24. Analysis of variance results for chuck pinch strength of females

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F value**	**P value**
Age	4	118.42	100.62	25.15	31.97	0.00
Occupation	2	41.56	42.22	21.11	26.83	0.00
BMIP	2	3.71	3.71	1.85	2.35	0.10
Posture	1	0.18	0.18	0.18	0.23	0.63
Hand	1	37.08	37.08	37.08	47.12	0.00
Error	397	312.39	312.39	0.79		
Total	407	513.33				

Female pulp pinch strength was found to be affected by age, occupation, BMIP and hand factors. However, results indicate that posture is not a significant factor (Table 5.25).

Table 5.25. Analysis of variance results for pulp pinch strength of females

Source	DF	Seq SS	Adj SS	Adj MS	F value	P value
Age	4	49.61	33.75	8.44	13.43	0.00
Occupation	2	43.66	47.68	23.84	37.95	0.00
BMIP	2	9.17	9.17	4.58	7.30	0.00
Posture	1	0.40	0.40	0.40	0.63	0.43
Hand	1	26.56	26.56	26.56	42.28	0.00
Error	397	249.41	249.41	0.63		
Total	407	378.81				

5.5. Multiple Comparisons

The differences between levels of factors are analyzed by post-hoc analysis. T-tests were performed for factors that have two levels. Tukey's test was performed for unequal sample sizes and factors that have more than two levels. Post hoc analysis was performed for each pinch strength type. Posture differences were not analyzed since it was not found as significant.

5.5.1. Differences Between Pinch Strength Types

Tukey's test was performed to see the differences between lateral, chuck, pulp and pinch strength differences for both genders. Results indicate that there is a significant difference between each pinch strength type for both males and females (Table 5.26 and 5.27).

Leteral pinch strength was found to be the highest and tip pinch strength was found to be the lowest. Between chuck and pulp pinch, chuck pinch strength was higher than pulp pinch strength.

Table 5.26. Tukey's test results for pinch type differences in males

Pinch type difference	Difference of Means	Standard Error	P-value
Lateral - Chuck	1.17	0.08	0.00
Lateral - Pulp	3.12	0.08	0.00
Lateral - Tip	4.03	0.08	0.00
Chuck - Pulp	1.95	0.08	0.00
Chuck - Tip	2.86	0.08	0.00
Pulp - Tip	0.91	0.08	0.00

Table 5.27. Tukey's test results for pinch type differences in females

Pinch type difference	Difference of Means	Standard Error	P-value
Lateral - Chuck	0.72	0.08	0.00
Lateral - Pulp	2.26	0.08	0.00
Chuck - Pulp	1.54	0.08	0.00

5.5.2. Gender Effect

The mean pinch strength differences between males and females are shown in Figure 5.8 for each pinch type. It is clear from the boxplots that mean pinch strength of males are significantly higher than the mean pinch strength of females. T-tests also prove this difference (Table 5.28).

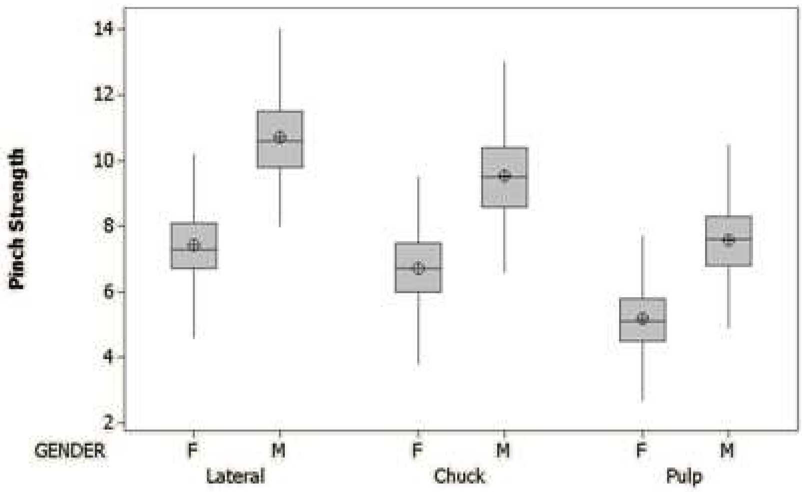

Figure 5.8. Boxplots of pinch strength types stratified by gender (F=Female, M=Male)

Table 5.28. T-test results for gender differences

LATERAL			
Gender difference	Difference of Means	Standard Error	P-value
Male-Female	3.29	0.08	0.00
CHUCK			
Gender difference	Difference of Means	Standard Error	P-value
Male-Female	2.88	0.08	0.00
PULP			
Gender difference	Difference of Means	Standard Error	P-value
Male-Female	2.44	0.07	0.00

5.5.3. Age Effect

Age was found as a significant factor in the MANOVA analysis. The differences between age groups are mentioned in this section.

Figure 5.9 shows the boxplots of male lateral pinch strength according to age groups. It is seen from the figure that lateral pinch strength increases up to group (40-49) and then decreases. The results of Tukey's test support this fact (Table 5.29). Lateral pinch strength is highest in age group 40-49 and lowest in age group 60-69.

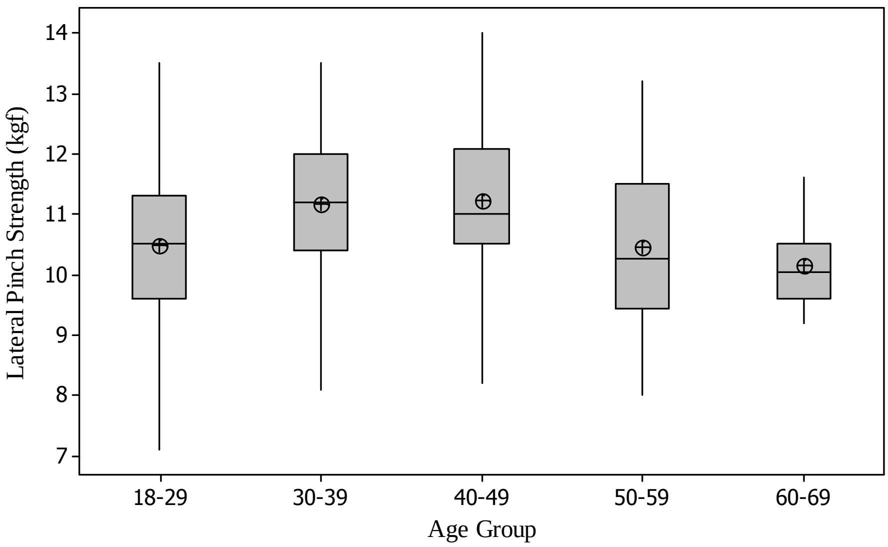

Figure 5.9. Boxplots of lateral pinch strength of males stratified by age

Table 5.29. Tukey's test results for age differences in male lateral pinch strength

Age Group Difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	-0.69	0.12	0.00
(18-29) – (40-49)	-0.74	0.15	0.00
(18-29) – (50-59)	0.04	0.16	1.00
(18-29) – (60-69)	0.33	0.18	0.39
(30-39) – (40-49)	-0.05	0.16	1.00
(30-39) – (50-59)	0.73	0.17	0.00
(30-39) – (60-69)	1.02	0.20	0.00
(40-49) – (50-59)	0.77	0.19	0.00
(40-49) – (60-69)	1.06	0.21	0.00
(50-59) – (60-69)	0.29	0.22	0.68

Figure 5.10 shows the boxplots of female lateral pinch strength according to age groups. Female lateral pinch strength is relatively stable in ages between 18 and 59 but then decreases significantly.

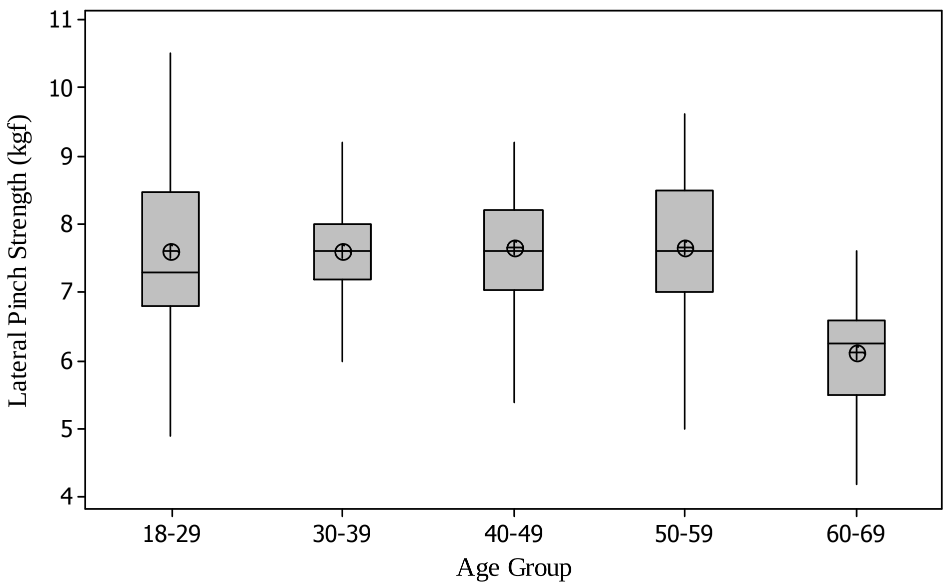

Figure 5.10. Boxplots of lateral pinch strength of females stratified by age

Table 5.30. Tukey's test results for age differences in female lateral pinch strength

Age Group Difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	-0.02	0.14	1.00
(18-29) – (40-49)	-0.06	0.14	0.99
(18-29) – (50-59)	-0.07	0.14	0.99
(18-29) – (60-69)	1.47	0.15	0.00
(30-39) – (40-49)	-0.05	0.17	1.00
(30-39) – (50-59)	-0.05	0.17	1.00
(30-39) – (60-69)	1.49	0.18	0.00
(40-49) – (50-59)	0.00	0.17	1.00
(40-49) – (60-69)	1.53	0.18	0.00
(50-59) – (60-69)	1.53	0.18	0.00

The boxplots of male chuck pinch strength (Figure 5.11) and Tukey's test results (Table 5.31) indicate that male chuck pinch strength increases up to age group 40-49 and then starts to decrease.

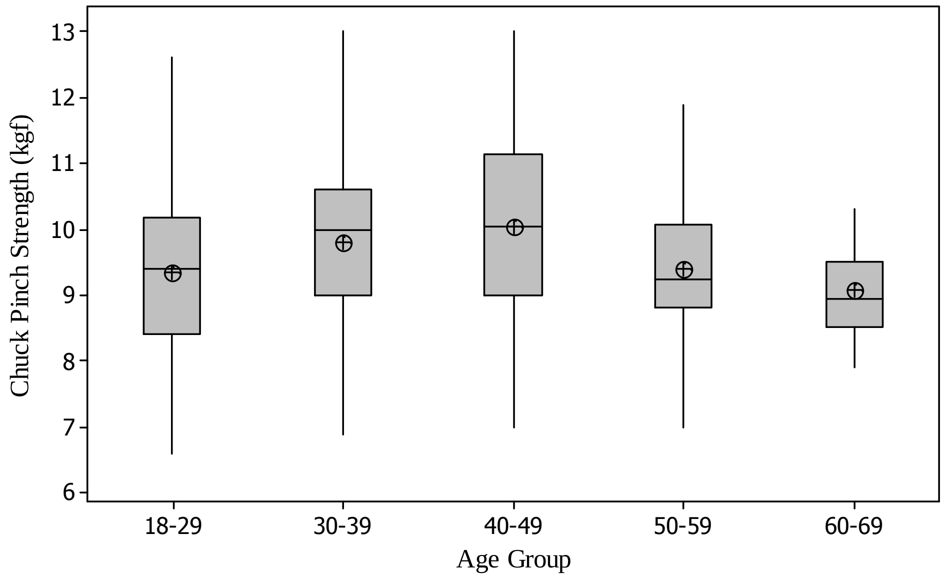

Figure 5.11. Boxplots of chuck pinch strength of males stratified by age

Table 5.31. Tukey's test results for age differences in male chuck pinch strength

Age-group difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	-0.44	0.13	0.01
(18-29) – (40-49)	-0.69	0.16	0.00
(18-29) – (50-59)	-0.04	0.17	1.00
(18-29) – (60-69)	0.28	0.20	0.62
(30-39) – (40-49)	-0.25	0.18	0.63
(30-39) – (50-59)	0.40	0.19	0.22
(30-39) – (60-69)	0.72	0.21	0.01
(40-49) – (50-59)	0.64	0.21	0.02
(40-49) – (60-69)	0.97	0.23	0.00
(50-59) – (60-69)	0.32	0.24	0.66

Female chuck pinch strength differences according to age groups are similar to female lateral pinch strength results. It is seen from the boxplots (Figure 5.12) that female chuck pinch strength is relatively stable between ages 18 and 59 but decreases in age group 60-69. Tukey's test results give the same conclusion (Table 5.32).

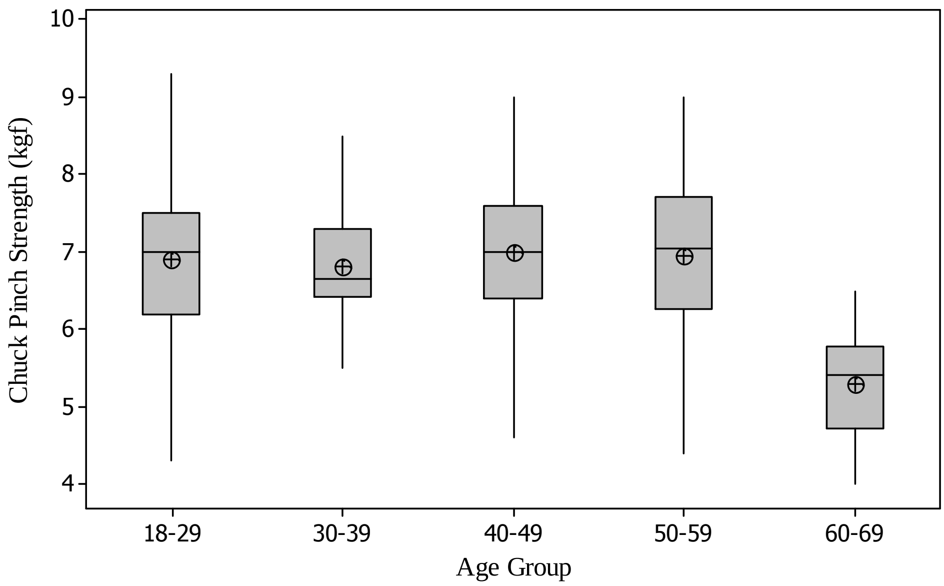

Figure 5.12. Boxplots of chuck pinch strength of females stratified by age

Table 5.32. Tukey's test results for age differences in female chuck pinch strength

Age-group difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	0.09	0.13	0.96
(18-29) – (40-49)	-0.11	0.13	0.93
(18-29) – (50-59)	-0.06	0.13	0.99
(18-29) – (60-69)	1.59	0.14	0.00
(30-39) – (40-49)	-0.19	0.16	0.73
(30-39) – (50-59)	-0.14	0.16	0.89
(30-39) – (60-69)	1.51	0.17	0.00
(40-49) – (50-59)	0.05	0.16	1.00
(40-49) – (60-69)	1.70	0.17	0.00
(50-59) – (60-69)	1.65	0.17	0.00

Pulp pinch strength results for males are given in table 5.33. As it is seen from the boxplots (Figure 5.13), pulp pinch strength is highest in age group 40-49 and lowest in age group 60-69.

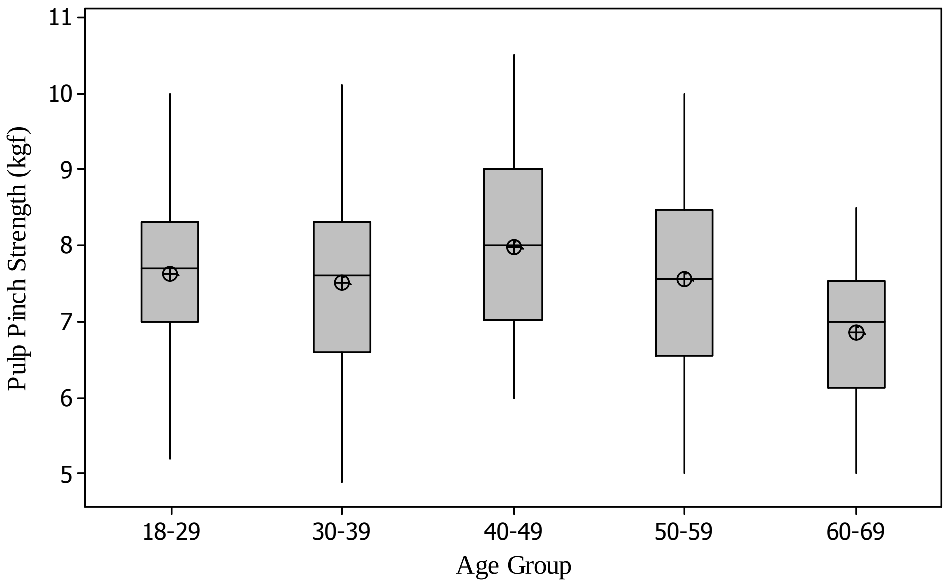

Figure 5.13. Boxplots of pulp pinch strength of males stratified by age

Table 5.33. Tukey's test results for age differences in male pulp pinch strength

Age-group difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	0.11	0.12	0.89
(18-29) – (40-49)	-0.35	0.15	0.13
(18-29) – (50-59)	0.06	0.16	1.00
(18-29) – (60-69)	0.78	0.18	0.00
(30-39) – (40-49)	-0.46	0.16	0.04
(30-39) – (50-59)	-0.05	0.17	1.00
(30-39) – (60-69)	0.67	0.19	0.01
(40-49) – (50-59)	0.41	0.19	0.19
(40-49) – (60-69)	1.12	0.21	0.00
(50-59) – (60-69)	0.71	0.22	0.01

The age group differences in female pulp pinch strength are shown in Figure 5.14. It is seen from the figure that there is a significant decrease in age group 60-69. Tukey's test results indicate that pulp pinch strength of females is stable between ages 18 and 59 and decreases significantly in age group 60-69 (Table 5.34).

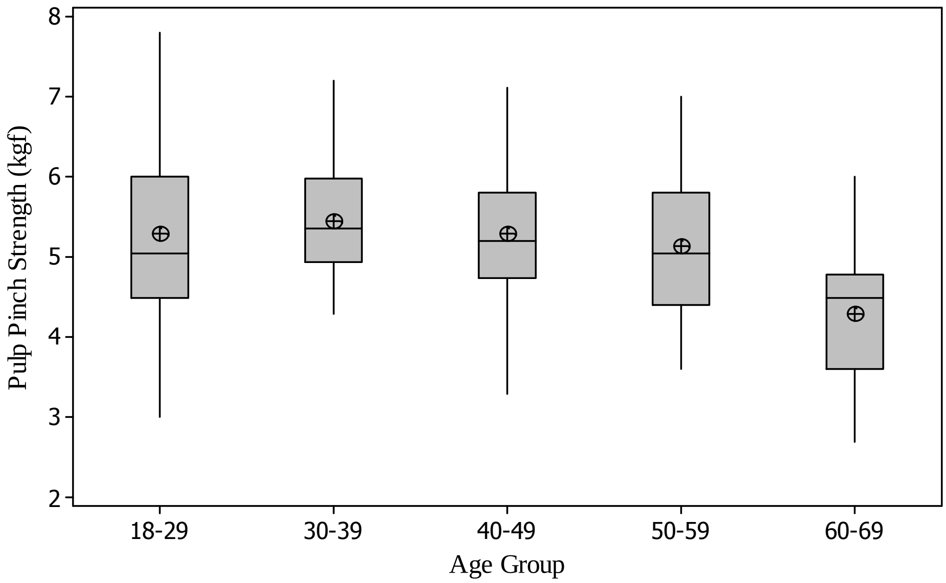

Figure 5.14. Boxplots of pulp pinch strength of females stratified by age

Table 5.34. Tukey’s test results for age differences in female pulp pinch strength

Age-group difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	-0.15	0.12	0.72
(18-29) – (40-49)	0.01	0.12	1.00
(18-29) – (50-59)	0.16	0.12	0.63
(18-29) – (60-69)	1.02	0.13	0.00
(30-39) – (40-49)	0.16	0.14	0.79
(30-39) – (50-59)	0.31	0.14	0.18
(30-39) – (60-69)	1.16	0.15	0.00
(40-49) – (50-59)	0.15	0.14	0.82
(40-49) – (60-69)	1.01	0.15	0.00
(50-59) – (60-69)	0.86	0.15	0.00

Boxplots for male tip pinch strength according to age groups is shown in Figure 5.15. Results of Tukey’s test indicate that there is a significant decrease at age group 60-69, but tip pinch strength is stable between ages 18 and 49 (Table 5.35).

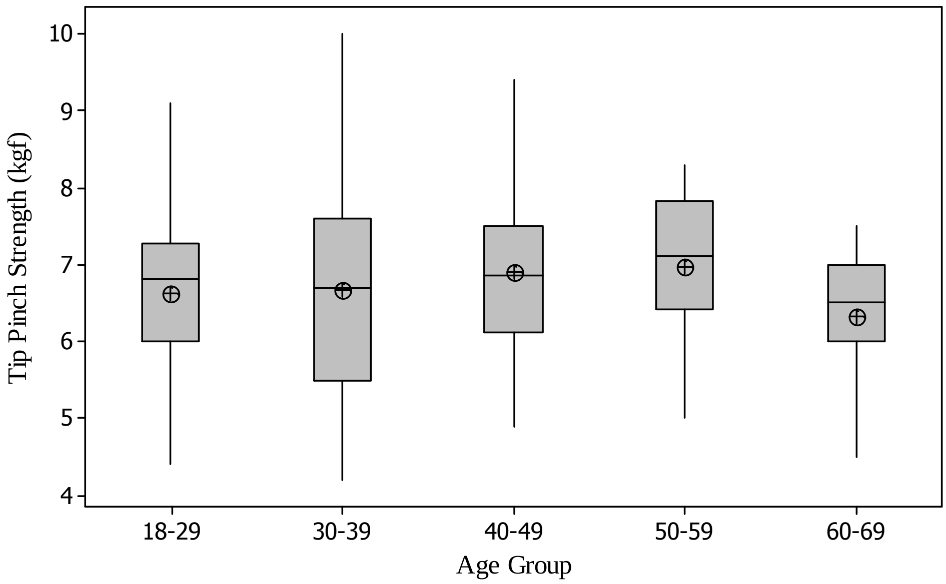

Figure 5.15. Boxplots of tip pinch strength of males stratified by age

Table 5.35. Tukey's test results for age differences in male tip pinch strength

Age-group difference	Difference of Means	Standard Error	P-value
(18-29) – (30-39)	-0.04	0.12	1.00
(18-29) – (40-49)	-0.29	0.15	0.30
(18-29) – (50-59)	-0.34	0.16	0.20
(18-29) – (60-69)	0.30	0.18	0.45
(30-39) – (40-49)	-0.24	0.16	0.55
(30-39) – (50-59)	-0.30	0.17	0.41
(30-39) – (60-69)	0.35	0.19	0.38
(40-49) – (50-59)	-0.05	0.19	1.00
(40-49) – (60-69)	0.59	0.21	0.04
(50-59) – (60-69)	0.64	0.22	0.03

5.5.4. Occupation Effect

Occupation group was found as a significant factor affecting pinch strength. The tests for differences in pinch strength according to occupation groups are mentioned in this section.

Figure 5.16 shows the boxplots male lateral pinch strength according to occupation groups and Table 5.36 presents the Tukey's test results. Results indicate that lateral pinch strength of males is highest in manual workers and lowest in students. The differences between groups were found to be significant.

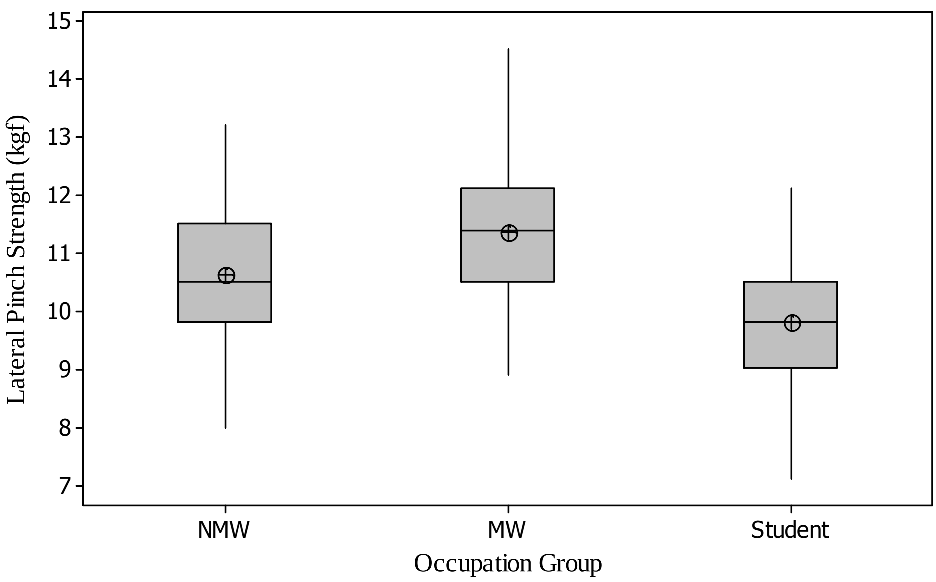

Figure 5.16. Boxplots of lateral pinch strength of males stratified by occupation

Table 5.36. Tukey's test results for occupation differences in male lateral pinch strength

Occupation-group difference	Difference of Means	Standard Error	P-value
Non-Manual – Manual	-0.73	0.11	0.00
Non-Manual – Student	0.81	0.13	0.00
Manual – Student	1.54	0.13	0.00

It is seen from Figure 5.17. that there are differences in lateral pinch strength between groups. But Tukey's test results indicate that the difference between non-manual workers and students is not significant (Table 5.37). The strongest group is manual workers as in male lateral pinch strength.

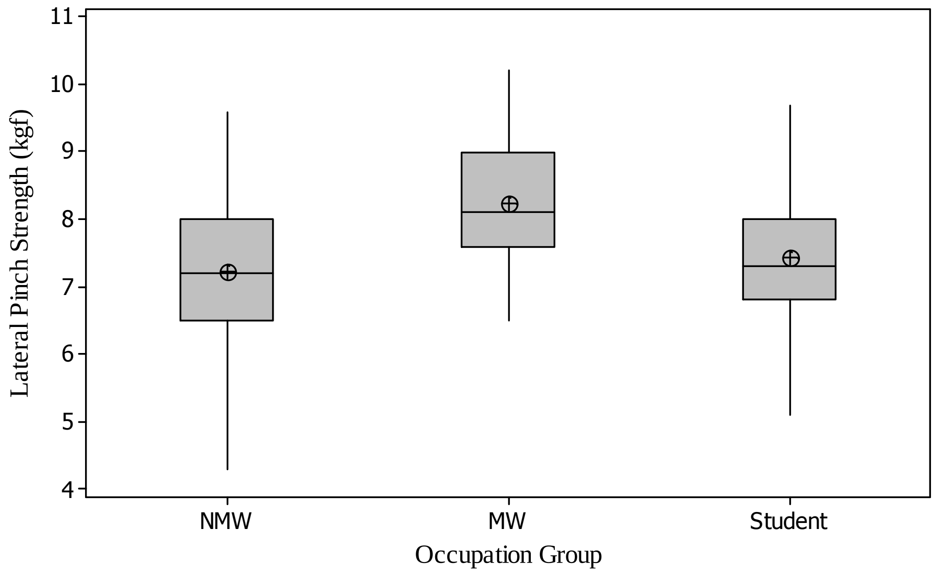

Figure 5.17. Boxplots of lateral pinch strength of females stratified by occupation

Table 5.37. Tukey's test results for occupation differences in female lateral pinch strength

Occupation-group difference	Difference of Means	Standard Error	P-value
Non-Manual – Manual	-1.01	0.13	0.00
Non-Manual – Student	-0.20	0.11	0.18
Manual – Student	0.81	0.15	0.00

Figure 5.18 presents the boxplots for male chuck pinch strength according to occupation groups. The results of Tukey's test indicate that there is a significant difference between each group with manual workers being highest and students being lowest (Table 5.38).

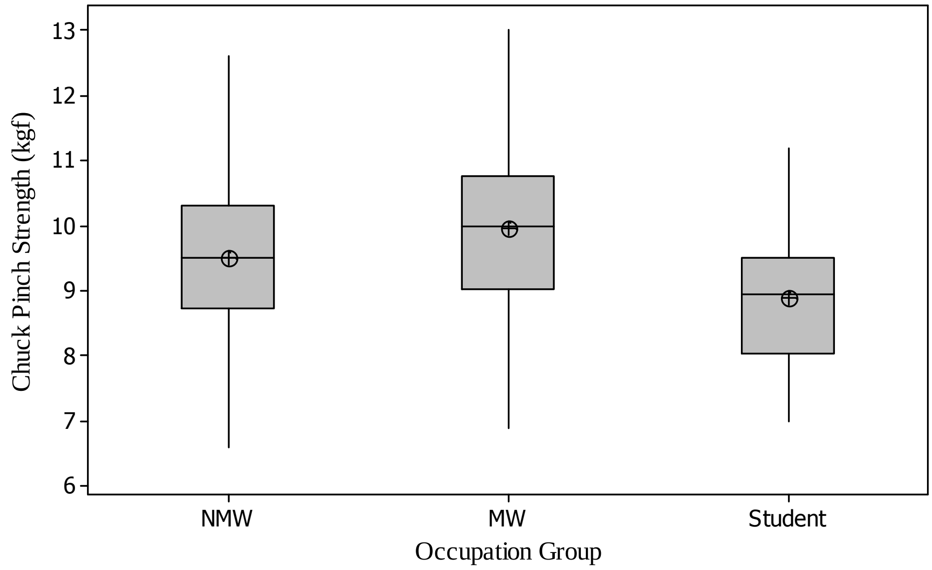

Figure 5.18. Boxplots of chuck pinch strength of males stratified by occupation

Table 5.38. Tukey's test results for occupation differences in male chuck pinch strength

Occupation-group difference	**Difference of Means**	**Standard Error**	**P-value**
Non-Manual – Manual	-0.45	0.12	0.00
Non-Manual – Student	0.62	0.14	0.00
Manual – Student	1.07	0.14	0.00

Chuck pinch strength of females changes according to different age groups. Manual It can be seen from the boxplots (Figure 5.19) and from the results of Tukey's test (Table 5.39) that manual workers are the strongest group.

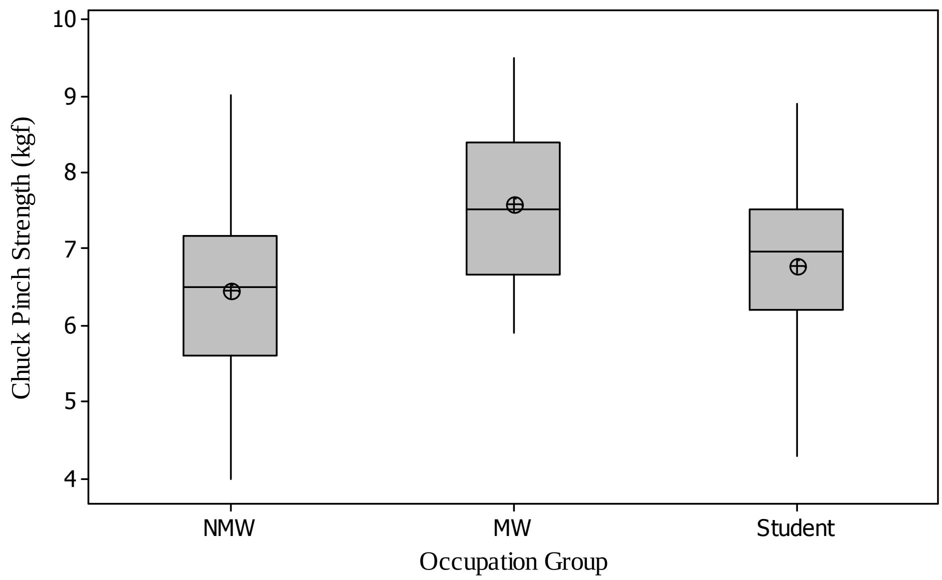

Figure 5.19 Boxplots of chuck pinch strength of females stratified by occupation

Table 5.39. Tukey's test results for occupation differences in female chuck pinch strength

Occupation-group difference	**Difference of Means**	**Standard Error**	**P-value**
Non-Manual – Manual	-1.12	0.13	0.00
Non-Manual – Student	-0.33	0.11	0.01
Manual – Student	0.80	0.14	0.00

Occupation group differences are not the same as other pinch types in male pulp pinch strength. Non manual workers were found to be the weakest but there is not a significant difference between manual workers and students (Figure 5.20 and Table 5.40).

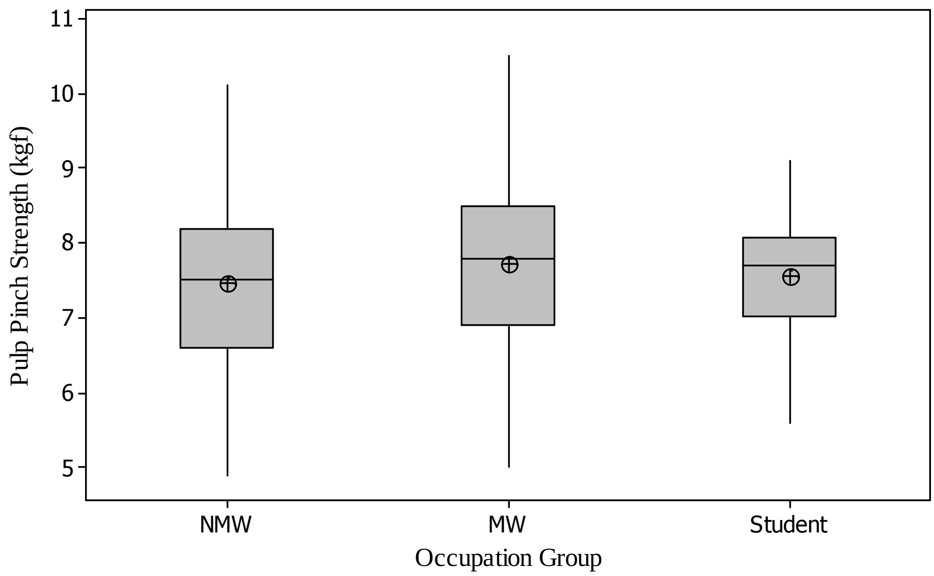

Figure 5.20. Boxplots of pulp pinch strength of males stratified by occupation

Table 5.40. Tukey's test results for occupation differences in male pulp pinch strength

Occupation-group difference	**Difference of Means**	**Standard Error**	**P-value**
Non-Manual – Manual	-0.25	0.11	0.05
Non-Manual – Student	-0.09	0.13	0.76
Manual – Student	0.16	0.13	0.43

Each occupation group was found to be significantly different from each other in female pulp pinch strength with manual workers being the strongest and non-manual workers being the weakest (Table 5.41). These obvious differences can also be seen from the boxplots (Figure 5.21).

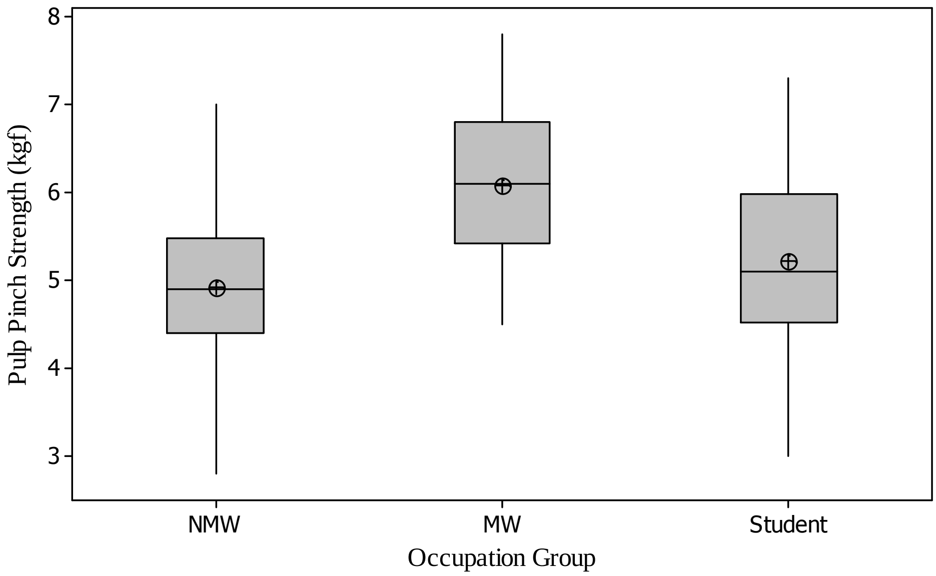

Figure 5.21. Boxplots of pulp pinch strength of females stratified by occupation

Table 5.41. Tukey's test results for occupation differences in female pulp pinch strength

Occupation-group difference	**Difference of Means**	**Standard Error**	**P-value**
Non-Manual – Manual	-1.16	0.11	0.00
Non-Manual – Student	-0.30	0.09	0.00
Manual – Student	0.86	0.13	0.00

It is seen Figure 5.22 that male tip pinch strength is stable between occupation groups. Tukey's test support the result that the differences between occupation groups are not significant (Table 5.42).

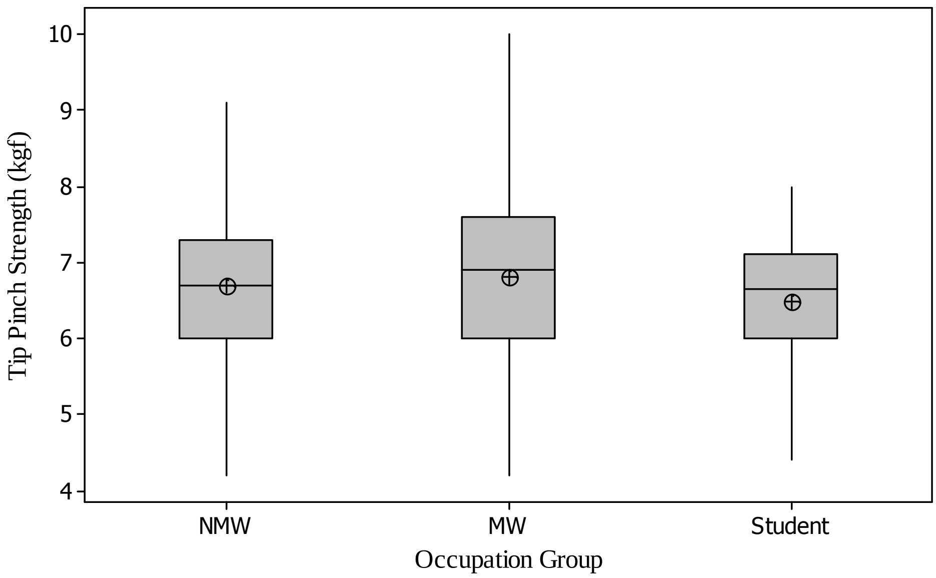

Figure 5.22. Boxplots of tip pinch strength of males stratified by occupation

Table 5.42. Tukey's test results for occupation differences in male tip pinch strength

Occupation-group difference	Difference of Means	Standard Error	P-value
Non-Manual – Manual	-0.11	0.11	0.57
Non-Manual – Student	0.21	0.13	0.23
Manual – Student	0.32	0.13	0.04

5.5.5. BMIP Effect

Male lateral pinch strength values were found to be significantly different between normal and overweight people (Table 5.43). This result can be seen from the boxplots that are provided in Figure 5.23.

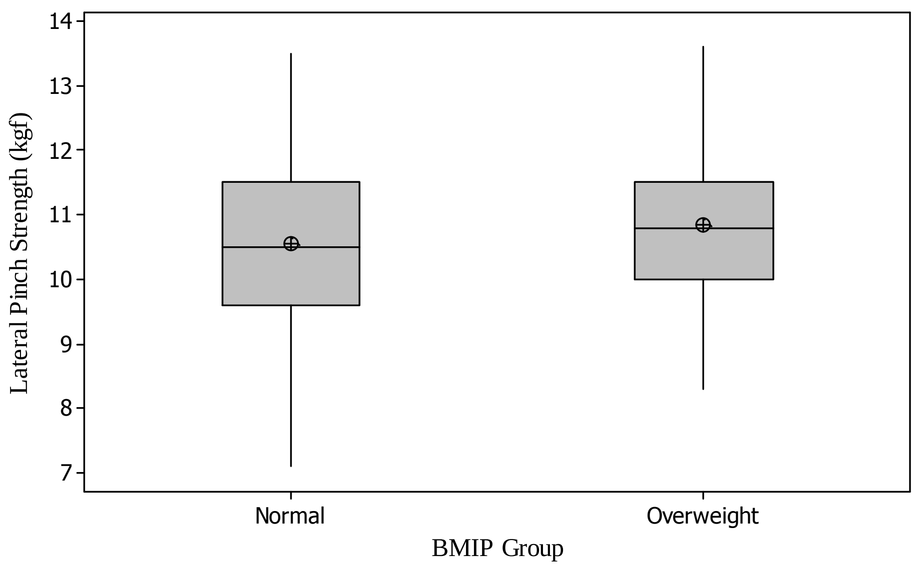

Figure 5.23. Boxplots of lateral pinch strength of males stratified by BMIP

Table 5.43. T-test results for BMIP group differences in male lateral pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Normal – Overweight	-0.30	0.11	0.01

It is seen from the boxplots in Figure 5.24. that female mean lateral pinch strength is not very different between BMIP groups. The results prove the fact that there is not a significant difference between BMIP groups is female lateral pinch strength.

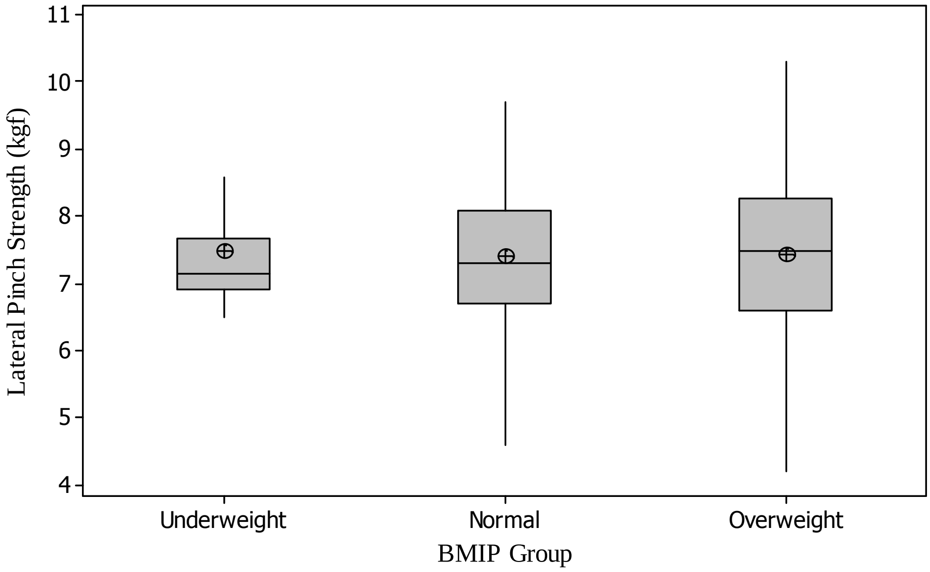

Figure 5.24. Boxplots of lateral pinch strength of females stratified by BMIP

Table 5.44. Tukey's test results for BMIP group differences in female lateral pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Underweight – Normal	0.07	0.17	0.91
Underweight – Overweight	0.04	0.18	0.97
Normal – Overweight	-0.03	0.10	0.95

Figure 5.25 provides the boxplots for male chuck pinch strength and Table 5.45 gives the statistical results. Results indicate that there is not a significant difference between normal and overweight males in chuck pinch strength.

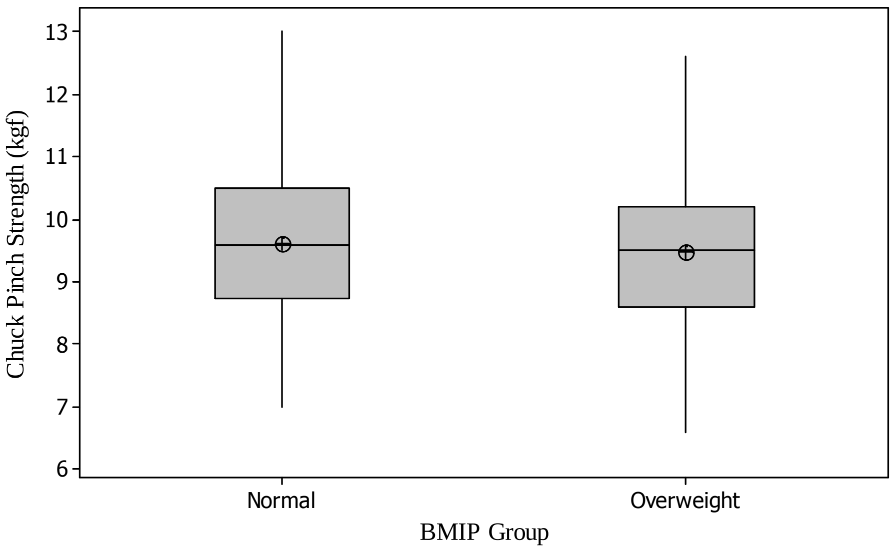

Figure 5.25. Boxplots of chuck pinch strength of males stratified by BMIP

Table 5.45. T-test results for BMIP group differences in male chuck pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Normal – Overweight	0.12	0.12	0.29

Like male chuck pinch strength, female chuck pinch strength is found to be indifferent between BMIP groups. This result can be seen from Figure 5.26 and table 5.46.

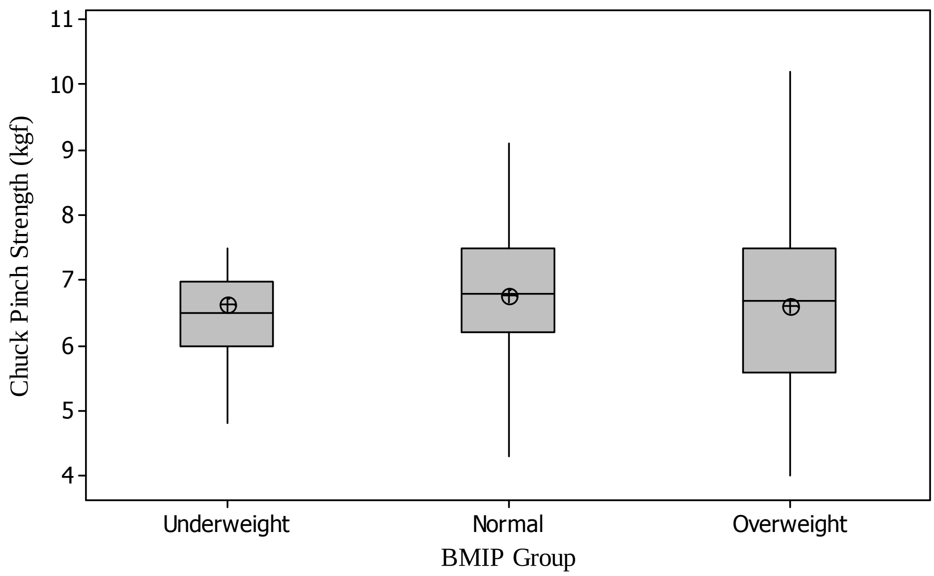

Figure 5.26. Boxplots of chuck pinch strength of females stratified by BMIP

Table 5.46. Tukey's test results for BMIP group differences in female chuck pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Underweight – Normal	-0.15	0.16	0.61
Underweight – Overweight	0.02	0.17	0.99
Normal – Overweight	0.17	0.09	0.16

Figure 5.27 and Figure 5.28 provide boxplots for male and female pulp pinch strength according to BMIP groups. It is seen from the boxplots that there is not much change in mean values of BMIP groups for both genders. The results of tests confirm this idea and indicate that the differences between BMIP groups are not significant for both genders (Table 5.47 and 5.48).

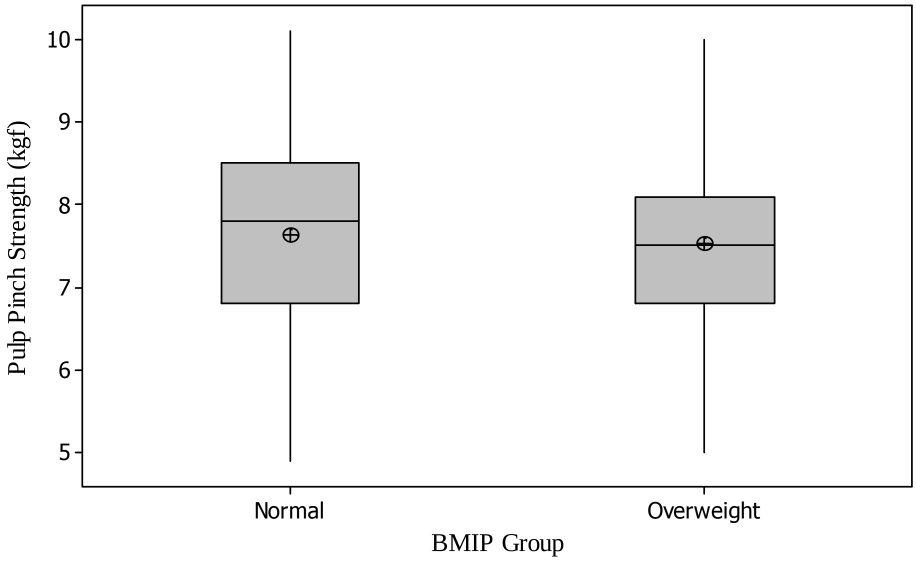

Figure 5.27. Boxplots of pulp pinch strength of males stratified by BMIP

Table 5.47. T-test results for BMIP group differences in male pulp pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Normal – Overweight	0.11	0.10	0.26

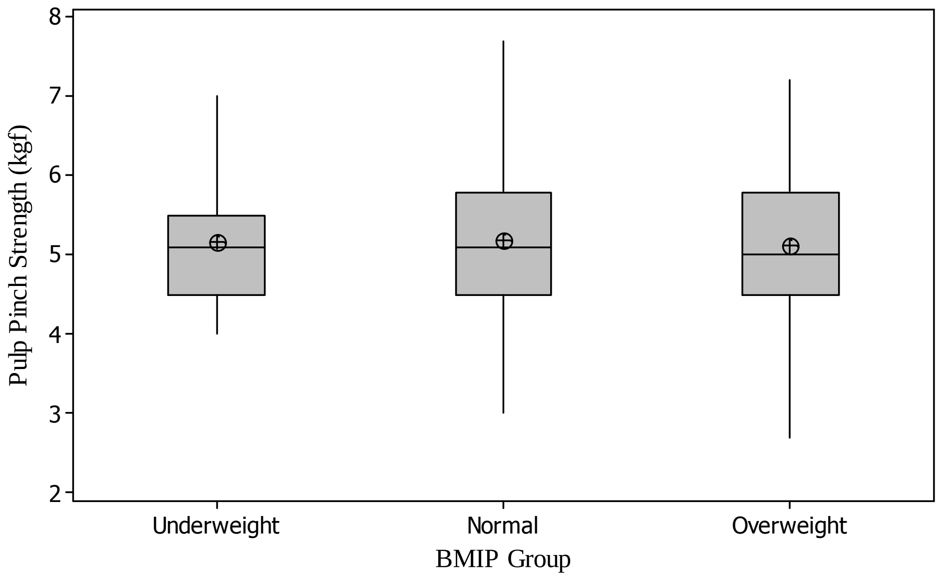

Figure 5.28. Boxplots of pulp pinch strength of females stratified by BMIP

Table 5.48. Tukey's test results for BMIP group differences in female pulp pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Underweight – Normal	-0.02	0.14	0.99
Underweight – Overweight	0.05	0.15	0.95
Normal – Overweight	0.07	0.08	0.68

The boxplots for tip pinch strength of males are seen in Figure 5.29. The results of t-test indicate that the strength differences between normal and overweight people are not significant (Table 5.49).

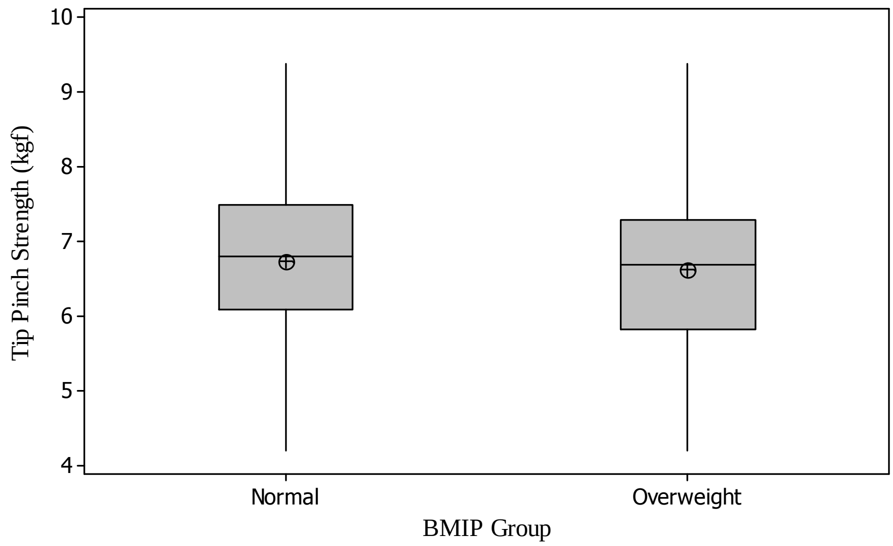

Figure 5.29. Boxplots of tip pinch strength of males stratified by BMIP

Table 5.49. T-test results for BMIP group differences in male tip pinch strength

BMIP-group difference	Difference of Means	Standard Error	P-value
Normal – Overweight	0.11	0.10	0.28

5.5.6. Hand Effect

Hand factor was found as a significant factor in the MANOVA results. The boxplots in this section provides a visual display of differences between hand groups for each pinch strength type and gender (Figure 5.30, Figure 5.31, Figure 5.32, Figure 5.33, Figure 5.34, Figure 5.35, and Figure 5.36). Paired t -test results prove that dominant and non-dominant hand pinch strengths are significantly different for each pinch strength type and gender

(Table 5.50, Table 5.51, Table 5.52, Table 5.53, Table 5.54, Table 5.55, and Table 5.56). Pinch strength of dominant hand was found to be stronger than non-dominant hand.

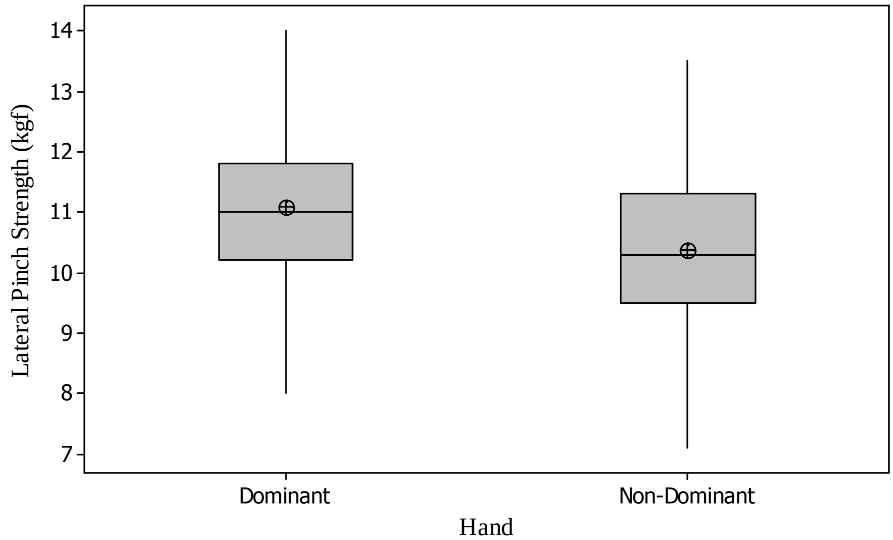

Figure 5.30. Boxplots of lateral pinch strength of males stratified by hand

Table 5.50. Paired t-test results for hand group differences in male lateral pinch strength

Hand-group difference	**Difference of Means**	**Standard Error**	**P-value**
Dominant - Non-Dominant	0,72	0,03	0,00

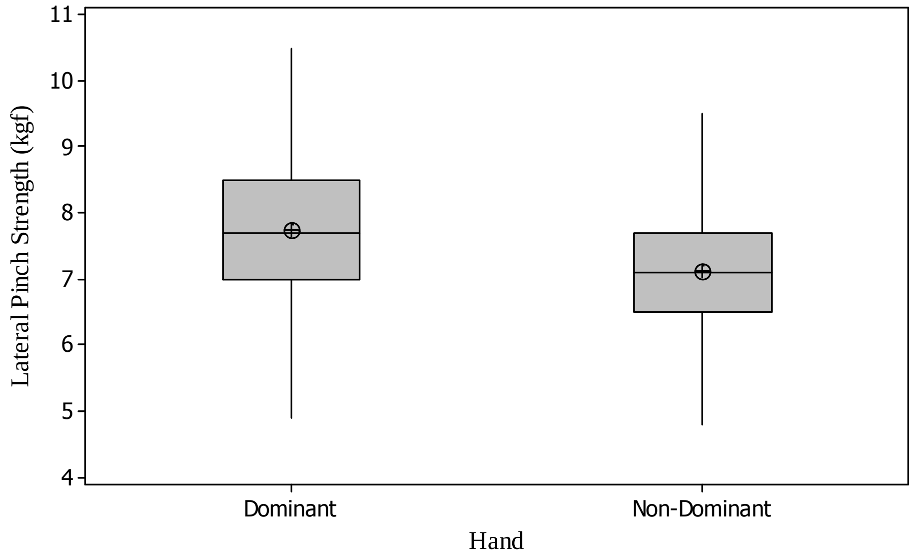

Figure 5.31. Boxplots of lateral pinch strength of females stratified by hand

Table 5.51. Paired t-test results for hand group differences in female lateral pinch strength

Hand-group difference	Difference of Means	Standard Error	P-value
Dominant - Non-Dominant	0,61	0,03	0,00

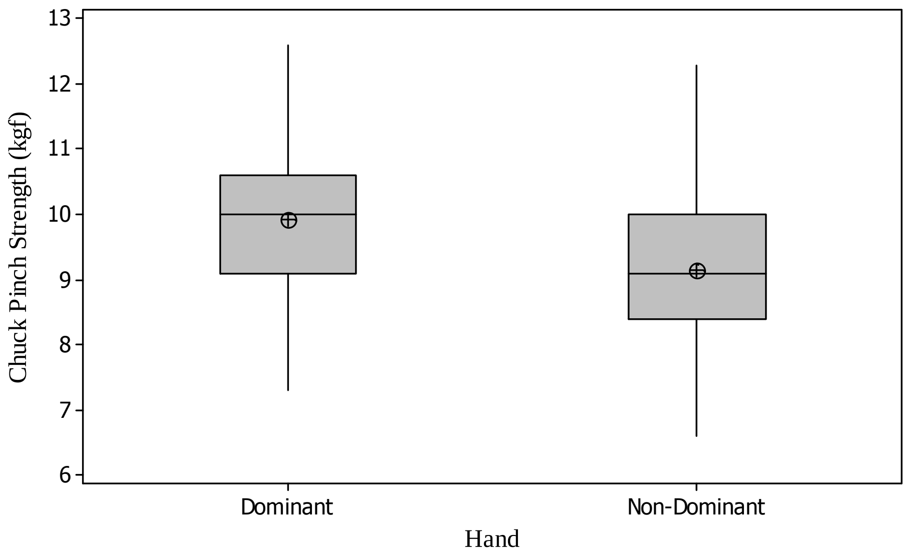

Figure 5.32. Boxplots of chuck pinch strength of males stratified by hand

Table 5.52. Paired t-test results for hand group differences in male chuck pinch strength

Hand-group difference	Difference of Means	Standard Error	P-value
Dominant - Non-Dominant	0,76	0,03	0,00

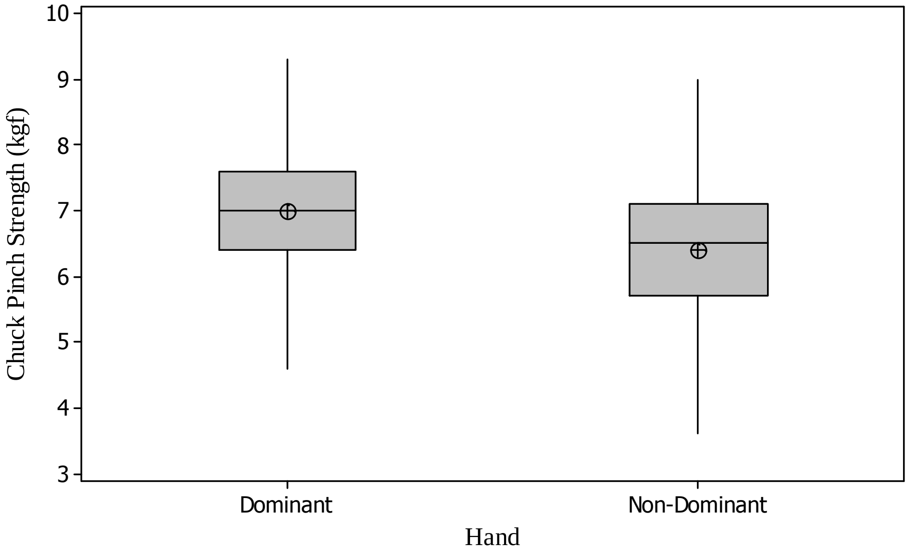

Figure 5.33. Boxplots of chuck pinch strength of females stratified by hand

Table 5.53. Paired t-test results for hand group differences in female chuck pinch strength

Hand-group difference	Difference of Means	Standard Error	P-value
Dominant - Non-Dominant	0,33	0,09	0,00

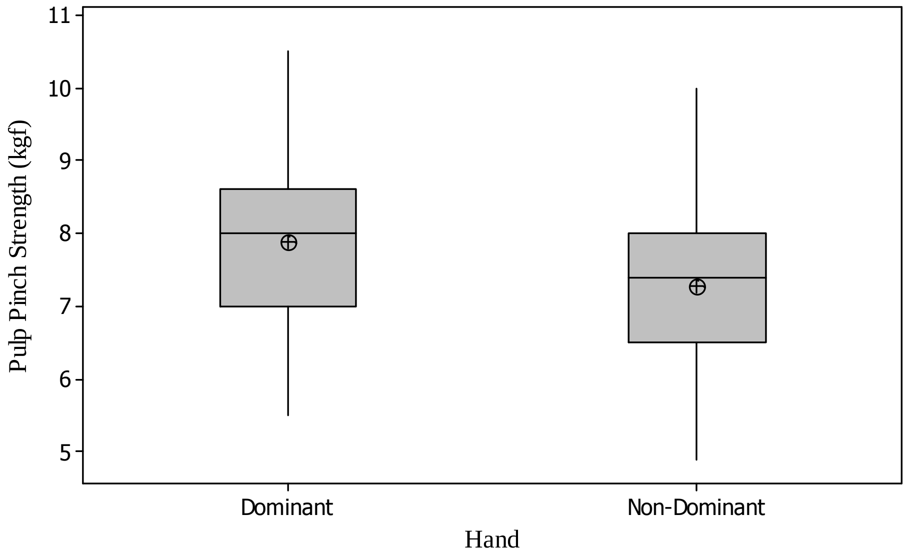

Figure 5.34. Boxplots of pulp pinch strength of males stratified by hand

Table 5.54. Paired t -test results for hand group differences in male pulp pinch strength

Hand-group difference	Difference of Means	Standard Error	P-value
Dominant - Non-Dominant	0,60	0,02	0,00

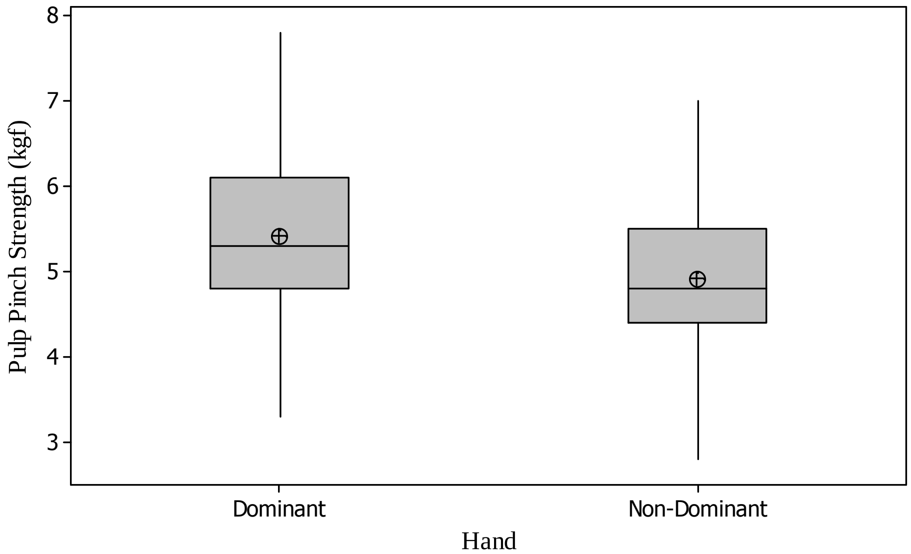

Figure 5.35. Boxplots of pulp pinch strength of females stratified by hand

Table 5.55. Paired t -test results for hand group differences in female pulp pinch strength

Hand-group difference	Difference of Means	Standard Error	P-value
Dominant - Non-Dominant	0,51	0,02	0,00

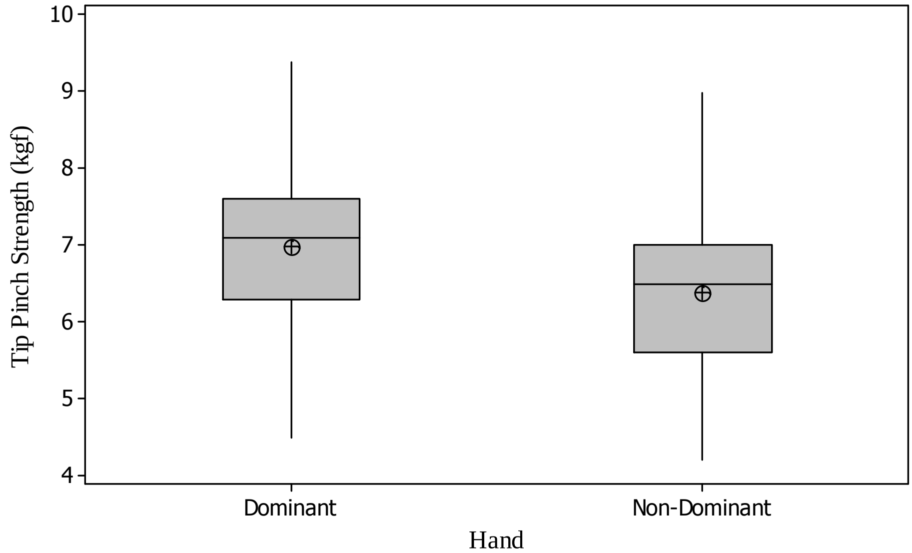

Figure 5.36. Boxplots of tip pinch strength of males stratified by hand

Table 5.56. Paired t -test results for hand group differences in male tip pinch strength

Hand-group difference	Difference of Means	Standard Error	P-value
Dominant - Non-Dominant	0,59	0,02	0,00

5.6. Regression Analysis

The results of MANOVA and correlation analysis were used for developing prediction equations for pinch strength of males and females. When applying regression, every factor and anthropometric measurements were used and main effects of factors were considered. Moreover squares of variables were taken into account to increase the power of prediction. Stepwise regression was used for deciding about the best model for fit. The process of stepwise regression includes adding the most significant variable to equation and removing the least significant variable from the equation. The p-values which were smaller than 0.05 were considered as significant. Many trials were made with variables to find the model that fits best by checking the R^2_{adj} values. As a result the model which gave the highest R^2_{adj} value was chosen as the prediction equation. A multiple linear regression model was determined as a suitable model for males and females separately.

5.6.1. Checking the Regression Assumptions

The fulfillment of assumptions is checked before applying the regression analysis. Some of these assumptions were the same that are checked before MANOVA. The ones that are not checked (multicollinearity and autocorrelation) are mentioned in the result tables of regression analysis. The results indicate that there are not significant violations of assumption, therefore it can be said that the regression analysis with the used variables is valid.

5.6.2. Prediction Equation for Male Pinch Strength

The regression equation for male pinch strength is stated in Figure 5.37.

$$\begin{aligned}\text{Male pinch strength} &= 9.32 - 1.41 \times \text{Pinch Type} + 0.16 \times \text{Circumference of Fist} - 0.67 \\ &\times \text{Hand Type} + 0.13 \times \text{Circumference of Forearm} - 0.06 \times \text{Forearm length} \\ &- 0.87 \times \text{BMIP} - 0.01 \times \text{Age} - 0.16 \times \text{Occupation Group}\end{aligned}$$

(R^2= 0.70; R^2_{adj} = 0.69; SE= 1.1; Durbin-Watson=1.4)

Where,

Pinch Type = 1 for Lateral Pinch Strength
2 for Three-Jaw Chuck Pinch Strength
3 for Pulp Pinch Strength
4 for Tip Pinch Strength,

Circumference of Fist (in cm),

Hand Type = 1 for Dominant Hand
2 for Non Dominant Hand,

Circumference of Forearm (in cm),

Forearm Length (in cm),

BMIP = 2 for Normal
3 for Overweight,

Age (in years),

Occupation Group= 1 for Non Manual Workers
2 for Manual Workers
3 for Students.

Figure 5.37. Regression equation for male pinch strength

The results of regression analysis for males are seen in Table 5.57. It is seen from the table that each factor is significant (p-value < 0.05). The variance inflation factor (VIF) indicates whether multicollinearity exists or does not. Multicollinearity is not desired because it can increase the variance of regression coefficients and make them difficult to interpret. If 1<VIF<5, we can say that predictors are moderately correlated. VIF values greater than 10 means multicollinearity and is not wanted (Kalaycı, 2006). Since the VIF values in the table are between 1 and 5 we can say that multicollinearity does not exist in the results of regression.

Table 5.57. Regression results for male pinch strength

	Coefficient	**SE Coefficient**	**T-value**	**P-value**	**VIF**
(Constant)	9.32	0.68	13.67	0.00	
Pinch Type	-1.41	0.02	-62.64	0.00	1.00
CFI	0.16	0.02	7.05	0.00	2.26
Hand	-0.67	0.05	-13.31	0.00	1.00
CFO	0.13	0.03	5.15	0.00	3.66
LF	-0.06	0.01	-4.95	0.00	1.22
BMIP	-0.87	0.25	-3.50	0.00	2.32
Age	-0.01	0.00	-3.92	0.00	1.86
Occupation_Group	-0.16	0.04	-3.76	0.00	1.68

The significance of the regression model is validated by the ANOVA table. The results for male pinch strength are shown in Table 5.58. It is seen from the table that the regression variables contribute significantly to the regression model.

Table 5.58. ANOVA table for the regression model of male pinch strength

	Sum of Squares	**DF**	**Mean Square**	**F-value**	**P-value**
Regression	5257.71	8	657.21	544.69	0.00
Residual	2296.11	1903	1.21		
Total	7553.82	1911			

5.6.3. Prediction Equation for Female Pinch Strength

The regression equation for male pinch strength is stated in Figure 5.38.

$$\text{Female Pinch Strength} = -2.47 - 1.13 \times \text{Pinch Type} + 0.04 \times \text{Height} - 0.57 \times \text{Hand Type} - 0.04 \times \text{Age} + 0.2 \times \text{Circumference of Fist} + 1.49 \times \text{BMIP}$$

(R^2= 0.60; R^2_{adj} = 0.60; SE= 0.91; Durbin-Watson= 1.35)

Where,

Pinch Type = 1 for Lateral Pinch Strength
2 for Three-Jaw Chuck Pinch Strength
3 for Pulp Pinch Strength,

Height (in cm),

Hand Type= 1 for Dominant Hand
2 for Non Dominant Hand,

Age (in years),

Circumference of Fist (in cm),

BMIP= 1 for Underweight
2 for Normal
3 for Overweight,

Figure 5.38. Regression equation for female pinch strength

Table 5.59 gives the results of regression analysis. From the p-values we can say that each factor significantly effects female pinch strength (p-value<0.05). Moreover VIF values indicate that multicollinearity does not exist.

Table 5.59. Regression results for female pinch strength

	Coefficient	**SE Coefficient**	**T-value**	**P-value**	**VIF**
(Constant)	-2.47	0.90	-2.73	0.01	
PinchType	-1.13	0.03	-35.43	0.00	1.00
Height	0.04	0.01	8.29	0.00	1.21
Hand	-0.57	0.05	-11.00	0.00	1.00
Age	-0.04	0.00	-15.30	0.00	1.63
CFI	0.20	0.03	7.34	0.00	1.77
BMIP	1.49	0.24	6.19	0.00	2.28

Table 5.60, shows the significance of the regression model. It proves that regression variables significantly affect the model.

Table 5.60. ANOVA table for the regression model of male pinch strength

	Sum of Squares	**DF**	**Mean Square**	**F-value**	**P-value**
Regression	1504.94	6	250.82	301.17	0.00
Residual	1013.55	1217	0.83		
Total	2518.49	1223			

6. DISCUSSION

6.1. Discussion on the Results of Current Study

The results of this study are, in general, consistent with a number of other studies in literature. The important factors in determining the pinch strength capacity are found as gender, age, occupation, weight, height, hand dominance and hand anthropometry. Moreover the differences between each pinch strength type (lateral, three-jaw chuck, pulp and tip) were found significant.

Lateral pinch strength was found highest in both genders. It was then followed by chuck pinch strength, pulp pinch strength and finally tip pinch strength. The ordering of these were the same for both males and females. The differences between the means were larger in males than females.

Results indicate that on average males are stronger than females in pinch strength. The mean pinch strength of males is found significantly higher than females. This fact is mentioned in many studies in literature (Imrhan and Loo, 1989; Crosby and Wehbe, 1994; Mathiowetz *et al*., 1985) and is proven once more in the current study. Pinch strength is related to hand anthropometry and circumference of fist and circumference of forearm are found as significant factors affecting pinch strength. Muscle strength is a function of size of related muscles and since the hand and forearm muscles of men are larger than women, this can explain the difference in pinch strength between genders (Ekşioğlu, 2009).

The results of current study indicate that there is a curvilinear relationship between pinch strength and age. Pinch strength makes a peak in the third age group (40-49) for then starts to decline for males. For females pinch strength was relatively stable in the first 3 groups and then starts to decrease. For both gender the decrease in pinch strength starts at age about 50 and the pinch strength of age group 5 (60-69) is significantly lowest of all groups. These results are consistent with earlier study (Mathiowetz *et al*., 1985).

Another effect on pinch strength is the occupation type. The results of current study show that there is a significant difference between non-manual workers, manual workers and students. Manual workers are found to be the strongest of all occupation groups in each pinch strength type and for both males and females. The reason for this may be the fact that hands are used more forcefully in manual jobs, thus their muscles get bigger and stronger (Ekşioğlu, 2009). Minimum strength values were obtained in students group for males (except pulp pinch strength). However, non-manual workers were the weakest group for females in each pinch strength type. The results were not consistent with an earlier study by Lau and Ip (2006). Lau and Ip found out that manual workers are not necessarily stronger than non-manual workers. But in the current study this suggestion is confuted.

Weight and height of a person are found as factors affecting pinch strength in the regression analysis of the current study. Body mass index prime is a measure that includes weight and height of the person. Regression analysis results indicate that BMIP positively affects female pinch strength whereas it negatively affects male pinch strength.

Dominant and non-dominant hand difference is one of the factors that are investigated in the current study. Results indicate that for both genders, dominant hand is significantly stronger than non-dominant hand. The results were the same in all pinch strength types. The muscles that are used more, get stronger and since dominant hand is used more it is obvious that strength values of dominant hand will be higher (Ekşioğlu, 2009). This fact was established in many previous studies (Young *et al*., 1989; Lau and Ip, 2006; Jansen *et al*., 2003).

Another factor that is investigated in the current study is posture. Sitting and standing posture effects are examined and the results indicate that there is not a significant difference in pinch strength. This result was valid for both genders and for all pinch strength types that are included in this study. Pinch strength is mainly related to arm and hand postures and sitting or standing only changes the body posture but arm and hand postures remain the same. Therefore we can conclude that pinch strength does not change when only body posture changes and arm-hand postures does not change. The result of this study is similar to a previous study which is conducted on hand grip strength (Silahlı, 2008). This result allows us to make comparisons with other studies which use sitting or standing posture.

6.2. Comparison with Previous Studies

In this part, some of the results of current study were compared to other studies in literature. The information about earlier studies (sample type, equipment, posture, measured strength type, etc.) were mentioned in literature review part.

The testing positions and other factors such as sample type are different in every study. Some of them can match with the current study in some ways and these are used for comparison.

Mathiowetz *et al*. (1985) made a normative data study on pinch strength. The subjects (310 male, 318 female) were aged between 20 and 75^{+}. The age range is similar with the current study. Moreover, maximum of trials were recorded as the maximum isometric pinch strength as in the current study. The testing procedure was also similar with the current study. Sitting posture was determined for lateral pinch strength, three-jaw chuck pinch strength and tip pinch strength. Measurements were taken from both dominant and non dominant hands. The results of the study indicated that average pinch strength was relatively stable up to 50 years and after that a gradual decline began. In the current study pinch strength is found to make a peak in the age group 3 (40-49 years) for males and relatively stable for females. The decrease pattern is the same as in Mathiowetz *et al*. (1985).

Jansen *et al*. (2003) investigated the effects of forearm position on pinch strength. One of the testing postures was neutral posture as in the current study. 44 males and 91 females were included in the study and their ages were between 20 and 88. As in the current study, sitting posture was used and other procedures were also similar. The sampling was randomly made including different occupation and BMIP groups. Therefore this study can be compared to the current study by using the general mean values for measurements (Table 6.1). Lateral pinch, three-jaw chuck pinch and pulp pinch strengths of both dominant and non-dominant hands were measured. Results of the study indicated that dominant hand was stronger than the non dominant hand. Moreover lateral pinch strength was the highest and pulp pinch strength was the lowest with chuck pinch strength being in the middle. In the current study, the same results were confirmed for both genders.

Another study which used participants aged between 18 and 67 was made by Young *et al*. (1989). They used the standardized testing posture as in the current study and measured lateral pinch strength. Both dominant and non dominant hand measurements were taken. Since the characteristics of the experimentation were similar to current study, it was chosen for comparison. The findings were the same as the current study that dominant hand pinch strength was significantly higher than the non-dominant hand pinch strength.

Crosby *et al*. (1994) made a normative study on hand strength and they measured lateral pinch strength and pulp pinch strength. Again the measurements were taken while the subject was sitting and the testing procedure was similar with the current study. 105 men and 109 women were randomly selected and their ages ranged between 16 and 63. The aim of the study was to compare dominant and non-dominant hand strength and it was found that dominant hand was stronger than non-dominant hand. This result was consistent with the current study.

A comparison of current study and the studies that are mentioned above is given in Table 6.1 and Table 6.2. The boxes display the mean values and standard deviations. The values are presented in kilogram force. The empty boxes mean that there is not a measurement available in that testing position.

The results indicate that there are differences between the mean pinch strength values of different studies. The differences are partly due to age-range, occupation and sample size differences. Other factors may be geographical region, fitness level, anthropometric factors and genetics. Therefore an accurate comparison should be at least based on gender, age and occupation stratified strength data.

For instance, a study was made for comparing the dominant and non dominant hand lateral pinch strengths of normal Chinese male subjects (Lau and Ip, 2006). The stratification was made for occupation groups such as manual workers and non-manual workers. The comparison of this study with the current study indicates that on average the population of Turkey is stronger than the population of China for both non-manual workers and manual workers. This comparison is more accurate than the previous comparisons (Table 6.3).

The results suggest that for pinch strength, universal reference values do not exist. Therefore, national differences must be considered in designing for pinch strength. For clinical purposes, clinicians must also choose the closest population pinch strength values for the comparison of their patients' pinch strength to make accurate diagnosis and treatment protocols.

Table 6.1 Comparison of current study with literature for males

Study	**Males**							
	DLPSit	**NDLPSit**	**DCP Sit**	**NDCP Sit**	**DPP Sit**	**NDPP Sit**	**DTP Sit**	**NDTP Sit**
Mathiowetz, et al. (1985)	11.11 (±2.09)	10.71 (±2.09)	10.61 (±2.27)	10.43 (±2.4)			7.71 (±1.86)	7.44 (±1.81)
Jansen et al. (2003)	10.5 (±2.42)	10.14 (±2.33)	9.38 (±2.34)	9.14 (±2.24)	7.013 (±1.62)	6.78 (±1.77)		
Young et al. (1989)	11.52 (±1.67)	11.02 (±1.6)						
Crosby et al. (1994)	12.25 (±2.27)	11.79 (±2.27)			8.62 (±1.81)	8.17 (±1.81)		
Current Study	11 (±1.2)	10.3 (±1.2)	11.1 (±1.3)	10.4 (±1.2)	10 (±1.3)	9.2 (±1.2)	7.9 (±1.1)	7.3 (±1.1)

Table 6.2 Comparison of current study with literature for females

Study	**Females**					
	DLPSit	**NDLPSit**	**DCP Sit**	**NDCP Sit**	**DPP Sit**	**NDPP Sit**
Mathiowetz, et al. (1985)	7.35 (±1.36)	6.94 (±1.41)	7.39 (±1.72)	7.12 (±1.63)		
Jansen et al. (2003)	7.27 (±1.51)	6.68 (±1.55)	6.92 (±1.62)	6.35 (±1.52)	4.89 (±1.16)	4.55 (±1.15)
Young et al. (1989)	7.26 (±1.11)	6.71 (±0.96)				
Crosby et al. (1994)	9.07 (±2.27)	8.62 (±1.81)			6.35 (±1.81)	5.90 (±1.36)
Current Study	7.70 (±1.20)	7.10 (±1.10)	7.00 (±1.10)	6.40 (±1.10)	5.40 (±10)	4.90 (±0.90)

Table 6.3 Comparison of current study with the study by Lau and Ip

Study	Non-manual		Manual	
	DLPSit	**NDLPSit**	**DLPSit**	**NDLPSit**
Lau and Ip (2006)	10.40 (±1.60)	9.60(±1.50)	10.90(±1.50)	9.80(±1.50)
Current Study	10.90(±1.10)	10.20(±1.10)	11.70(±1.10)	10.90(±1.10)

7. CONCLUSIONS

Based on the analysis results, summary of the conclusions drawn from this study in terms of objectives are enumerated below:

(i) Maximum voluntary isometric pinch strength norms of health adult population of Turkey are established.

(ii) Overall mean pinch strength capacity of females for three pinch strength types (lateral, chuck, pulp) is about 70 % of mean pinch strength capacity of males.

(iii) Lateral pinch strength is found to be strongest for both genders and it is followed by chuck pinch strength, pulp pinch strength and tip pinch strength.

(iv) The relationship between age and pinch strength is curvilinear for males and maximum pinch strength values are obtained at 40-49 years age range. Female pinch strength is relatively stable between 18 and 59. After (50-59) age range, male and female pinch strength starts to decrease significantly.

(v) Manual workers are stronger than non-manual workers and students for both genders.

(vi) For both genders in overall, BMIP is found to have no practically significant effect on pinch strength capacity.

(vii) For both males and females, the dominant hand strength is greater than the non-dominant hand strength for all pinch types. For males, non-dominant hand lateral pinch strength is 94% of dominant hand lateral pinch strength; non-dominant hand chuck pinch strength is 92% of dominant hand chuck pinch strength; non-dominant hand pulp pinch strength is 93% of dominant hand pulp pinch strength; non-dominant hand tip pinch strength is 91% of dominant hand tip pinch strength. For females, non-dominant hand lateral pinch strength is 92% of dominant hand lateral pinch strength; non-dominant hand chuck pinch strength is 91% of dominant hand chuck pinch strength; non-dominant hand pulp pinch strength is 91% of dominant hand pulp pinch strength. On average, the difference between dominant and non dominant hand strength is 7.5% for males and 8.5% for females.

(viii) Posture (sitting or standing) had no significant effect on pinch strength.

(ix) Circumference of forearm and circumference of fist were also found as significant factors in determining the pinch strength. Male pinch strength is positively affected by both of these factors and female pinch strength is positively affected by circumference of fist.

(x) Comparisons with other studies indicate that there are variations in pinch strength values across some nationalities. Roughly speaking, the pinch strength capacity of the population of Turkey is similar to the pinch strength capacity of some US samples and greater than a Chinese sample.

The current study has the following limitations: The family roots of the participants included every region of Turkey, but they were living in the metropolitan city of Istanbul and its surrounding areas. Therefore, the effects of living environment of the subjects were not studied. Moreover, the study does not include some heavy manual workers such as farmers, miners and forest workers. Inclusion of these workers in the sample is expected to increase the estimated pinch strength values of the studied population.

This study is the first attempt to establish pinch strength norms of healthy adult population of Turkey. From now on in Turkey, it is hoped that the jobs, machines and products requiring pinch force will be designed taking the pinch strength norms developed through this study as reference. Moreover, in clinical settings in Turkey, physicians and therapists will refer to these pinch strength norms in their patient treatment plans. Finally, it is also hoped that this study will contribute to the world strength database.

APPENDICES

In the appendix section, the forms that were used in the study are included. These forms are personal consent form, brief medical history form, data collection form and the form of experimental design.

A.1 and A.2: Brief medical history form was prepared for subjects to check if they were healthy enough to participate in the study. It was adopted from a previous study which is done by Silahlı(2008). This form was also prepared in both languages.

A.3 and A.4: Personal consent form is prepared in both English and Turkish and it includes a detailed description of the aim and procedures of the study. All of the participants voluntarily signed the form in order to participate in the study.

A.5: Data collection form is used for recording the descriptive, anthropometric and strength data of the subjects during the experiments.

A.6 and A.7: Instructions were prepared for the subjects in order to inform them about the testing procedure. It was prepared in English and Turkish.

A.1. Brief Medical History Form

Check if answer is "yes" only. Leave others blank.

- ☐ Have you ever been diagnosed with any disorders in your arm joints (cysts or any other syndromes)?
- ☐ Have you been diagnosed as having high blood pressure?
- ☐ Do you ever have pain in your heart or chest?
- ☐ Do you ever experience a racing heart rate?
- ☐ Does your heart ever skip beats?
- ☐ Have you ever been diagnosed with an abnormal ECG or EKG?
- ☐ Do you often experience difficulty in breathing?
- ☐ Do you sometimes get out of breathing when sitting still or sleeping?
- ☐ Are you currently going renal dialysis?
- ☐ Do you have any history of rheumatoid arthritis?

Check space if you now have or recently had.

- ☐ Recurring pain in shoulders, elbows, wrists or hands?
- ☐ Migraine or recurrent headaches?
- ☐ Kidney problems?
- ☐ Significant vision or hearing problems?
- ☐ Glaucoma or increased pressure in the eyes?
- ☐ High blood pressure?
- ☐ Hyperthyroidism?
- ☐ Diabetes mellitus?
- ☐ Amyloidosis (particularly, deposits of amyloid tissues in joints)?
- ☐ Vitamin B6 deficiency?

Check space for medications you are now taking.

- ☐ Blood pressure
- ☐ Glaucoma
- ☐ Anti-inflammatory
- ☐ Thyroid
- ☐ Diabetes or abnormal blood sugar

Please list any other prescribed medications you are now taking.

A.2. Sağlık Anketi

Aşağıdaki sorulara cevabınız evet ise çarpı işaretiyle işaretleyiniz, cevabınız hayır ise lütfen boş bırakınız.

- ☐ Kol eklemlerinizde hastalığınız oldu mu (kist veya çeşitli sendromlar gibi)?
- ☐ Yüksek tansiyon sorununuz oldu mu?
- ☐ Daha önce kalp veya göğüs ağrısı şikayetiniz oldu mu?
- ☐ Daha önce kalp çarpıntısı sorununuz oldu mu?
- ☐ Kalbinizde tekleme oldu mu?
- ☐ Anormal ECG veya EKG teşhisiyle karşılaştınız mı?
- ☐ Nefes alırken herhangi bir zorluk çektiğiniz oldu mu?
- ☐ Otururken veya uyurken nefesiniz kesildi mi?
- ☐ Böbrek sorunundan dolayı diyaliz makinesine bağlanmakta mısınız?
- ☐ Romatoid arterit hastalığına yakalandınız mı?

Aşağıdaki sorunlarla daha önce karşılaşmışsanız veya şu anda bu sorunlar sizde mevcut ise çarpı işaretiyle işaretleyiniz, yoksa lütfen boş bırakınız.

- ☐ Omuz, dirsek, el bileği ve ellerinizde sürekli ağrı
- ☐ Migren veya sürekli baş ağrısı
- ☐ Böbrek problemleri
- ☐ Ciddi görme ve duyma problemleri
- ☐ Glokom (karasu hastalığı) veya yüksek göz tansiyonu
- ☐ Hipertansiyon
- ☐ Tiroit büyümesi
- ☐ Şeker hastalığı
- ☐ Değişik organ veya dokularda amiloid birikimi
- ☐ B6 vitamini eksikliği

Aşağıdaki sorunlarla ilgili ilaç alıyorsanız, çarpı işaretiyle işaretleyiniz.

- ☐ Yüksek tansiyon
- ☐ Glokom
- ☐ Ateş düşürücü
- ☐ Tiroit
- ☐ Diyabet veya anormal kan şekeri

Yukarıdaki sorunlar dışında herhangi bir sorundan dolayı tedavi olmaktaysanız veya ilaç almaktaysanız lütfen aşağıya belirtiniz.

A.3. Personal Consent Form

In this study, maximum tip, pulp, three-jaw chuck and lateral pinch forces for right and left hands in standing and sitting postures and maximum handgrip forces for right and left hand in sitting posture will be determined for the population of Turkey. You are an eligible participant for this study because you do not have any serious health problem that can adversely affect the performance of this study.

The strength results of this study will be useful for designing the tasks that are done by hand and designing the hand tools according to the people in Turkey. The designs that are done by using these results may lead to higher work efficiency and reduced risk of work related disorders.

If you decide to participate in the experiment, please be aware of the following issues:

1. Before the tests, you will be asked questions about your birth date, birthplace and the place you live now, your family origin, your mother and father's birthplace, ethnicity, occupation and dominant hand. Moreover, your height, weight, circumference of your forearm, circumference of your fist and your forearm-hand length will be measured.
2. The tests will be done according to Caldwell protocol. The tests will be done in random order and in each test you will perform your maximum force. When you are ready for the experiment, you will start with the experimenter's command, reach your maximum exertion in about 1– 2 seconds and hold it for 3 – 4 seconds. The tests will be done for right and left hands in sitting posture for handgrip strength; for right and left hands in sitting and standing posture for tip, pulp, three-jaw chuck and lateral pinch strength. For each testing position, the tests will be done at least twice. Therefore the total number of the tests will be at least 36. The tests will be done in the order that is told you before and you will have a 2-minute rest between two successive experiments to minimize fatigue effect. Whenever the strength variation is more than 10 percent between two trials corresponding to the same test combination, the trials will be repeated as many times as needed. The maximum of the two trials, which is suitable with the conditions, will be recorded as your maximum voluntary contraction for that test. The body postures will be shown to you by the experimenter.
3. Before the tests, participants should not be too hungry, too full or sleepless, and should not consume harmful substances. Moreover, they must be healthy enough to perform the tests. After the tests, you may experience some minor soreness in arm muscles.

Your participation is completely voluntary. You may choose to withdraw from participation at any time. All information obtained during this study will be held in strict confidence and only the mean, maximum and minimum values of the data will be used in the study.

If at any time you have questions regarding this research or if you want to add some contributions to this research, you may contact either H. Fulya KAYA or Assoc. Prof. Mahmut EKŞİOĞLU from Department of Industrial Engineering, Boğaziçi University.

By placing your signature below, you will accept that your participation to this study is voluntary. However, you can choose to withdraw from participation at any time at no cost or obligation to you.

Signature of Participant: Date:

A.4. Kişisel Kabul Formu

Bu çalışmada, Türk insanının ayakta ve oturma pozisyonunda sağ ve sol el parmaklarındaki maksimum parmak ucu, yassı parmak ucu, üçlü kavrama ve yanal parmak kavrama kuvvetleri ile oturma pozisyonundaki maksimum sağ ve sol el sıkma kuvvetleri belirlenecektir. Bu çalışmaya engel olacak herhangi bir sağlık probleminizin olmamasından dolayı, çalışmaya uygun durumda bulunmaktasınız.

Bu çalışmadan elde edilecek kuvvet değerleri, el ile yapılan işlerin ve el aletlerinin Türkiye insanına göre tasarlanmasında faydalı olacaktır. Bu verileri kullanarak yapılacak tasarımlar hem iş verimini arttırmaya yardımcı olacak hem de iş hastalıklarını azaltmada katkı sağlayacaktır.

Deneye katılmaya karar verdiyseniz lütfen aşağıdaki konulara dikkat ediniz:

1. Deney öncesinde size doğum tarihiniz, doğduğunuz ve şu an yaşadığınız yer, aile kökeniniz, anne babanızın doğum yeri, etnik kökeniniz, mesleğiniz ve baskın elinizin hangisi olduğu ile ilgili sorular sorulacaktır. Ayrıca; boyunuz, kilonuz, ön kolunuzun çevresi, yumruğunuzun çevresi ve önkol-el uzunluğunuz ölçülerek kaydedilecektir.

2. Deneyler Caldwell protokolüne göre gerçekleştirilecektir. Rassal sırayla yapılacak olan testlerde her bir test türü için maksimum kuvvetinizi uygulamanız gerekmektedir. Deney esnasında hazır olduğunuz an “başla” komutundan sonra yaklaşık 1 – 2 saniyede maksimum kuvvetinize çıkmanız ve bu kuvveti 3 – 4 saniye boyunca tutmanız gerekmektedir. Bu deney el sıkma kuvveti için oturarak sağ ve sol el için; parmak ucu, yassı parmak ucu, üçlü kavrama ve yanal parmak kuvvetleri için ise oturarak ve ayakta iken sağ ve sol el için yapılacaktır. Deneyde her koşul için asgari 2 deneme yapılacaktır. Bu durumda toplam test kombinasyonu en az 36 olmaktadır. Deneyler size belirtilen sırada yapılacak, her denemeden sonra 2 dakikalık bir dinlenme süresi olacaktır. Eğer aynı test kombinasyonundaki iki deney verisi arasında %10’dan büyük bir sapma varsa, deneye bu şartı sağlayıncaya kadar devam edilecektir. Her deneyde şartları sağlayan iki denemenin maksimum olanı kaydedilecektir. Deney esnasında vücut pozisyonu deney yürütücüsü tarafından size gösterilecektir.

3. Deneylerden önce çok aç, fazla tok veya uykusuz olunmamalı, zararlı maddeler tüketilmemelidir. Ayrıca gerekli olan sağlık şartlarına sahip olmanız gerekmektedir. Deneylerin sonunda, küçük çaplı kas yorgunluğu gerçekleşebilir.

Bu deneye katılım tamamen gönüllüdür ve katılım için bir zorlama ile karşılaşmanız söz konusu değildir. İstediğinizde çalışmanın herhangi bir aşamasında çalışmayı terk edebilirsiniz. Elde edilecek kişisel bilgiler kimseyle paylaşılmayacak, tez çalışmasında sadece verilerin ortalaması (kime ait olduğu belirtilmeksizin) ve maksimum ve minimum değerleri belirtilecektir.

Bu çalışmayla ilgili sorularınız ve katkılarınız olması durumunda Boğaziçi Üniversitesi Endüstri Mühendisliği Bölümü’nde H. Fulya KAYA veya Doç. Dr. Mahmut EKŞİOĞLU ile temasa geçebilirsiniz

Aşağıya atacağınız imza, bu çalışmaya gönüllü olarak katılmak istediğinizi belirtmektedir. Ayrıca çalışmayı yarıda bırakmanız durumunda, size herhangi bir yükümlülük getirmemektedir.

Katılımcının İmzası: Tarih:

A.5. Data Collection Sheet

1. General Information about the Subject

Information	**Datum**
Birth date	Day: Month: Year:
Birthplace	
The place he/she lives now	
Family origin city	
Mother and father’s birthplace	
Ethnicity	
Gender	
Occupation	
Dominant hand	

2. Anthropometric Measurements of the Subject

Stature (cm)	
Weight (kg)	
Circumference of forearm (cm)	
Circumference of fist (cm)	
Forearm-hand length (cm)	

3. Grip Strength Data of the Subject

Measure (kgf)	**Trial 1**	**Trial 2**
Dominant hand grip strength (sitting, neutral posture)		
Non-dominant hand grip strength (sitting, neutral posture)		

4. Pinch Strength Data of the Subject

Measure (kgf)	**Trial 1**	**Trial 2**
Dominant hand lateral pinch strength (sitting)		
Non-dominant lateral pinch strength (sitting)		
Dominant hand lateral pinch strength (standing)		
Non-dominant lateral pinch strength (standing)		
Dominant hand three-jaw chuck pinch strength (sitting)		
Non-dominant three-jaw chuck pinch strength (sitting)		
Dominant hand three-jaw chuck pinch strength (standing)		
Non-dominant three-jaw chuck pinch strength (standing)		
Dominant hand pulp pinch strength (sitting)		
Non-dominant hand pulp pinch strength (sitting)		
Dominant hand pulp pinch strength (standing)		
Non-dominant pulp pinch strength (standing)		
Dominant hand tip pinch strength (sitting)		
Non-dominant hand tip pinch strength (sitting)		
Dominant hand tip pinch strength (standing)		
Non-dominant tip pinch strength (standing)		

A.6. Instructions

1. You have read the personal consent form and received information about the experiment. Now, move and shake your hands to warm up your muscles. Take a couple of deep breath and get ready for the experiments.
2. The experimenter will show you the appropriate posture for each measurement.
3. When you are ready for the experiments, inform the experimenter.
4. Start applying force with experimenter's "START" command and squeeze the gauge as hard as you can and reach your maximum in about 1 second. Hold your maximum for about 3 seconds.
5. Stop applying force with the experimenter's "STOP" command.
6. Move your hand which you have applied force and relax your muscles. Get ready for the following test.

A.7. Talimatlar

1. Kişisel kabul formunu okudunuz ve deney hakkında bilgi edindiniz. Şimdi ellerinizi hareket ettirerek ve sallayarak kaslarınızı biraz ısıtın. Birkaç kez derin nefes alıp vererek deneye hazır hale gelin.
2. Her ölçüm için uygun pozisyon deneyi yaptıran kişi tarafından size gösterilecektir.
3. Deneye başlamaya hazır olduğunuzda bunu belirtiniz.
4. Deneyi yaptıran kişinin “BAŞLA” komutu ile kuvvet uygulamaya başlayın ve kuvvet ölçeri sıkabildiğiniz kadar sıkarak yaklaşık 1 saniyede maksimum kuvvetinize ulaşın. Maksimum kuvvetinizi yaklaşık 3 saniye boyunca sürdürmeye çalışın.
5. Deneyi yaptıran kişinin “BİTİR” komutu ile kuvvet uygulamayı sonlandırın.
6. Kuvvet uyguladığınız elinizi hareket ettirerek kasların rahatlamasını sağlayın ve bir sonraki teste hazır hale getirin.

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