ISOMETRIC GRIP STRENGTH DISTRIBUTION OF A TURKISH SAMPLE AS A FUNCTION OF POSTURE AND SUPPORT

by

Baykar Silahlı

B.S., Industrial Engineering, Yıldız Technical University, 2004

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Industrial Engineering
Boğaziçi University
2008

ACKNOWLEDGEMENTS

I would like to express my truthful appreciation to my thesis supervisor Assist. Prof. Mahmut Ekşioğlu for his valuable guidance, support, encouragement and inexhaustible patience during my study. I would like to thank Prof. Ali Rıza Kaylan and Assist. Prof. Ali Ecder for their valuable suggestions as members of my thesis committee.

Deepest thanks are due to all subjects participating in strength tests, voluntarily. By using their grip strength data, the work is done.

I am also grateful to TÜBİTAK for their financial support throughout my master education.

Finally, I would like to express my special thanks to my family for their endless love, support, encouragement and patience throughout my life.

ABSTRACT

ISOMETRIC GRIP STRENGTH DISTRIBUTION OF A TURKISH SAMPLE AS A FUNCTION OF POSTURE AND SUPPORT

In physical work activities, a worker's capacity to perform mechanical work is partly determined by his/her capability to apply muscular strength. Especially in hand intensive jobs, to prevent fatigue and musculoskeletal disorders; to maximize quality, productivity and comfort; and minimize associated costs, strength capabilities of workers should be determined in order to match them with job strength demands. By using grip strength data, it can be ensured that the majority of workforce is capable to perform a given task, and the percentage of strength required by a repetitive task can be assessed so that fatigue is avoided.

The main objective of this study was to estimate the maximum voluntary isometric (static) grip strength distribution of Anatolian people related to gender, age, occupation, and body characteristics. Another objective of the study was to investigate the effects of body posture and hand support on grip strength. For the purpose, a sample of 208 healthy participants (composed of 129 males and 79 females) with family origin from the seven regions of Turkey was recruited. The participants were sampled in a manner so that all working age and occupation groups were included in the study. The study involved both laboratory and field studies. Besides strength, some other body measurements such as stature and weight distributions of the sample were also estimated. The comparisons were also made with the strength data of the populations of several countries.

Following the statistical analysis, the results were documented. According to the results, the male mean grip strength value was about 44% higher than the female mean grip strength value. Dominant hand was significantly stronger than non-dominant hand for both male and female. The heavy manual workers were, on average, stronger than the light manual workers and students were. The mean male grip strengths were similar from age group (18-29) to (40-49) years, and started decreasing thereafter. On the other hand, female

mean grip strength increased from (18-29 yr.) age group to (30-39 yr.) age group and started decreasing thereafter. Grip strength increased significantly with support; however, body posture did not have significant effect on grip strength. Body mass index had also significant effect on mean grip strength. It was also concluded that the mean grip strength of the studied sample was while significantly higher than those of the Chinese samples; depending on the compared study, was either similar or lower than those of American and British samples.

ÖZET

BİR TÜRK ÖRNEKLEMİNİN STATİK EL-KAVRAMA KUVVETİNİN VÜCUT POZİSYONUNA VE DESTEĞE BAĞLI OLARAK DAĞILIMI

Fiziksel işlerde bir işçinin mekanik iş kapasitesi, kısmen kas kuvveti kapasitesine bağlıdır. Özellikle ellerin yoğun olarak kullanıldığı işleri, işgücünün kuvvet kapasitesine göre tasarlayarak, işgücünün gereksiz yorgunluğu ve kas-iskelet hastalıkları önlenebilir, verimlilik, kalite ve konfor artırılarak, bağlı maliyetler azaltılabilir. Bu da herşeyden önce işgücü kapasitesinin bilinmesine bağlıdır. El-kavrama kuvveti verilerinin kullanılmasıyla, işgücünün büyük bir bölümünün verilen bir işi yapabilip yapamayacağı ve herhangi tekrarlamalı bir iş için yorgunluk olmadan gerekli olan kuvvet yüzdesinin ne olacağı belirlenebilir.

Bu çalışmanın ana amacı Anadolu insanının maksimum statik el-kavrama kuvveti dağılımının cinsiyet, yaş, meslek ve vücut özelliklerine bağlı olarak hesaplanmasıdır. Çalışmanın diğer bir amacı ise, vücut pozisyonu ve dinamometrenin desteklenip desteklenmemesinin el-kavrama kuvveti üzerindeki etkilerinin incelenmesidir. Bu amaçla, aile kökenleri Türkiye'nin yedi farklı bölgesinden olan, farklı yaş ve meslek gruplarındaki 129 bay ve 79 bayandan oluşan 208 sağlıklı katılımcının el-kavrama kuvveti ölçümleri gerçekleştirildi. Ölçümlerin bir bölümü laboratuarda diğer bölümü ise laboratuar dışında yapıldı. Kuvvet verisi dışında katılımcıların boy ve ağırlık dağılımları da belirlendi. Elde edilen kuvvet verileri çeşitli ülkelerdeki kuvvet verileriyle karşılaştırıldı.

İstatistiksel analizden sonra, elde edilen sonuçlara göre erkeklerin ortalama el-kavrama kuvvetinin bayanlarınkinden yaklaşık % 44 daha fazla olduğu görüldü. Baskın elin baskın olmayan ele göre istatistiksel olarak kuvvetli olduğu belirlendi. Ağır işlerde çalışanların, öğrencilere ve hafif işlerde çalışanlara göre daha güçlü oldukları tespit edildi. Erkeklerde ortalama el-kavrama kuvvetinin 18 ile 49 yaş grupları arasında değişimediği fakat 49 yaşından sonra bu kuvvetin azaldığı görüldü. Bayanlarda ise, el-kavrama kuvveti 18 yaşından itibaren yaşla birlikte artarak 30-39 yaş grubunda maksimuma ulaştı ve daha

sonra artan yaşla azaldı. El-kavrama kuvvetinin dinamometrenin desteklenmesiyle arttığı görüldü, ancak vücut pozisyonunun el-kavrama kuvvetini istatistiksel olarak etkilemediği belirlendi. Vücut kitle endeksinin, el-kavrama kuvveti üzerinde istatistiksel olarak etkisinin olduğu tespit edildi. Diğer ülkelerde yapılan çalışmalarla karşılaştırıldığında, Türk örnekleminin ortalama el-kavrama kuvvetinin Çin örneklemlerinin ortalama el-kavrama kuvvetinden daha fazla olduğu, Amerikan ve İngiliz örneklemlerinin ortalama el-kavrama kuvvetlerine göre ise, karşılaştırılan çalışmaya bağlı olarak, eşit veya daha az olduğu sonuçlarına varıldı.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS /ABBREVATIONS

ANOVA	Analysis of variance
ASHT	The American Society of Hand Therapists
BMI	Body mass index
BMIP	Body mass index prime
cm	Centimeter
D	Dominant hand
DD	Handgrip strength of dominant hand in sitting posture
DDS	Dominant handgrip test while sitting and dynamometer supported
DDU	Dominant handgrip test while sitting and dynamometer unsupported
DUS	Dominant handgrip test while standing and dynamometer supported
DUU	Dominant handgrip test while standing and dynamometer unsupported
DF	Degrees of freedom
HMW	Heavy manual workers
LHL	Length of left hand
LHW	Width of left hand
LMW	Light manual workers
LWC	Circumference of left wrist
kg	Kilogram
kgf	Kilogram force
m	Meter
mm	Millimeter
MS	Mean of squares
MVC	Maximum voluntary contraction
N	Newton
n	Sample size
ND	Handgrip strength of non-dominant hand in sitting posture
NDS	Non-dominant handgrip test while sitting and dynamometer supported
NDU	Non-dominant handgrip test while sitting and dynamometer unsupported
NID	Normally and independently distributed

Nm	Newton × meter
NUS	Non-dominant handgrip test while standing and dynamometer supported
NUU	Non-dominant handgrip test while standing and dynamometer unsupported
RHL	Length of right hand
RHW	Width of right hand
RWC	Circumference of right wrist
SD	Standard deviation
SE	Standard error
SS	Sum of squares
TCLm	Thumb crotch length
VIF	Variance inflation factor
yr	Year

1. INTRODUCTION

Ergonomics or human factors engineering is a scientific multidisciplinary field concerned with the understanding of interactions among humans and other elements of a system, and the application of designing jobs, systems, machines, tools, equipment, safety and comfort, considering human capacity, cognitive abilities and limitations (International Ergonomics Association, 2000). One of these capacities is muscular strength which is necessary in designing safe and acceptable jobs and equipment for minimizing associated costs and preventing work related musculoskeletal disorders (cumulative trauma disorders), which are physical ailments that develop over a long period of time as a result of working in awkward posture and repeated, continuous exposure of a particular body part (tissue or joint) to stressors such as high work pressure, low control and monotony (Mital and Kumar, 1998; Carayon *et al*., 1999). Static (isometric) muscle strength is a type of strength that is the capacity of muscles to produce force or torque by a single maximal voluntary isometric exertion in which the body segment involved remains stationary. Maximal voluntary exertion is the highest level of voluntary exertion that a person can achieve without inducing unacceptable pain (Khalil *et al.*, 1987). Some of the widely used isometric strengths are hand grip strength, arm strength, shoulder strength, leg strength and torso strength.

In occupational activities, a person's capacity to perform mechanical work is determined by his/her ability to exert muscular strength (Mital and Kumar, 1998). The objective of strength tests is to produce data that enable estimating the strength capacity of a population. By using strength data, it can be ensured that the majority of a population is able to perform a given task, and the percentage of maximum strength required by a repetitive task can be assessed so that fatigue is avoided (Xiao *et al.*, 2005).

Published research indicates a number of strength studies performed on various populations around the world, especially in Western countries. However, there is none about the people of Turkey. To fill this gap, this study is focused on determining maximum voluntary isometric grip strength capacity of Turkish population, as a function of gender, age, occupation, body mass, hand, posture and support. To do this, a number of healthy volunteers were recruited to conduct the strength tests in two body postures for both left and right hands while the hand is supported or not at Boğaziçi University Ergonomics Laboratory. For some workers, strength tests were done in separate workplaces after providing similar conditions with the Ergonomics Laboratory.

The thesis is organized as follows: Chapter 2 contains a literature review about isometric muscle strength studies performed in various countries. In Chapter 3, the main objectives of the current study are presented. Chapter 4 describes the methodology of the experiments that includes description of subjects, equipment, procedures while executing the tests and statistical analysis of the collected data. In Chapter 5, the results of the isometric grip strength data and anthropometric data are given. Moreover, this chapter also demonstrates the results of statistical analysis. Chapter 6 presents a discussion of present study results and a comparison with the results of the previous studies carried out in other parts of the world. Finally, in the last chapter, conclusions of the current study are presented.

2. LITERATURE REVIEW

Strength is a muscle's capacity to exert maximal effort or resist maximal opposing force. It is often measured in terms of the force lifted or force exerted against a fixed weight. Human muscular strengths can be classified according to two criteria: (i) characteristics of the effort, and (ii) characteristics of application. Based on effort characteristics, human muscular strengths can be either dynamic or static (isometric). In dynamic muscle strength tests, body segments move and muscle length changes significantly. Dynamic muscle strengths can be isotonic or isokinetic. In isotonic muscle exertion, the muscle force is constant. However, in isokinetic muscle exertion, the rate of shortening or lengthening of the muscle is constant. In contrast with dynamic muscle force, in static muscle strength tests the muscle produces its maximal force while the body remains stationary (Mital and Kumar, 1998).

Based on the characteristics of application, human strength can be dynamic functional strength or static functional strength. Dynamic strengths can be: (i) isoinertial muscle strengths, (ii) psychophysical muscle strengths, (iii) simulated job dynamic strengths, and (iv) repetitive dynamic strengths. Isoinertial muscle exertions reflect a person's ability to overcome the initial static resistance (maximum weight a person can handle and move to an assigned point at freely chosen speed). Psychophysical muscle strength is a person's measure of psychophysically determined maximum acceptable level of force application. Simulated job dynamic strengths are dynamic (isokinetic or psychophysical) human muscle strengths measured while simulating the job in terms of body posture and speed of limb movement. Repetitive dynamic strengths are isokinetic or psychophysical dynamic strengths that take into account the effect of frequency of exertion. Based on application, static strengths can be: (i) simulated job static strengths, (ii) repetitive static muscular strengths, and (iii) continuous static muscular strengths. Simulated job static strengths are static strengths that are measured while simulating job conditions in terms of the body posture (location of hands, arm orientation, feet etc.). Continuous static muscle strength (endurance) tests are performed for depicting how the strength declines with the duration of sustained exertion, namely endurance time.

Repetitive static muscle strengths are maximal static exertions applied at specified frequencies. In this case, the muscular strength also declines with the duration of exertions but not quite as rapidly as in the case of continuous static muscular exertions (Mital and Kumar, 1998).

A widely used isometric muscle strength datum in designing hand intensive work and hand-tools is grip strength that is the main topic of this study. The factors that influence the grip strength are: (i) gender, (ii) age, (iii) heredity, (iv) posture, (v) grip span or grip diameter, (vi) handedness, (vii) variation during the day, (viii) variation from day to day, (ix) fitness level, (x) speed of exertion, (xi) duration and frequency of exertion, (xii) anthropometric variables, (xiii) psychological factors, and (xiv) environmental factors (Bechtol, 1954; Mital and Kumar, 1998; Slob, 2000).

The devices used for grip strength tests can be classified into four basic categories: hydraulic, pneumatic, mechanical and strain gauges. Hydraulic instruments are sealed systems and record grip strength in kilograms or pounds of force. In this category, the most widely used device is Jamar dynamometer that can be adjusted to five different positions for various sizes of hands. Pneumatic instruments use the compression of an air-filled bulb or bag to determine grip pressure in millimeters of mercury, or pounds per square inch. They are commonly used with clients who have painful hands, as they are viewed as being softer and more comfortable to grasp. Mechanical instruments record grip strength based on the amount of tension produced in a steel spring. Finally, strain gauges commonly measure grip strength in Newtons of force (Innes, 1999).

There is a vast literature on isometric grip strength testing in which isometric grip strength data of a population were collected and some statistical analyses were performed to understand correlations between body dimensions and muscle strength data. Some of them presented in the following.

A poorly designed hand tool can cause to increase risk factors of musculoskeletal disorders and decrease the performance of workers. Therefore, the size of grip span of a hand tool is a critical factor in designing a new hand device. To this end, investigation have been performed by some researchers for determining the optimum grip span (which is the distance between the two grip bars of the grip dynamometer or tool on which the subject's hand has to grasp tightly to exert its strength) corresponding to maximum isometric grip strength (e.g., Montoye and Faulkner, 1964; Chuang *et al.*, 1997; Ekşioğlu, 2004).

Montoye and Faulkner (1964) conducted a study to measure grip strength of dominant hand of 138 males (from five to 52 years old) and 64 females (from four to 42 years old). They used an adjustable grip dynamometer with 10 settings of 0.25 cm (3.50-5.75 cm) and one trial was taken at each grip setting to determine the optimum setting. To minimize fatigue effect, a two-minute rest separated each trial. The subjects took the tests in a standing position, and the dynamometer was held by them, without any support. The researchers also measured hand length, hand width and length of second finger for each subject. According to this study, the best criterion for determining optimal dynamometer setting is hand width. The optimum dynamometer setting is 3.5 cm for females whose hand width is less than 6.5 cm, 4.0 cm for females whose hand width is between 6.5 to 7.5 cm and 4.5 cm for females whose hand width is over 7.5 cm. For males, the optimum dynamometer settings are 0.5 cm greater than those of females are, for each group.

Chuang *et al.* (1997) measured grip strength of both hands of 120 volunteer Chinese young male students of ages 16 to 20 years (24 students in each age group) in Taiwan. Grip strength was measured with four different grip spans (4, 5, 6, and 7 cm) for both hands, by using a versatile digital dynamometer. Finally, the grip strength was measured by subjects' preferred hand, once more. In each case, subjects squeezed the dynamometer five seconds while they were standing with shoulder adducted and neutrally, elbow flexed at 150° and the forearm and wrist in neutral position, and they had a two minute-rest between each trial to minimize fatigue effect. The maximum of three attempts was reported as the result of tests, for both hands. They reported that the means of the length of the preferred grip spans were 5.4 cm for both hands. The most preferable grip span setting among the four selections was 5 cm for both hands, and the maximum grip force was exerted at this span; however, the variations among grip forces at 5 cm, 6 cm and the preferred grip spans were not significant. Although the preferred grip span was determined by the subject, it did not always produce the maximal grip force. They also reported that on the average, the mean grip strength of the left hand was eight per cent less than that of the right hand. Finally, they reported that the grip strength values of their study were lower than those of other countries.

Ekşioğlu (2004) investigated the optimum grip span relative to an individual's hand anthropometry for an isometric power grip exertion. In the study, nine different widths of span, separated with 0.5 cm intervals, were tested across 12 right handed male university students, for their preferred hand. The span size was function of one's modified thumb crotch length, which is the distance between thumb base and the middle furrow of the middle finger. Overall results of his study indicate that the optimum grip span for maximum isometric grip force corresponds to 2 cm to 2.5 cm less than the modified thumb crotch length.

While conducting a study about grip strength, not only grip span but also, positions have importance. Besides grip span, a number of researchers have investigated the effects of posture, elbow and wrist position on grip strength (e.g., O'Driscoll *et al.*, 1992; Ng and Fan, 2001; Hillman *et al.*, 2005).

O'Driscoll *et al.* (1992) investigated the relationship between wrist position and grip strength in 20 right handed healthy subjects, with 20 to 51 years age. During the tests, they used both of five grip span settings of Jamar hand dynamometer. According to this study, the optimum position for the wrist is 33-40 degrees extension and seven degrees ulnar deviation. Their results showed that the degree of wrist extension for optimum grip strength was inversely and linearly related to how large a setting on the Jamar dynamometer was used. Therefore, for grasping a larger object, wrist position would tend toward flexion. It was also reported that the optimum wrist position for maximal grip strength is the same for both men and women, and also for the dominant and non-dominant hands.

Ng and Fan (2001) investigated the effects of different elbow positions during gripping among 30 right handed healthy adults (15 men and 15 women with mean age of 31.6 years and with standard deviation of 5.29 years). Grip strength was measured in both hands at 0°, 30°, 60°, 90° and 120° of elbow flexion (in a randomized order for each participant), while the Jamar dynamometer was supported by the experimenter. In each elbow position, participants squeezed the handle (second setting of grip span) for five seconds, and they repeated the test after a two-minute rest. The higher reading of the two trials was used for analysis. The results of this study showed that the grip strength at 0°, 30° and 60° are 0.5 to three per cent lower than the measurements taken at 90° of elbow flexion, but the differences are not statistically significant. Grip strength at 120° was significantly lower than all other positions on both sides, whereas the grip strength at 90° was the highest among all positions tested.

Hillman *et al*. (2005) examined the difference between different postures for handgrip strength testing among 55 healthy subjects (26 males and 29 females). Their results indicate that there was no significant difference between measurements made in bed and on an armchair but the measurements made in a chair were significantly higher than those made in bed and in an armchair. There was no significant difference between measurements made in bed and on an armchair, but the measurements made in a chair were significantly higher than those made in bed and in an armchair.

In the grip strength testing procedure, the strength tests are generally done more than once. However, using average or maximum of between these trials is disputable. To investigate this, Haidar *et al*. (2004) compared average grip strength with maximum grip strength. They measured grip strength of 50 male (age from 23 to 63 years, with mean 37) and 50 female (age from 21 to 58 years, with mean 34) healthy hospital workers in standard posture (the subjects were seated with shoulder adducted and neutrally, elbow flexed at 90° and the forearm and wrist in neutral position) for each hand, with a Jamar dynamometer. Participants were allowed to choose the most comfortable handle position for their hand size. Testing always started with the dominant hand. Participants were given instructions to hold the handle and squeeze as hard as they could for up to six seconds and then relax. Three consecutive measurements of grip strength were obtained for each dominant and non-dominant hand with a one minute interval between measurements. They found that the two methods (using average or maximum of the trials) are consistent with no statistically significant difference.

Some researchers (e.g., Schmidt and Toews, 1970; Mathiowetz *et al.*, 1985; Peebles and Norris, 2003; Bao and Silverstein, 2005; Nicolay and Walker, 2005; Bohannon *et* al., 2006; Hu *et al.*, 2007) have conducted studies in which they investigated grip strength as a function of gender, age, height and weight of the participants. The results of these studies are presented below.

Schmidt and Toews (1970) measured grip strength of 1,128 healthy male and 80 healthy female employee applicants (with an age range of 18 to 62 years) for dominant and non-dominant hands, by using the Jamar dynamometer. The handgrip spacing was set at 3.81 cm (1.5 inches) for all subjects. All tests were done without a warm-up period; three attempts with each hand were made alternately, beginning with the dominant hand. They found three per cent difference in grip strength between the major and minor hands. They reported that the average value of grip strength of males was significantly higher than that of females was. They concluded that grip strength is proportional to height and weight up to 190.5 cm (75 inches) and 97.5 kg (215 pounds), and grip strength is directly proportional to age up to 32 years and inversely proportional thereafter.

Mathiowetz *et al.* (1985) depicted normative right and left handgrip strength data of 310 male (with a mean age of 49.03 years) and 328 female (with a mean age of 49.75 years) adults, ages 20 to 94, using the Jamar hand dynamometer with standardized positioning and instructions. In the standardized positioning (which was suggested by the American Society of Hand Therapists, 1981), the subjects were seated on a chair without armrests with his/her shoulder adducted and neutrally, elbow flexed at 90° and the forearm and wrist in neutral position. The grip span of the dynamometer was fixed to second setting (4.76 cm), and it was held around the readout dial by the examiner, during the tests. For each strength test, the scores of three successive trials were recorded for each hand. According to their study, dominant hand is stronger than non-dominant one. A high correlation was seen between grip strength and age, and in general, grip strength peaks within the 25 to 39 age group for both man and woman subjects and gradually declines thereafter.

Peebles and Norris (2003) collected data on children through to the older adult on a series of six strength measurements, all of which were intended to be directly applicable to design: (1) finger push strength, (2) pinch-pull strength, (3) handgrip strength, (4) wrist-twisting strength, (5) opening strength, and (6) push and pull strength. For the handgrip strength testing, 65 males (aged between two to 80 years) and 88 females (aged between two to 86) squeezed three cylindrical handles of a strain gauge (diameter with 30, 50 and 70 mm) for five seconds with their dominant hand, while standing and adopting a free posture. The exertion time was five seconds. They found that, the optimum handle diameter for males who are aged from two to 10 years and from 16 to 70 years was 50 mm. However, the optimum handle diameter was 70 mm for 11-15 and 71-80 years old males. On the other hand, for females, the optimum handle diameter was 30 mm for age two to five, 50 mm for age six to 70, and 70 mm for age 71 to 86. Results showed that no significant differences in maximum grip strength were found between male and female children (2-15 years). However, in adults aged 16 years and over, males were generally found to be significantly stronger than females. Moreover, strength was found to increase with age throughout childhood, to peak adulthood, and then decrease with age from around 50 years.

Bao and Silverstein (2005) collected normative data of power grip strength with a newer digital dynamometer whose grip span was set at 2.5 cm. Strength tests were repeated three times and the highest value was used as the strength value. One hundred and twenty (64 females, 56 males) subjects volunteered in the experiments with mean age of 43 years for males and 44 years for females. As a result of their study, they reported that men had significantly higher power grip strength compared to women. On average, power grip strength of men was about 60 per cent higher than that of women. Correlation analyses between the strengths and age showed that there was a decreasing trend that with the increase of age, the power grip strengths were decreasing among men and women. However, such a trend was weak and was only statistically significant among women, but not men. Body height seemed to be positively correlated with power grip strength.

Nicolay and Walker (2005) examined grip strength for 51 individuals (34 females, and 17 males), aged 18-33 years. During the tests, subjects were seated upright and perpendicular to a laboratory table, resting the elbow comfortably on the table between about 90° and 120°. The wrist was in a neutral position. A non-adjustable hand dynamometer with 7.3 cm grip span was used for the tests. As a result, for the combined gender sample the dominant hand was significantly stronger than the opposite hand. Males generated significantly greater maximum grip force than females. When the sample was broken down by gender, it was discovered that only females possessed a significant difference in the strength between the two hands; males showed no significant differences between their dominant and opposite hands. In both genders, about one-third of all participants exhibited greater maximum strength in the non-dominant hand.

Bohannon *et al*. (2006) investigated the studies about grip strength test to depict an age, gender reference values for adult grip strength (for dominant and non-dominant hands) with a Jamar dynamometer. Relevant data from 12 sources (3,317 subjects) were employed. Means and 95 per cent confidence intervals are presented for the left and right sides of men and women in 12 age groups (20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75+ years). The consolidated grip strength reference values offer a better standard for comparison than provided by any single study alone. They found that the maximum grip strength value was seen in 30–34 age group, for both males and females.

Hu *et al*. (2007) collected anthropometric data and measured handgrip strength of 58 female (age range: 65-81 years, mean 71.2) and 50 male (age range: 65-85 years, mean 71.5) subjects from Chinese population. The handgrip dynamometer, which was used in the tests, has two parallel bars, and the position of the inner bar is adjustable so that the distance between the two bars can be set according to the hand size of the subject. After performing the tests, they found percentile values of strength measurement for both males and females. They found the mean grip strength value 38 kgf for males, and 21 kgf for females.

Occupation of a person can also affect his/her grip strength. To investigate effect of different types of occupations, some researchers (e.g., Josty *et al.*, 1997; Xiao *et al.*, 2005; Lau and Ip, 2006; Anakwe *et al.*, 2007) have conducted studies in which they collected grip strength of different types of workers whose classification were generally based on power demand level of their jobs.

Josty *et al.* (1997) measured grip strengths of both hands of 44 non-manual right handed male workers (office workers with age range 19-45, mean 29 years), 38 light manual right handed male workers (car mechanics with age range 16-56, mean 30 years), and 32 heavy manual right handed male workers (farmers with age range 17-65, mean 43 years) with the Jamar hand dynamometer (in third handle position), to see the strength differences between different occupational groups. The recommendation made by for testing was followed the American Society of Hand Therapists (ASHT). They measured the grip strength for each hand twice, and if the grip strength difference between two hands was more than 10 per cent, a third reading was taken. In order to eliminate fatigue effect, the test was performed on one hand after another, always starting with the dominant hand. They concluded that heavy manual workers have the strongest grip strength with the least difference between hands (no statistically significant difference between the dominant and non-dominant grip of heavy manual workers), and office workers have the weakest grip strength with the greatest difference between hands.

Xiao *et al.* (2005) provided dominant and non-dominant grip strength data from a Chinese population (146 male and 47 females) with different occupations. While executing the tests, the subjects seated and dynamometer was held with palm facing up. The subject was given three trials, one warm-up trial at 48 per cent effort and two trials at MVC, and average of two trials (in which they reached to their maximum for one second and held them three seconds) were reported as the subject's score. According to their study, the mean female strengths were about 50 per cent lower than the male values. Industrial workers and students had higher mean strengths than administrators for males, and industrial workers had higher mean strengths than students.

Lau and Ip (2006) compared the power grip between the dominant and non-dominant hands for 64 healthy Chinese male subjects of different occupational demand (32 light manual workers, and 32 heavy manual workers). They classified the job groups according to their power demand level. All of the subjects were right hand dominant. Results showed that heavy manual workers stronger than light manual workers, and both the heavy manual and light manual workers demonstrated stronger power grip strengths in their dominant hands.

Anakwe *et al*. (2007) measured forearm circumference and grip strength of two hundred and fifty healthy subjects (172 men, 88 women), with a Jamar dynamometer in second setting. As a result, grip strength was consistently greater for men than women.

Handgrip strength was greatest for the 35 to 44 year old group for both genders. Although there was a large range of forearm circumferences in the population, there was little difference between hand lengths for each subject (less than two cm). They found a positive correlation between forearm circumference and grip strength for both males and females.

The summaries of the above mentioned studies are presented in Table 2.1 and Table 2.2. Methods and procedures of the current study are developed in the light of those reviewed studies.

Table 2.1. Summary of the descriptive data of the reviewed grip strength studies

Source	**Location**	**Sample type (Size, Gender, Age)**	**Measure used**	**Dynamometer**	**Grip span**	**Posture**	**Measured Hand**	**Support**	**Rest time**	**Squeeze time**
Montoye and Faulkner (1964)	USA	138 M (5-52 yr.) 64 F (4-42 yr.)	One	Smedley (mechanic)	10 settings (3.5-5.75 cm)	Stand	Dominant	No	2 min.	
Chuang *et al.* (1997)	China	120 M (16-20 yr.) (18 ± 1.42 yr.)	Best of three	Digital dynamometer	4 settings (4, 5, 6, 7 cm) and preferred	Stand	Both	No	2 min.	5 sec.
Ekşioğlu (2004)	USA	12 M (21-33 yr.) (25.6 ± 3.3 yr.)	Best of three	Jamar	3rd setting (5.9 cm)	Stand	Both	No	3 min.	5 sec.
			Best of three	Lafayette (modified)	TCL_m – 2 cm Thumb crotch length	Sit	Dominant	Yes	5 min.	5 sec.
O'Driscoll (1992)	Canada	10 M and 10 F	One	Jamar	5 settings (3.49-8.57 cm)	Sit	Both	No		
Ng and Fan (2001)	Hong Kong	15 M and 15 F (31.6 ± 5.29 yr.)	Best of two	Jamar	Fixed (2nd setting) (4.76 cm)	Sit	Both	Yes	2 min.	5 sec.
Hillman *et al.* (2005)	UK	26 M (27-42 yr.) 29 F (29-44 yr.)	Mean of three	Strain gauge		Sit	Both	Both	1 min.	
Haidar *et al.* (2004)	UK	50 M (23-63 yr.) 50 F (21-58 yr.)	Mean and best of three	Jamar	Preferred span	Sit	Both	Yes	1 min.	6 sec.
Schmidt and Toews (1970)	USA	1128 M (18-62 yr.) 80 F (18-52 yr.)	Three	Jamar	Fixed (3.81 cm)		Both			
Mathiowetz *et al.* (1985)	USA	310 M (mean:49.03) 328 F (mean: 49.75) (Range 20-94 yr.)	Mean of three	Jamar	Fixed (2nd setting) (4.76 cm)	Sit	Both	Yes		
Peebles and Norris (2003)	UK	65 M (2-80 yr.) 88 F (2-90 yr.)	One	Strain gauge	3 settings (3, 5, 7 cm)	Stand	Dominant	No		5 sec.
Bao and Silverstein (2005)	USA	56 M (mean: 44) 64 F (mean: 43)	Best of three	Strain gauge (digital)	Fixed (2.5 cm)		Dominant		No formal	5 sec.
Nicolay and Walker (2005)	USA	17 M (18-33 yr.) 34 F (18-29)	Best of three	Qubit system (strain gauge)	Fixed (7.3 cm)	Sit	Both	Yes		2 sec.
Bohannon *et al.* (2006)	USA	1477 M 1840 F		Jamar						
Hu *et al.* (2007)	China	50 M (65-85) 58 F (65-81)	One	Smedley (mechanic)			Dominant			4-6 sec.
Josty *et al.* (1997)	UK	114 M with three occupation groups	Best of two	Jamar	Fixed (3rd setting) (6.03 cm)	Sit	Both	No	No	
Xiao *et al.* (2005)	China	146 M (3 job groups) 47 F (2 job groups)	Mean of two	Lafayette	Fixed (2.5 cm)	Sit	Both	Yes	No formal	4 sec.
Lau and Ip (2006)	China	64 M (32 light manual, 32 heavy manual workers)	Mean of three	Jamar	Fixed (3rd setting) (6.03 cm)	Sit	Both		2 min.	3 sec.
Anakwe *et al.* (2007)	UK	172 M (49 heavy manual workers) 78 F	Best of five	Jamar	Fixed (2nd setting) (4.76 cm)	Sit	Both		No formal	

Table 2.2. Results of some of the reviewed studies

Source	Location	Sample type	Grip span (cm)	Grip Strength (kgf)	
				D	ND
Chuang *et al.* (1997)	China	120 M	4	38.7	35.7
			5	40.6	37.5
			6	40.2	37.2
			7	37.1	34.9
			Preferred	39.8	37.2
Ekşioğlu (2004)	USA	12 M	Jamar, 3rd setting (5.9 cm)	45.9	
			Lafayette, TCL_m – 2 cm	45.4	
Ng and Fan (2001)	Hong Kong	15 M, 15 F (Combined)	4.8	37.4	34.3
Hillman *et al.* (2005)	UK	26 M		48.5	45.9
		29 F		31.6	30
Haidar *et al.* (2004)	UK	50 M	Preferred	49	46
		50 F	Preferred	31	30
Schmidt and Toews (1970)	USA	1128 M, 80 F (Combined)	3.8	51.3	49.8
Mathiowetz *et al.* (1985)	USA	310 M	4.8	47.4	28.5
		328 F	4.8	42.2	24.5
Bao and Silverstein (2005)	USA	56 M	2.5	47.9	
		64 F	2.5	30	
Nicolay and Walker (2005)	USA	17 M	7.3	39.5	39.5
		34 F	7.3	20.4	16.8
Hu *et al.* (2007)	China	50 M		38	
		58 F		21	
Josty *et al.* (1997)	UK	34 Office workers	6	46.1	41.9
		38 Car mechanics	6	52.5	50.7
		32 Farmers	6	53.7	53.6
Xiao *et al.* (2005)	China	75 M Industrial W.	2.5	43.3	43.1
		36 M Student	2.5	45.2	42.1
		35 M Office clerk	2.5	40.3	39.8
		12 F Industrial W.	2.5	26	25.1
		35 F Student	2.5	22.3	20
Lau and Ip (2006)	China	32 M Light Manual	6	39.2	34.8
		32 M Heavy M.	6	41.4	39.5
Anakwe *et al.* (2007)	UK	49 M Heavy M.	4.8	54.4	
		123 M Light M.	4.8	46.2	

D: Dominant hand; ND: Non-dominant hand; kgf: Kilogram force

3. OBJECTIVES OF THE STUDY

Many industrial activities are performed through human intervention. Therefore, knowledge of what a person can or cannot do under specified circumstances is essential for efficient work and equipment design and injury prevention. In a variety of production processes, force application is an essential activity. For example, working with tools requires application of significant grip force. High and repetitive grip force application may injure the hands, especially in awkward postures. To design a job requiring grip force, the grip strength capability of workers must be known, so that designers can match the demands of the jobs to the grip strength capability of workers. Besides industrial engineers and ergonomists, measurement of human strengths is of interest to many other professionals in many other disciplines, such as physiotherapy, orthopedics, medicine, etc.

Although there are extensive studies about handgrip strength in Western countries, there is not a study about strength distribution of Turkish population. This study is the first attempt to fill this gap. Therefore, the objectives of this study are:

1. Estimating the maximum voluntary isometric grip strength distribution of Turkish population from a sample data

2. Investigating the effects of hand support, and body posture on grip strength

3. Investigating the effects of gender, age, height, weight and occupation on grip strength

4. Comparing the strength data of Turkish population with the strength data of population of other countries.

4. METHODOLOGY

4.1. Subjects

Participants included 208 volunteers (129 males and 79 females) recruited for this study. The subjects were recruited in the city of İstanbul in Turkey. Due to its demographic characteristics, the population of İstanbul approximately represents the general population of Turkey. Figure 4.1 shows the dispersion of the birthplaces of the participants' parents with respect to the geographical regions of Turkey. Subjects were categorized into three groups, namely light manual workers, heavy manual workers, and university students, according to their power demand levels, and categorization was based on the "Regulation of Heavy and Dangerous Labors" which was published in the "Turkish Official Newspaper" on 16 June 2004. All subjects were free from hypertension, heart disease, diabetes, rheumatoid arthritis, arm pain and musculoskeletal disorders. Only seven male and six female subjects were left-hand dominant. The demographic profile of the 208 subjects is summarized in Table 4.1. Table 4.2 shows the occupation types of subjects except university students, in detail. Table 4.3 describes the number of male and female participants by age and occupation groups.

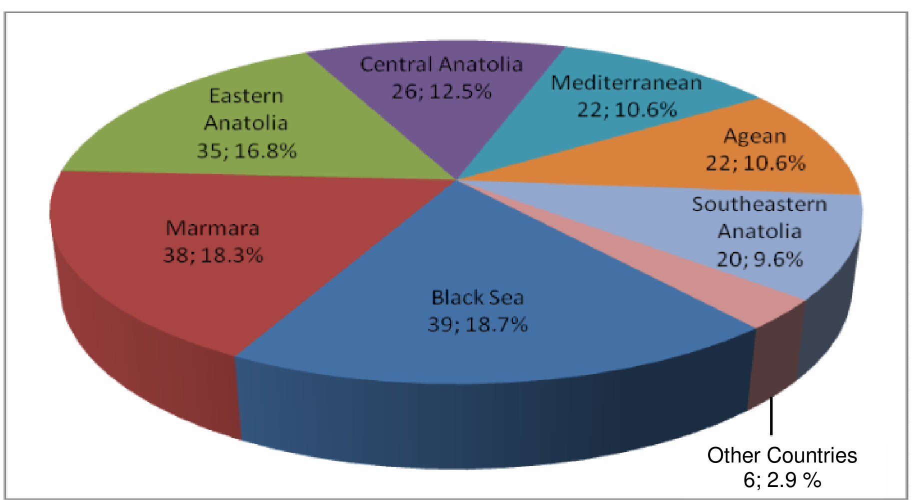


Figure 4.1. Distribution of birthplaces of the participants' parents

Table 4.1. Demographic profile of subjects

	Male (n = 129)		Female (n = 79)	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**
Age (yr)	33.36 ± 13.24	18-69	34.34 ± 15.1	18-68
Weight (kg)	78.44 ± 12.72	50-120	61.35 ± 12.34	45-116
Height (cm)	176.28 ± 7.32	158-198	161.99 ± 5.79	148.5-174

Table 4.2. Distribution of occupations of subjects*

Male		Female
Light manual workers (71)	**Heavy manual workers (23)**	**Light manual workers (55)**
Accounting clerk (4)	Baker (1)	Accounting clerk (8)
Antiquarian (1)	Car mechanic (2)	Bank clerk (1)
Architect (1)	Carpenter (6)	Canteen worker (3)
Bank clerk (1)	Electrician (2)	Clothing salesperson (4)
Canteen worker (6)	Ironworker (4)	Coiffeur (1)
Chauffeur (1)	Lathe operator (3)	Cook (1)
Civil engineer (3)	Locksmith (1)	Foreign trade expert (6)
Clothing salesperson (1)	Plumber (1)	Custodian (2)
Coiffeur (2)	Porter (1)	Housewife (16)
Computer engineer (2)	Press operator (1)	Industrial engineer (1)
Control engineer (1)	Repairman of household equipment (1)	Insurance agent (1)
Cosmetic salesperson (1)		Logistics company clerk (4)
Courier (1)		Nurse (1)
Electronics engineer (10)		Office manager (1)
Finance inspector (1)		Post office clerk (1)
Foreign trade expert (2)		Secretary (3)
Grocer (1)		Tourism agent (1)
Housekeeper (3)		
Human resources expert (1)		
Industrial engineer (5)		
Marketing expert (2)		
Mechanical engineer (1)		
Music instruments shopkeeper (1)		
Musician (1)		
Parking garage worker (2)		
Peddler (2)		
Pharmacist (2)		
Pilot (1)		
Public relations expert (1)		
Real-estate agent (2)		
Security personnel (1)		
Tailor (1)		
Teacher (5)		
Waiter (1)		

* Number of subjects is shown in parentheses.

Table 4.3. Number of subjects by gender, age and occupational groups

Occupation	**Age group (yr)**	**Number**		
		Male	**Female**	**All**
Light manual workers	18-29	36	17	53
	30-39	12	12	24
	40-49	8	10	18
	50-59	7	9	16
	60-69	8	7	15
	All	71	55	126
Heavy manual workers	18-29	6	0	6
	30-39	7	0	7
	40-49	5	0	5
	50-59	5	0	5
	All	23	0	23
University students	18-29	34	24	58
	30-39	1	0	1
	All	35	24	59
Total		129	79	208

4.2. Equipment

Before the strength tests, some anthropometric dimensions of the participants were measured. A mechanical scale was used to weigh participants, which was checked for accuracy with known weights before the tests. A wall-mounted meter was devised to measure the height of the some of the subjects in the Ergonomics Laboratory. For the tests performed outside of the laboratory, the subjects' heights were measured by a GPM anthropometer (Figure 4.2). A tape measure was used to measure circumferences of wrists of the participants. Finally, to measure length and width of hands of the participants a sliding caliper was used (Figure 4.3).

Figure 4.2. GPM Anthropometer

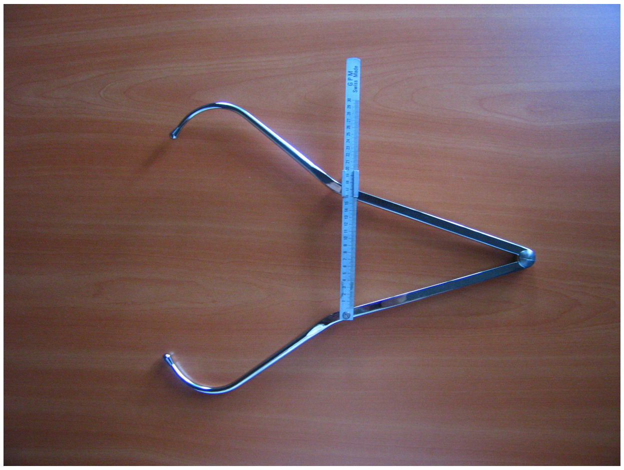


Figure 4.3. Sliding caliper

The strength tests were administered with a hydraulic Jamar handgrip dynamometer (Model 5030J1, Sammons Preston Roylan, Chicago, USA), which is considered a standard isometric grip strength testing device (Figure 4.4). This dynamometer displays grip force in pounds and kilograms up to 200 pounds or 90 kilograms. It has a peak-hold needle that automatically retains the highest reading until reset. The dynamometer accommodates various size hands because its handle adjusts to five grip positions: from 3.5 cm to 8.6 cm (1.375 to 3.375 inches), in 1.27 cm (0.5 inch) increments. The mass of the dynamometer is 0.682 kg. Before the strength tests, the dynamometer is calibrated for accuracy with known weights. An adjustable chair was used for sitting posture grip tests.

Figure 4.4. Jamar hand dynamometer

4.3. Testing Procedure

For the tests, the subjects were recruited in the city of İstanbul in Turkey. Potential subjects were told that a series of body dimension measurements and handgrip strengths were going to be measured. After explaining the aims of the study, all candidate subjects filled a “Brief Medical History Form” to confirm that they were healthy enough for the tests. The candidate subjects who were free from hypertension, heart diseases, diabetes, rheumatoid arthritis, arm pain and musculoskeletal disorders were accepted to participate in the study.

After determining that a subject is suitable for the tests, he/she signed a “Personal Consent Form”, which includes a detailed description of the aim and procedures of the study, to show that he/she is voluntarily participating in study. In the personal consent form, it was reported that all information obtained during the study would be held in strict confidence. However, seven out of the 208 subjects refused to sign the personal consent form due to personal reasons. Both the brief medical history form and personal consent form were prepared in Turkish (Appendix A).

The participants then were asked their birth date, birthplace, dominant hand and occupation. Birthplace of their parents were also asked to the participants to understand their real geographical root, because most people in İstanbul came from other cities. If the birthplaces of a participant’s mother and father differ from each other, the experimenter asks to him/her the city that he/she feels himself/herself from.

Following to collect descriptive data of the subjects, their heights (in cm) and weights (in kgf) were measured. In the Ergonomics Laboratory, the wall-mounted meter was used; but outside the laboratory, the GPM anthropometer was used for measuring height of the participants (Figure 4.5 and 4.6). To understand that if height measurement devices give consistent results with each other, the height measurement was conducted with both wall-mounted meter and GPM anthropometer, for five chosen participants. In this case, the measurements gave same results for each subject. To weigh the participants, a mechanical scale (with one kilogram increments), which had been checked for accuracy with known weights before the tests, was used. While weighing, the subjects wore light clothes as much as they could. Therefore, they did not wear shoes, watch or any accessory such as jewelry, wallet, key etc. In addition, the participant was not very hungry or full.

Figure 4.5. Measurement of height with wall-mounted meter

Figure 4.6. Measurement of height with the anthropometer

After measuring height and weight, hand length, hand width and circumference of wrists were measured for both right and left hands, in centimeters. Five male and four female subjects did not participate in this part of study. Therefore, the number of the subjects that participated in this part of the study is 124 males and 75 females. A tape measure was used to measure circumferences of wrists of the participants (Figure 4.7). Finally, to measure length and width of hands of the participants a sliding caliper was used. While measuring hand length and hand width, the subject sit with the hand and fingers extended, palm up (Figure 4.8). The length of the hand was measured from the wrist crease to the tip of the middle finger. For measuring the width of the hand, the maximum breadth across the palm of the hand was measured (Figure 4.9). Therefore, the distance between the second metacarpal's distal end and the fifth metacarpal's end was measured as hand width (Vasu and Mital, 2000). Table 4.4 shows the hand length, hand width and wrist circumference data of the subjects.

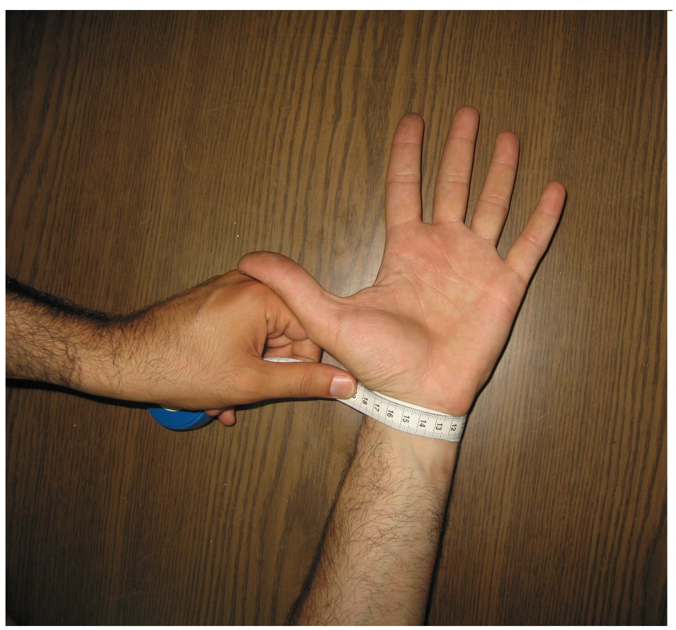


Figure 4.7. Measurement of circumference of wrist

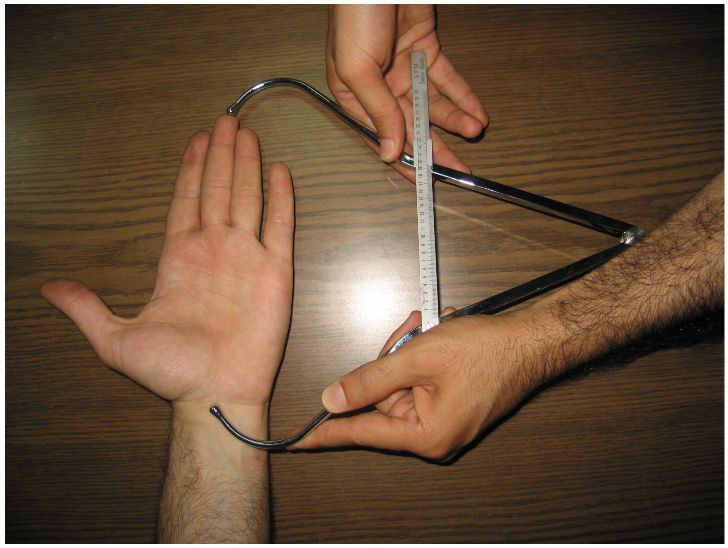


Figure 4.8. Measurement of hand length

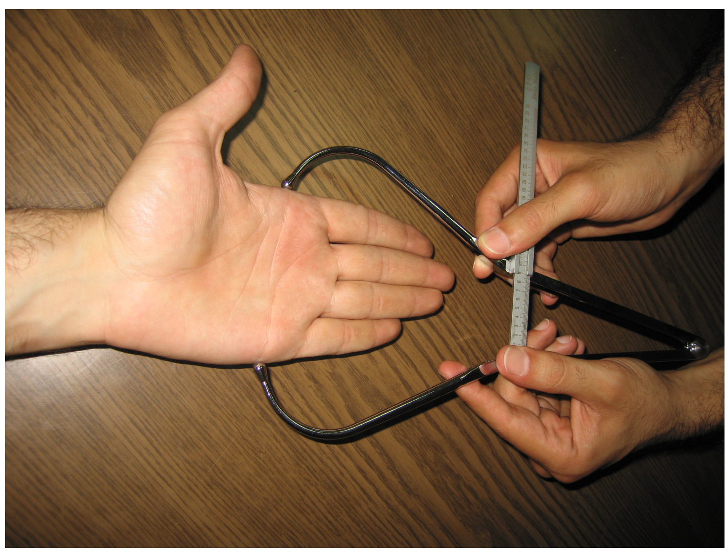


Figure 4.9. Measurement of hand width

Table 4.4. Anthropometric dimensions of hands of the participants

Measurement Type	Male (n = 124)		Female (n = 75)	
	Mean ± SD	**Min-Max**	**Mean ± SD**	**Min-Max**
Right hand				
Hand length (cm)	18.83 ± 0.93	16.5-20.8	17.23 ± 0.67	15.6-18.9
Hand width (cm)	8.69 ± 0.48	7.1-9.8	7.72 ± 0.37	6.9-8.8
Wrist circumference (cm)	17.48 ± 0.97	15-20.1	15.63 ± 1.14	13.8-19
Left hand				
Hand length (cm)	18.83 ± 0.91	16.4-20.7	17.23 ± 0.7	15.7-18.8
Hand width (cm)	8.67 ± 0.5	7.1-9.7	7.71 ± 0.37	7-8.9
Wrist circumference (cm)	17.47 ± 1	15-20.5	15.66 ± 1.16	13.7-19

Following the measurement of hand dimensions of the subjects, the grip strength tests were started. The subjects were first familiarized with the equipment and procedures for collecting maximum voluntary contraction (MVC) data. Before the actual tests, first the subjects moved and shook their hands and fingers to speed up their blood circulation, as a warm-up period. Then, they performed trial tests, at approximately 50 per cent effort, with different dynamometer grip span setting to determine their "preferred span", for which they felt they could produce their maximal strength, comfortably. While 41 males and 69 females preferred second setting, 88 males and 10 females preferred third setting of the handle. After setting the dynamometer to the preferred span, each subject's MVC were collected according to Caldwell Protocol (1974). The grip strength tests were performed in four different postures for both dominant and non-dominant hands. Therefore, maximal grip strengths were recorded while:

1. The subjects were standing up with shoulder adducted with 90° elbow angle and dynamometer unsupported.
2. The subjects were standing up with shoulder adducted with 90° elbow angle and dynamometer supported by the experimenter.
3. The subjects were comfortably sitting on an adjustable chair with shoulder adducted with 90° elbow angle and dynamometer unsupported.
4. The subjects were comfortably sitting on an adjustable chair with shoulder adducted with 90° elbow angle and dynamometer supported by the experimenter.

In standing postures, upper arms were kept vertical while touching on the side of the body with 90º elbow angle and neutral wrist posture. In this posture, the test was done for both supported dynamometer and unsupported dynamometer cases, for understanding the effect of dynamometer weight on grip strength. If the dynamometer was unsupported, the subject holds it. However, in supported dynamometer case, the experimenter holds the dynamometer from top and bottom of it, to minimize the weight effect of the dynamometer on the strength value. Each test was performed at least twice for each hand. Therefore, the minimum number of the tests performed in standing posture is eight. The position of the hand remained consistent in each test; because it has been shown that grip strength can be dependent on wrist position (O'Driscoll *et al.*, 1992). Figure 4.10 and 4.11 show the measurement of grip strength value of left and right hands while the subject was in standing posture for supported and unsupported dynamometer cases.

Figure 4.10. Measurement of grip strength value of right hand while the subject is standing and dynamometer is unsupported

Figure 4.11. Measurement of grip strength value of left hand while the subject is standing and dynamometer is supported

In sitting postures, subjects were seated comfortably on a chair without armrests. The shoulder was adducted and neutrally rotated, the elbow flexed at 90°, with the forearm and wrist in neutral position, and the knees flexed at 90°. In this posture, the test was done for both supported and unsupported dynamometer cases as in the standing posture. In supported dynamometer case, the experimenter squatted down to hold the dynamometer. The number of the tests performed in sitting posture is eight. Measurement of grip strength of left and right hands in sitting posture can be seen in Figure 4.12 and 4.13 for supported and unsupported dynamometer cases.

Figure 4.12. Measurement of grip strength value of left hand while the subject is sitting and dynamometer is unsupported

Figure 4.13. Measurement of grip strength value of right hand while the subject is sitting and dynamometer is supported

According to Caldwell Protocol, after ensuring that the subject was “ready” for the test, the experimenter instructed each subject in the same tone of voice, “The purpose of this test is to measure your maximum voluntary grip strength. In this position, I want you to hold the handles of the dynamometer and squeeze as hard as you can, without jerking. I want you to reach your maximum exertion in about one second and hold it for about four seconds”. For both dominant and non-dominant hands, the subjects performed a minimum of two trials in each test combination. Whenever the strength variation was more than 10 per cent between two trials, the subject was asked to repeat the test once more. Therefore, the maximum of the two trials, within 10 per cent of each other, was recorded on the “Data Collection Form” as the subject’s MVC for that test combination. The data collection form also includes descriptive and anthropometric data of the subjects. This form can be seen in Appendix A. To eliminate fatigue effect on grip strength, the subjects were allowed to rest about two minutes between trials. The tests were performed sequentially with dominant and non-dominant hands. During the testing, the experimenter did not provide any feedback about the strength values to the subjects. Verbal encouragements, rewards, goal setting, competition and noise were also avoided.

4.4. Design of the Experiment

4.4.1. Experimental Variables

There are two types of experimental variables in a design. One of them is design factors (independent variables) that are the input of the model. The other is response variable (output) of the model which is dependent on the design factors.

There are seven design factors (independent variables) in this study. These factors are hand, support, posture, gender of the subject, age group, body mass index prime (BMIP) group, and occupation group of the subjects. Grip strength is the response variable of the design. Levels of the factors for both males and females can be seen in Table 4.5.

Table 4.5. Design factors and levels of them

Design Factors	**Number of Levels**	**Levels**
Hand	2	(0) Gripping the dynamometer with non-dominant hand (1) Gripping the dynamometer with dominant hand
Posture	2	(0) Gripping the dynamometer while sitting (1) Gripping the dynamometer while standing
Support	2	(0) Dynamometer is unsupported by the experimenter (1) Dynamometer is supported by the experimenter
BMIP group	3	(1) Underweight (BMIP of the subject is less than 0.74) (2) Normal (BMIP of the subject is between 0.74 to 1) (3) Overweight (BMIP of the subject is above 1)
Occupation group	3	(1) University student (2) Light manual worker (3) Heavy manual worker
Age group	5	(1) 18-29 yr. (2) 30-39 yr. (3) 40-49 yr. (4) 50-59 yr. (5) 60-69 yr.

The body mass index prime (BMIP) is a statistical measure of the weight of a person scaled according to height. It is defined as the individual's body weight divided by the 25 times square of their height (kg/m^2) (Wikipedia, 2008).

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

4.4.2. Experimental Conditions

For each subject, each test was performed for hand, posture and support factors. Each test was done at least twice. For each test, each subject performed eight test conditions randomly and only maximum value was considered. There were 179 male and 79 female subjects. Therefore the number of recorded grip strength data points (test runs) is 208 * 8 * 2 = 3,328 (Table 4.6). However, the number of strength data points considered for analysis is 3,328 / 2 = 1,664. The orders and response data for each condition were recorded in Experimental Conditions Form that can be seen in Appendix B.

Table 4.6. Experimental conditions

	Posture															
	Stand								Sit							
	Unsupported				Supported				Unsupported				Supported			
	Right		Left		Right		Left		Right		Left		Right		Left	
Subject No.	Trials		Trials		Trials		Trials		Trials		Trials		Trials		Trials	
	1	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
2	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
3	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
207	3297	3298	3299	3300	3301	3302	3303	3304	3305	3306	3307	3308	3309	3310	3311	3312
208	3313	3314	3315	3316	3317	3318	3319	3320	3321	3322	3323	3324	3325	3326	3327	3328

Numbers in the cells are the run numbers of the test.

4.4.3. Experimental Model

A completely randomized block design, subjects serving as blocks, was found suitable for this study. By blocking on the subjects, the power of the test can be increased by removing the effects of different subjects on grip strength. This would allow us to defect smaller differences between factor effects (Montgomery, 2005). In the model, interaction effects between treatments were neglected and only main effects were taken into consideration. Because after running ANOVA for both males and females, all interaction effects were found non-significant since their p-values were very high. Therefore, for this case, the reduced statistical model for randomized block design for both males and females is:

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

for

$i = 0,1$ (0: Gripping the dynamometer with non-dominant hand)
(1: Gripping the dynamometer with dominant hand)
$j = 0,1$ (0: Gripping the dynamometer while sitting)

(1: Gripping the dynamometer while standing)

$k = 0,1$ (0: Gripping the dynamometer while it is unsupported by the experimenter)

(1: Gripping the dynamometer while it is supported by the experimenter)

$l = 1, 2, 3$ (1: Underweight; body mass index prime of the subject is less than 0.74)

(2: Normal; body mass index prime of the subject is between 0.74 to 1)

(3: Overweight; body mass index prime of the subject is above 1)

$m = 1, 2$ for females

$m = 1, 2, 3$ for males (1: University students)

(2: Light manual workers)

(3: Heavy manual workers)

$n = 1, 2, 3, 4, 5$ (1: 18-29 years)

(2: 30-39 years)

(3: 40-49 years)

(4: 50-59 years)

(5: 60-69 years)

$p = 1, 2,\ldots, 79$ for females (number of female subjects)

$p = 1, 2,\ldots, 129$ for males (number of male subjects)

where,

$y_{ijklmnp}$: $ijklmnp^{th}$ response (maximal grip strength)

μ: overall 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 support factor

τ_l: effect of l^{th} level for body mass index prime (BMIP) group factor

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

η_n: effect of n^{th} level for age group factor

β_p: effect of p^{th} block

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

Each participant performed the tests in a predetermined random sequence. The minimum number of tests that were performed by each subject is 8 * 2 = 16. The order of tests was randomized, but to speed up the process there were some restrictions:

1. To minimize movements, in first eight tests subjects performed the test in standing or while sitting. If the first eight tests are performed in standing, the last eight tests are performed while sitting (or vice versa). Therefore, there are two possible sequences in this case.
2. The first test was performed by left hand or right hand. The two sequential tests were not performed by the same hand. The possible number of orders in this case is two.

There was not any restriction for supporting or no supporting the dynamometer. Any two respective tests can be supported or unsupported. Therefore, possible orders were recorded in an Excel spreadsheet. Then, a column of random numbers was generated by using RAND ( ) function, and were sorted by that column, as proposed by Montgomery (2005). The first 208 orders were chosen for the tests and each subject performed the tests in this predetermined order.

4.4.4. Determining Sample Sizes

In any experimental design problem, a critical decision is the choice of sample size that is determining the number of replicates to run.

In this study, for determining the sample sizes to estimate the mean grip strengths, the following sample size formula was used (Devore, 2004):

$$n = (2z_{\alpha/2}\frac{s}{w})^2 \tag{4.3}$$

where, n is the minimum sample size, α is the significance level, s is the sample standard deviation and w is the desired width of the confidence interval of the mean grip strength (μ).

In this study, the selected values were: $\alpha = 0.1$ (for a 90 % confidence interval) and w = 3 kgf for males and 2 kgf for females. Based on the initial pilot studies on male and female grip strengths, s values were found as follows: s = 7.55 kgf for males and s= 4.84 kgf for females. Replacing these values and $z_{\alpha/2} = z_{0.05} = 1.645$ into the Equation 4.3, we obtain the minimum required sample sizes to estimate the mean grip strength values for 90% confidence interval:

$n_m = 69$ for males, and

$n_f = 64$ for females.

4.5. Statistical Analysis

Statistical analysis was performed using Minitab 15.0. P-values ≤ 0.05 were accepted as significant, and $0.05 \leq p \leq 0.1$ were accepted as marginal. For each gender, analysis of variance (ANOVA) was used to investigate the effects of BMI prime, occupation, age, hand, posture and support factors on grip strength. However, to use ANOVA, the following three assumptions must be satisfied:

1. The error terms (residuals) of the model must follow a normal distribution centered at zero ($\varepsilon \sim$ NID Normal $(0, \sigma^2)$)
2. There must not be any correlation between error terms (correlation of each value and the value before it) and correlation between independent variables and error terms
3. The variances of response variables for each treatment must not be different from each other (homogeneity assumption).

Firstly, normality of the residuals of grip strength data were tested by using Anderson-Darling normality test and normal probability plot of the residuals for both males and females and found that they follow normal distribution. Secondly, autocorrelation between residuals, and Pearson's correlation coefficients between independent variables and residuals were calculated for both males and females, to prove that they were independent to each other. After that, Bartlett's test was used to see that the sample variances in each treatment were not statistically different. For the same purpose, plot of residuals versus the fitted response were investigated for both males and females. Therefore, after meeting the three assumptions of ANOVA, it was used to investigate if the independent variables have an effect on grip strength, for men and women. After ANOVA, multiple comparison tests were performed. Tukey's test was used for unbalanced data for post-hoc analysis. Tukey's test was selected, because while making pairwise comparisons, the Tukey's method results in a narrower confidence limit, which is preferable (Toothaker, 1993). Moreover, because of its simplicity and nearly accurate control of the overall error rate, Tukey's test is recommended for pairwise comparisons (Hochberg and Tamhane, 1987). For unbalanced case, Tukey's test is sometimes called Tukey-Kramer, but throughout the manuscript it will also be referred as Tukey's test. The hypotheses of this test are (Montgomery, 2005):

$$H_0\text{: } \mu_i = \mu_j \qquad (4.4)$$

$$H_1\text{: } \mu_i \neq \mu_j$$

where i and j are treatment levels ($i \neq$ j). Tukey's procedure makes use of the distribution of the studentized range statistic which is equal to (Montgomery, 2005):

$$q = \frac{\bar{y}_{\max} - \bar{y}_{\min}}{\sqrt{MS_E / n}} \qquad (4.5)$$

where $\bar{y}_{\max}$ and $\bar{y}_{\min}$ are the largest and the smallest sample means, MS_E is mean squares due to error and n is the sample size. Due to q value, T value of Tukey's test for unequal sample sizes can be calculated as (Montgomery, 2005):

$$T_\alpha = \frac{q_\alpha(a, f)}{\sqrt{2}} \sqrt{MS_E \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \qquad (4.6)$$

where q_α *(a,f)* is the upper α percentage points of studentized range statistics (q), f is the number of degrees of freedom associated with the MS_E, a is the number of groups will be compared, n_i and n_j are the sample sizes of the groups. Moreover, a set of 100(1- α) confidence intervals for all pairs of means can be constructed as follows (Montgomery, 2005):

$$\bar{y}_{i.} - \bar{y}_{j.} - \frac{q_\alpha(a,f)}{\sqrt{2}}\sqrt{MS_E\left(\frac{1}{n_i}+\frac{1}{n_j}\right)} \le \mu_i - \mu_j \le \bar{y}_{i.} - \bar{y}_{j.} - \frac{q_\alpha(a,f)}{\sqrt{2}}\sqrt{MS_E\left(\frac{1}{n_i}+\frac{1}{n_j}\right)} \quad (4.7)$$

where $\bar{y}_{i.}$ and $\bar{y}_{j.}$ are the sample means of i^{th} and j^{th} groups and μ_i and μ_j are the population means of i^{th} and j^{th} groups ($i \neq j$).

For hand, posture and support factors which have two factor levels with balanced data, paired t-test was used for comparing sample means. Paired t-test can be more powerful than a two sample t-test because the latter includes additional variation arising from the independence of the observations. A paired t-test is not subject to this variation because the paired observations are dependent. Also, a paired t-test does not require both samples to have equal variance. Therefore, for analyzing differences between two treatments given to the same subject, paired t-test is useful to gain more statistical power (Minitab Inc., 2008). The hypotheses of paired t-test are (Montgomery, 2005):

$$H_0\text{: } \mu_d = 0 \quad (4.8)$$

$$H_1\text{: } \mu_d \neq 0$$

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

$$t_0 = \frac{\bar{d}}{S_d / \sqrt{n}} \quad (4.9)$$

where $\bar{d}$

$$\bar{d} = \frac{1}{n}\sum_{j=1}^{n} d_j \quad (4.10)$$

is the sample mean of the differences, S_d

$$S_d = \left[\frac{\sum_{j=1}^{n} (d_j - \bar{d})^2}{n-1} \right]^{1/2} \tag{4.11}$$

is the sample standard deviation of the differences, n is the sample size, and d_j is the j^{th} paired difference (Montgomery, 2005).

Following the ANOVA and multiple comparison tests, regression models were developed to predict grip strengths of both genders. Moreover, Pearson's correlation coefficients were calculated to understand the relationship between preferred span and hand width, hand length and wrist circumference. Percentile values of grip strength, height and weight data were also calculated for both gender for each testing position, age group and occupation group.

5. RESULTS

5.1. Results and Analysis of the Grip Strength Data

The mean, standard deviation and range of the grip strength values (in kgf) for eight different test positions by gender, age and occupation are summarized in Table 5.1.

Table 5.1. Grip strength values (in kgf*)

Age	N	DUU	NUU	DUS	NUS	DDU	NDU	DDS	NDS
Male	129	43.38±7.64 (16-61)	41.96±7.89 (15-60)	45.43±7.83 (18-66)	44.11±7.86 (16-63)	43.64±8.13 (18-64)	42.43±8.25 (18-62)	45.43±8.54 (19-65)	44.18±8.28 (18-67)
HMW**	23	46.83±4.37 (38-55)	46.09±4.93 (36-56)	48.87±5.03 (36-57)	47.78±5.62 (35-58)	46.65±4.82 (39-56)	45.39±5.22 (34-56)	48.73±5.67 (38-62)	47.3±5.65 (36-60)
18-29 years	6	49.17±3.76 (44-55)	47±3.22 (44-53)	50.83±4.54 (43-57)	50.17±2.56 (47-54)	48.5±3.33 (44-52)	46.83±3.71 (42-52)	50.17±3.43 (45-54)	48.67±2.94 (44-52)
30-39 years	7	47.14±5.58 (39-55)	47±5.2 (40-56)	49.43±4.58 (42-56)	49.14±4.81 (43-58)	46±5.6 (40-56)	45.14±4.41 (41-54)	48.86±6.72 (42-62)	47.57±5.38 (42-58)
40-49 years	5	45.6±4.62 (38-50)	45.2±6.53 (36-52)	48±7.45 (36-55)	47±8.43 (35-56)	47.4±5.27 (40-54)	45.6±5.41 (40-52)	50±6.52 (40-58)	48.6±6.88 (43-60)
50-59 years	5	44.8±1.92 (42-47)	44.6±5.55 (38-52)	46.6±3.58 (42-50)	43.8±5.26 (36-50)	44.6±5.22 (39-50)	43.8±8.26 (34-56)	45.6±5.86 (38-52)	44±7.45 (36-56)
LMW***	71	41.85±7.8 (16-61)	40.61±8.19 (15-60)	44.04±8.05 (18-66)	42.63±8.16 (16-63)	42.1±8.07 (18-63)	40.76±8.6 (18-61)	44.11±8.79 (19-60)	42.76±8.53 (20-62)
18-29 years	36	43.44±7.61 (27-61)	43.03±7.85 (28-60)	45.94±8.24 (32-66)	44.89±7.88 (31-63)	43.86±7.62 (27-63)	42.92±8.05 (28-61)	46.44± 8.49 (31-60)	45.28±8.23 (30-62)
30-39 years	12	43.25±7.93 (29-57)	41.75±8.39 (31-60)	45.5±6.92 (38-55)	43.25±8 (35-59)	44.58±7.39 (34-56)	42.5±8.12 (33-55)	47±7.11(34-58)	44.5±6.23 (36-54)
40-49 years	8	42.25±3.33 (36-46)	40.38±4.66 (34-48)	44±4.11 (38-50)	43.38±4.78 (38-51)	42.75±3.28 (36-46)	43.25±5.63 (37-50)	43.88±3.31 (37-47)	44.63±6.14 (37-50)
50-59 years	7	40.29±4.89 (34-48)	36.43±5.06 (28-42)	41.86±5.79 (33-48)	38.57±5.94 (29-47)	39.29±6.13 (27-47)	35±6.66 (21-42)	40.29±7.52 (26-50)	35.86±5.76 (24-43)
60-69 years	8	33.5±9.43 (16-45)	31.88±8.48 (15-41)	35.25±8.46 (18-43)	34.38±8.98 (16-45)	32.25±9.33 (18-44)	31±8.02 (18-41)	32.88±8.53 (19-42)	33±8.09 (20-43)
Students	35	44.22±8.28 (24-60)	42±8.06 (25-60)	46±8.28 (28-62)	44.69±7.81 (28-61)	44.77±9.35 (25-64)	43.89±8.48 (26-62)	45.94±9.11 (27-65)	45±8.71 (27-67)
18-29 years	34	44.26±8.4 (24-60)	41.94±8.17 (25-60)	46±8.41 (28-62)	44.71±7.93 (28-61)	44.74±9.49 (25-64)	43.88±8.61 (26-62)	45.91±9.25 (27-65)	44.91±8.82 (27-67)
30-39 years	1	43	44	46	44	46	44	47	48
Female	79	24.8±5.04 (12-37)	23.48±5.46 (10-35)	26.29±5.28 (13-41)	24.86±5.53 (12-36)	24.63±5.04 (11-37)	23.39±5.13 (10-34)	25.73±5.14 (13-40)	24.52±5.45 (11-36)
LMW	55	25.04±5.19 (12-37)	23.75±5.71 (10-35)	26.4±5.44 (13-41)	25.07±5.81 (12-36)	25±5.18 (11-37)	23.82±5.38 (10-34)	25.89±5.37 (13-40)	24.85±5.5 (11-36)
18-29 years	17	25.06±3.44 (18-30)	24.65±4.24 (17-32)	26.59±3.61 (21-32)	25.35±4.76 (18-34)	25.41±3.26 (20-32)	24.35±3.64 (17-32)	26.47±3.5 (20-32)	26.12±3.85 (20-33)
30-39 years	12	28.75±5.24 (17-37)	27±6.05 (14-35)	30.67±5.37 (20-41)	28.75±5.88 (16-36)	28.42±4.76 (19-37)	26.92±5.76 (17-34)	29.5±5.36 (18-40)	28.17±5.71 (16-36)
40-49 years	10	26±4.97 (16-32)	24.4±6.17 (14-33)	27±5.29 (18-35)	26.2±6.21 (15-33)	25.5±6.13 (14-33)	24.3±6.91 (14-32)	26.5±6.08 (16-33)	25±6.15 (15-32)
50-59 years	9	23.67±5.2 (12-30)	21.56±5.85 (10-28)	24.44±5.17 (13-30)	23.22±5.54 (12-29)	23.44±5.32 (11-28)	21.89±5.28 (10-26)	24±4.53 (13-28)	22.56±5.22 (11-29)
60-69 years	7	19±3.56 (14-24)	17.86±1.95 (14-20)	20.29±3.82 (14-25)	18.86±1.35 (16-20)	19.43±3.64 (14-24)	19±1.53 (17-21)	19.86±3.53 (14-23)	18.86±1.95 (15-21)
Students	24	24.25±4.74 (15-32)	22.88±4.88 (14-31)	26.04±5.01 (16-35)	24.38±4.92 (14-32)	23.79±4.69 (16-34)	22.42±4.48 (11-32)	25.38±4.67 (17-34)	23.75±5.36 (12-36)
18-29 years	24	24.25±4.74 (15-32)	22.88±4.88 (14-31)	26.04±5.01 (16-35)	24.38±4.92 (14-32)	23.79±4.69 (16-34)	22.42±4.48 (11-32)	25.384.67 (17-34)	23.75±5.36 (12-36)

* kgf: kilogram force; ** Heavy manual workers; *** Light manual workers

The notations that were used in the tables are:

NDS: Non-dominant handgrip test while sitting and dynamometer supported

DDS: Dominant handgrip test while sitting and dynamometer supported

NDU: Non-dominant handgrip test while sitting and dynamometer unsupported

DDU: Dominant handgrip test while sitting and dynamometer unsupported

NUS: Non-dominant handgrip test while standing and dynamometer supported

DUS: Dominant handgrip test while standing and dynamometer supported

NUU: Non-dominant handgrip test while standing and dynamometer unsupported

DUU: Dominant handgrip test while standing and dynamometer unsupported

Pearson's correlation coefficients between the independent variables (BMIP group, occupation group, age group, posture, hand, support) and grip strength values for males and females are given in Table 5.2. The p-values indicates that except posture effect (gripping the dynamometer while sitting or standing), the relationships between independent variables and grip strength are statistically significant.

Table 5.2. Correlations between grip strength values and independent variables

Item	**Age group**	**BMIP group**	**Job group**	**Posture**	**Hand**	**Support**
Grip strength of males	-0.297	0.114	0.075	-0.012	0.080	0.119
P-value	0.000	0.000	0.016	0.693	0.010	0.000
Grip strength of females	-0.236	0.093	0.075	0.027	0.122	0.120
P-value	0.000	0.020	0.049	0.496	0.002	0.002

ANOVA summaries of grip strength can be seen in Table 5.3 and Table 5.4 for males and females, respectively. In the ANOVA models, since the interaction effects were not significant, they were neglected. Therefore, while calculating sum of squares, only significant main effects were taken into consideration. These types of sum of squares were known as adjusted sum of squares.

Table 5.3. Analysis of variance table for grip strength for males

Source	DF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Block	128	45,981.71	45,981.71	359.23	79.38	0.000
Age group	4	9,287.7	9,457.2	2,364.3	46.93	0.000
BMIP group	2	2,618.1	3,297.5	1,648.7	32.72	0.000
Job group	2	3,177.7	3,177.7	1,588.8	31.54	0.000
Posture	1	10.3	10.3	10.3	0.20	0.652
Hand	1	436.3	436.3	436.3	8.66	0.003
Support	1	967.1	967.1	967.1	19.19	0.000
Error	892	5,409.01	5,409.01	6.01		
Total	1,031	67,887.8				

Table 5.4. Analysis of variance table for grip strength for females

Source	DF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Block	78	11,151.12	11,151.12	142.96	67.96	0.000
Age group	4	3,382.39	4,147.28	1,036.82	50.40	0.000
BMIP group	2	1,030.58	971.58	485.79	23.61	0.000
Job group	1	94.95	94.95	94.95	4.62	0.032
Posture	1	13.10	13.10	13.10	0.64	0.425
Hand	1	267.28	267.28	267.28	12.99	0.000
Support	1	256.98	256.98	256.98	12.49	0.000
Error	543	1,624.77	1,624.77	2.95		
Total	631	1,7821.16				

ANOVA tables show that, except posture factor, all independent variables significantly affect grip strength.

5.2. Multiple Comparisons

The ANOVA results indicated significant factor effects on grip strength, except posture. To determine which factor levels were significantly different, multiple comparison were made according to the following:

1. For unequal sample sizes, Tukey’s tests were performed,
2. For equal sample sizes with the same sample, paired t-tests were performed.

5.2.1. Gender Differences

Results indicate that gender is the most significant factor affecting the grip strength. The mean female grip strength is about 43.5 per cent lower than those of males. This huge difference can be seen by without using any statistical test. Boxplot of mean grip strengths for males and females is shown in Figure 5.1.

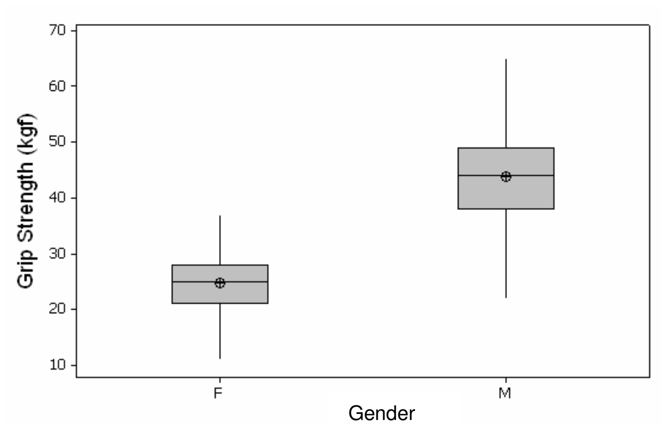
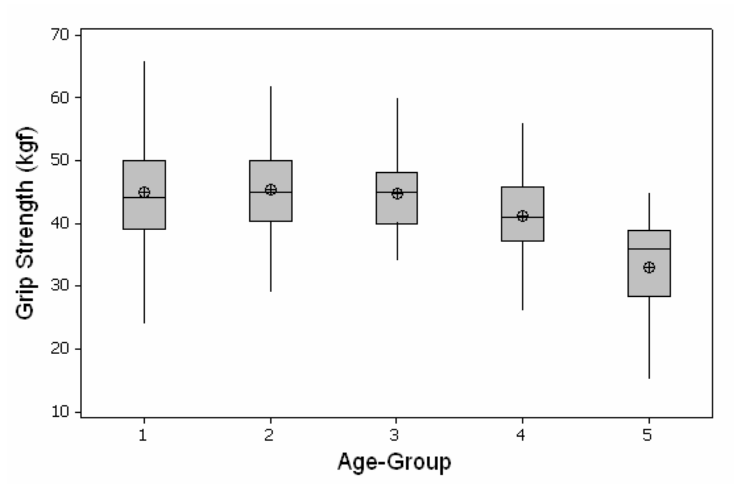


Figure 5.1. Boxplot of mean grip strength for males and females

5.2.2. Differences between Age Groups

Figure 5.2 shows boxplot of mean grip strength of males for different age groups. In Table 5.5, results of Tukey’s test can be seen for different age groups (for males). Results show that, although there were small differences between first (18-29 yr.), second (30-39 yr.), and third (40-49 yr.) age groups, they were not statistically significant. However, after age 50, mean grip strength value starts to decline, significantly. The minimum mean grip strength value was seen in fifth age group (60-69 yr.).



1: 18-29 yr.; 2:30-39 yr.; 3: 40-49 yr.; 4: 50-59 yr.; 5: 60-69 yr.

Figure 5.2. Boxplot of mean grip strength of males for different age groups

Table 5.5. Results of Tukey's test for different age groups (for males)

Age group difference	Difference of means	SE of difference	T-value	Adjusted p-value
Group 2 – Group 1	-1.30	0.704	-1.85	0.347
Group 3 – Group 1	-2.18	0.817	-2.79	0.052
Group 4 – Group 1	-7.05	0.892	-7.91	0.000
Group 5 – Group 1	-11.63	0.972	-11.97	0.000
Group 3 – Group 2	-0.88	0.899	-1.09	0.812
Group 4 – Group 2	-5.75	0.931	-6.18	0.000
Group 5 – Group 2	-10.34	1.093	-9.46	0.000
Group 4 – Group 3	-4.77	1.023	-4.66	0.000
Group 5 – Group 3	-9.36	1.161	-8.06	0.000
Group 5 – Group 4	-4.58	1.218	-3.76	0.000

Figure 5.3 provides boxplot of mean grip strength of females for different age groups. For females, the highest grip strength mean was in second age group (30-39 yr.). Table 5.6 shows the results of Tukey's tests for different age groups (for females). Results show that, the women whose ages are between 30 to 39 years are the strongest group and the differences between this group and the other groups are significant. The mean grip strength value of first group (18-29 yr.) was not significantly differing from than those of third (40-49 yr.) and fourth (50-59 yr.) age group. As a result, grip strength increases as age becomes greater up to 39 years, and decreases significantly thereafter. After age group four, the mean grip strength value significantly declines. Especially after age 60, the mean grip strength value becomes the weakest, dramatically.

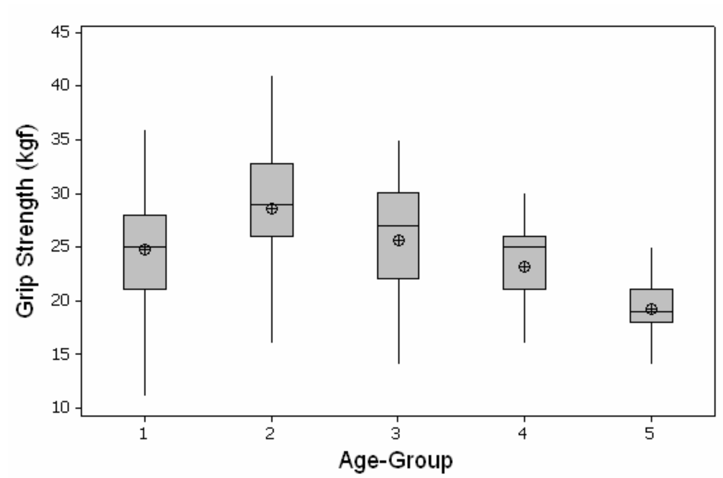


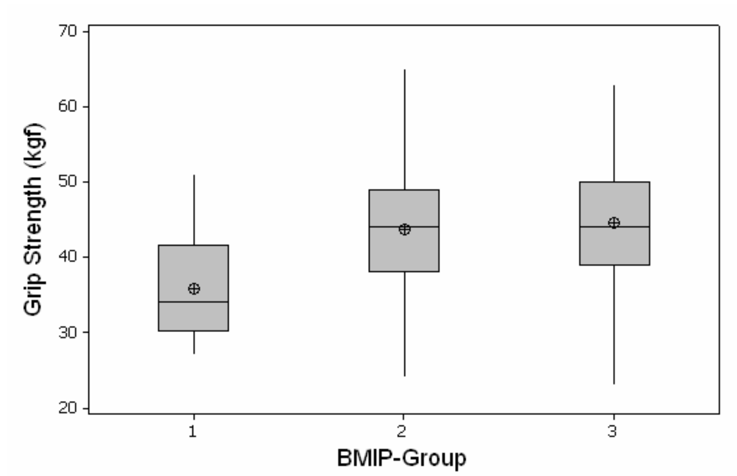
Figure 5.3. Boxplot of mean grip strength of females for different age groups

Table 5.6. Results of Tukey's test for different age groups (for females)

Age group difference	Difference of means	SE of difference	T-value	Adjusted p-value
Group 2 – Group 1	2.37	0.612	3.87	0.000
Group 3 – Group 1	-1.58	0.688	-2.30	0.531
Group 4 – Group 1	-4.82	0.766	6.29	0.000
Group 5 – Group 1	-8.34	0.783	-10.65	0.000
Group 3 – Group 2	-3.95	0.708	-5.58	0.000
Group 4 – Group 2	-7.19	0.774	-9.28	0.000
Group 5 – Group 2	-10.71	0.796	-13.44	0.000
Group 4 – Group 3	-3.23	0.751	-4.31	0.011
Group 5 – Group 3	-6.75	0.792	-8.52	0.000
Group 5 – Group 4	3.52	0.813	4.33	0.000

5.2.3. Differences between BMIP Groups

Tukey's test was also done for estimating if the differences between mean grip strength values in different BMIP (a statistical measure of the weight of a person scaled according to height) groups are significantly differ from each other. In Figure 5.4 and 5.5, boxplots of mean grip strength values for different BMIP groups can be seen for males and females, respectively. Moreover, Table 5.7 and 5.8 present the results of Tukey's test for different BMIP groups for males and females, respectively. Results show that, while there were significant differences between first and second groups, the differences between second and third groups were not significant, for either gender. To this end, the mean grip strengths of second and third age groups are statistically equal, and both groups statistically differ from the mean grip strength of the first BMIP group.



1: Underweighted; 2: Normal weighted; 3: Overweighted

Figure 5.4. Boxplot of mean grip strength of males for different BMIP groups

Table 5.7. Results of Tukey's test for different BMIP groups (for males)

BMIP group difference	Difference of means	SE of difference	T-value	Adjusted p-value
Group 2 – Group 1	8.31	1.498	5.01	0.000
Group 3 – Group 1	9.45	1.501	6.83	0.000
Group 3 – Group 2	1.14	0.502	1.85	0.154

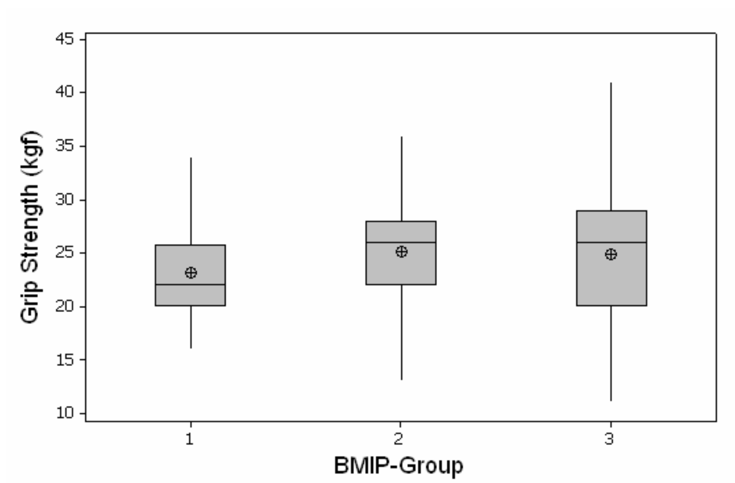


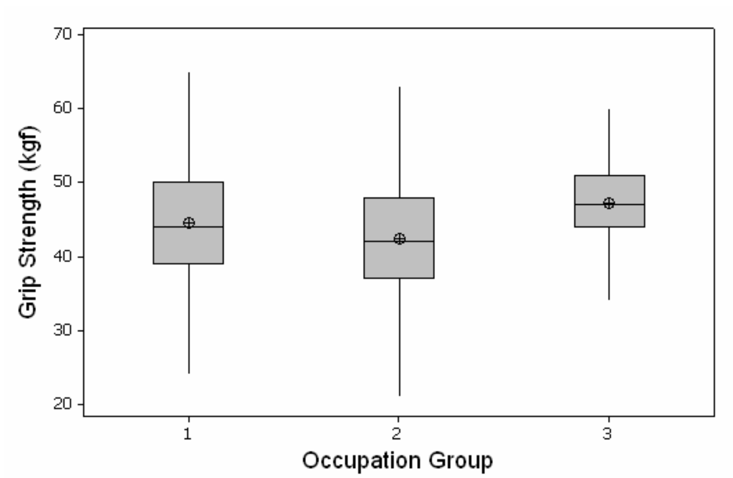
Figure 5.5. Boxplot of mean grip strength of females for different BMIP groups

Table 5.8. Results of Tukey's test for different BMIP groups (for females)

BMIP group difference	Difference of means	SE of difference	T-value	Adjusted p-value
Group 2 – Group 1	2.62	0.531	3.99	0.0002
Group 3 – Group 1	4.1	0.675	6.81	0.000
Group 3 – Group 2	1.48	0.498	-1.79	0.172

5.2.4. Differences between Occupation Groups

The handgrip strengths of the subjects were also different for each occupation group. Figure 5.6 shows the boxplot of mean grip strength values for different occupations for males. In the figure, group one represents university students, group two represents light manual workers, and group three represents heavy manual workers. The classification was done according to power demand level of the jobs. Heavy manual workers had the highest mean strength in three occupation groups, for males. Mean grip strength value of light manual workers were approximately equal to student's mean grip strength value. Also, Tukey's test depicted the same results. Results of the Tukey's test shows that, the mean grip strengths of students and light non-manual workers were not significantly different, but the mean grip strengths of heavy manual workers and the other groups were significantly different. The results of Tukey's test for different occupation groups for males were summarized in Table 5.9.



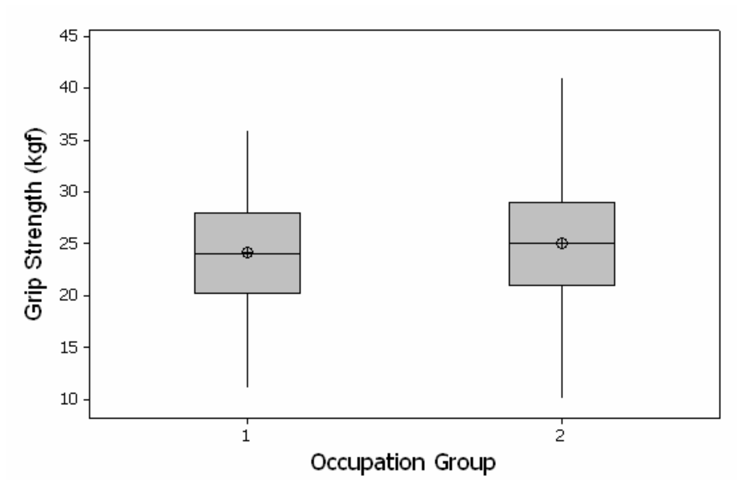
1: Students; 2: Light manual workers; 3: Heavy manual workers

Figure 5.6. Boxplot of mean grip strength of males for different occupation groups

Table 5.9. Results of Tukey's test for different occupation groups (for males)

Occupation group difference	Difference of means	SE of difference	T-value	Adjusted p-value
Group 2 – Group 1	-0.33	0.575	-0.58	0.832
Group 3 – Group 1	4.96	0.800	6.21	0.000
Group 3 – Group 2	5.29	0.671	7.89	0.000

For females, since there were not any heavy manual workers, the number of occupation groups was two. Figure 5.7 shows the boxplot of mean grip strength of females for two different occupation groups that was classified as university students and light manual workers. Table 5.10 presents the results of Tukey's test for different occupation groups for females. Results depict that the differences between mean grip strength values of university students and light manual workers were statistically significant. In contrast with males, female light manual workers have higher mean grip strength value than students have.



1: Students; 2: Light manual workers

Figure 5.7. Boxplot of mean grip strength of females for different occupation groups

Table 5.10. Results of Tukey's test for different occupation groups (for females)

Occupation group difference	**Difference of means**	**SE of difference**	**T-value**	**Adjusted p-value**
Group 2 – Group 1	1.10	0.511	2.15	0.032

5.2.5. Differences between Hands

The mean handgrip strengths were significantly different between hands within each group of subjects, for males. Figure 5.8 provides the boxplot of mean grip strength values for different hands for males. The mean handgrip strength value of dominant hand is 1.3 kgf (3.01%) higher than that of non-dominant hand, for males. This difference is 1.34 kgf (3.06%) for students, 1.33 kgf (3.2%) for light manual workers, and 1.13 kgf (2.42%) for heavy manual workers. In this case, since the number of grip strength data for dominant and non-dominant hands are equal for all males and for each occupation group, paired t-test was used to investigate whether the differences are significant or not. Table 5.11 presents the results of paired t-test for each occupation group and for all of the males, where ND and D represent handgrip strengths of non-dominant and dominant hands respectively. Since all of the p-values are lower than 0.05, all of the grip strength differences within hands for each group are statistically significant as also indicated by ANOVA.

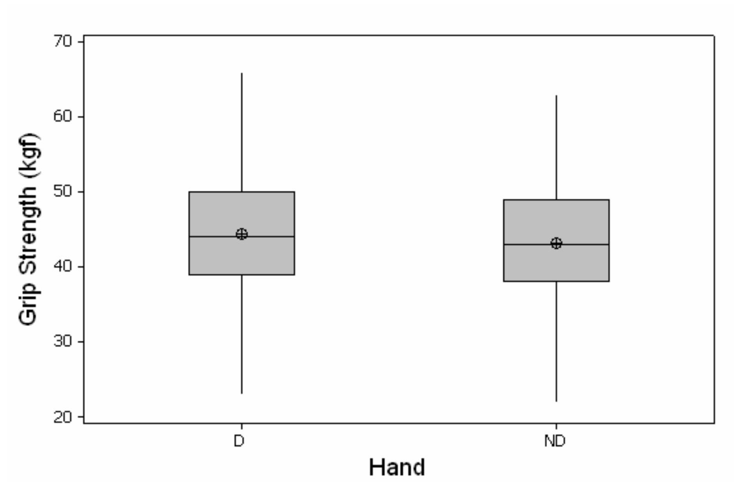


Figure 5.8. Boxplot of mean grip strength of males for different hands

Table 5.11. Results of paired t-test within hands for males

Group	Item	Sample Size	Mean	SD	SE of Mean	T-value	P-value
University students	ND	35	43.89	8.55	1.45	3.02	0.005
	D	35	45.24	8.10	1.37		
	D – ND	35	1.34	2.63	0.45		
Light manual workers	ND	71	41.69	7.97	0.95	3.98	0.000
	D	71	43.02	8.16	0.97		
	D – ND	71	1.33	3.42	0.34		
Heavy manual workers	ND	23	46.64	4.66	0.97	2.38	0.026
	D	23	47.77	4.98	1.04		
	D – ND	23	1.13	2.28	0.48		
All males	ND	109	43.17	7.85	0.69	5.54	0.000
	D	109	44.47	7.82	0.69		
	D – ND	109	1.3	2.67	0.24		

D: Grip strength of dominant hand; ND: Grip strength of non-dominant hand

Figure 5.9 shows the boxplot of mean grip strength values for different hands for females. The mean handgrip strength value of dominant hand for females is 1.3 kgf (5.4%) higher than that of non-dominant hand. This difference is 1.51 kgf (6.47%) for students and 1.21 kgf (4.96%) for light manual workers. In Table 5.12, the results of paired t-test can be seen for each occupation group and for all of the females. All of the p-values are lower than 0.05. To this end, all of the grip strength differences within hands for each group are statistically significant.

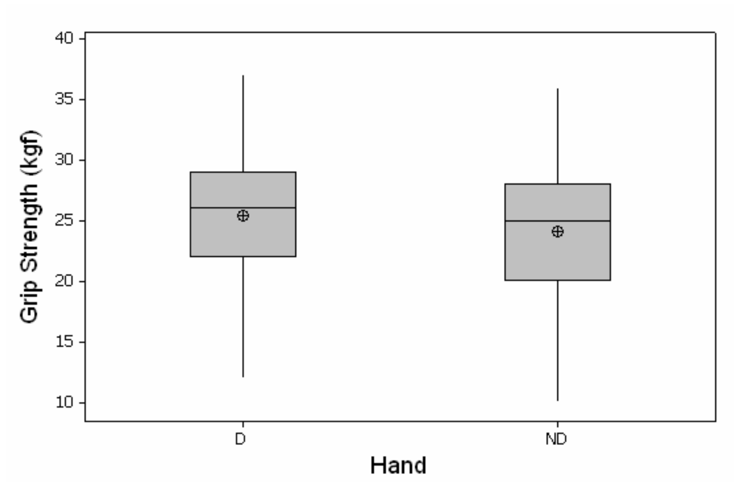


Figure 5.9. Boxplot of mean grip strength of females for different hands

Table 5.12. Results of paired t-test within hands for females

Group	Item	Sample Size	Mean	SD	SE of Mean	T-value	P-value
University students	ND	24	23.35	4.71	0.96	4.72	0.000
	D	24	24.86	4.56	0.93		
	D – ND	24	1.51	1.57	0.32		
Light manual workers	ND	55	24.37	5.48	0.74	4.12	0.000
	D	55	25.58	5.16	0.69		
	D – ND	55	1.21	2.18	0.29		
All females	ND	79	24.06	5.25	0.59	5.76	0.000
	D	79	25.36	4.96	0.56		
	D – ND	79	1.3	2.01	0.23		

D: Grip strength of dominant hand; ND: Grip strength of non-dominant hand

5.2.6. Differences between Postures

In Figure 5.10 and 5.11, boxplots of mean grip strength values for different postures can be seen for males and females, respectively. The mean handgrip strength value while sitting is 0.46% higher than that of standing for males. For females, the standing mean handgrip strength is 1.17% higher than the values while sitting. However, for both gender the differences are not statistically significant as indicated by ANOVA ($p > 0.05$). Paired t-tests also confirm the same result (Table 5.13).

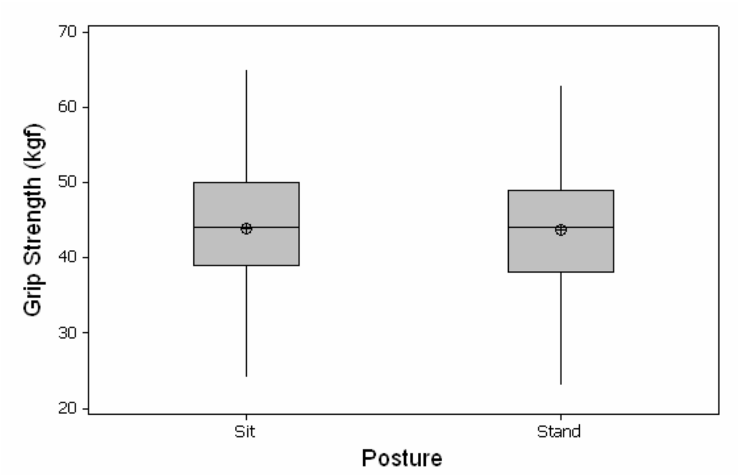


Figure 5.10. Boxplot of mean grip strength of males for body posture

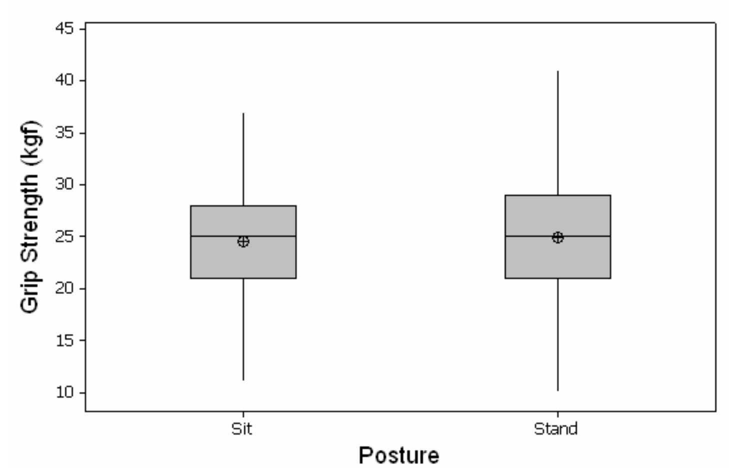


Figure 5.11. Boxplot of mean grip strength of females for body posture

Table 5.13. Results of paired t-test for body postures for males and females

Group	Item	Sample Size	Mean	SD	SE of Mean	T-value	P-value
Males	Sit	129	43.92	8.05	0.71	0.90	0.368
	Stand	129	43.72	7.59	0.67		
	Sit – Stand	129	0.20	2.51	0.22		
Females	Sit	79	24.57	4.99	0.56	-1.62	0.109
	Stand	79	24.86	5.15	0.58		
	Sit – Stand	79	0.29	1.58	0.18		

5.2.7. Differences between Supported and Unsupported Dynamometer Cases

To understand the effect of dynamometer weight on grip strength, experiments were done while the dynamometer supported or unsupported. The mean grip strengths while the dynamometer was supported by the experimenter are 1.94 kgf (4.52%) for males, and 1.27 kgf (5.3%) for females higher than those while the dynamometer was unsupported. Therefore, for both males and females, the differences were higher than the weight of the dynamometer (0.682 kg). Both differences are statistically significant as indicated by ANOVA. Paired t-tests confirm the same result (Table 5.14). Figure 5.12 and 5.13 shows the boxplots of mean grip strength of males and females for supported and unsupported dynamometer cases.

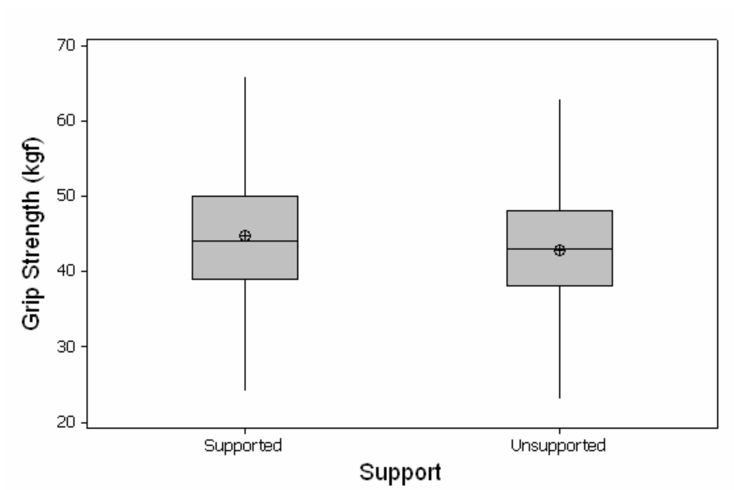


Figure 5.12. Boxplot of mean grip strength of males with dynamometer supported or unsupported

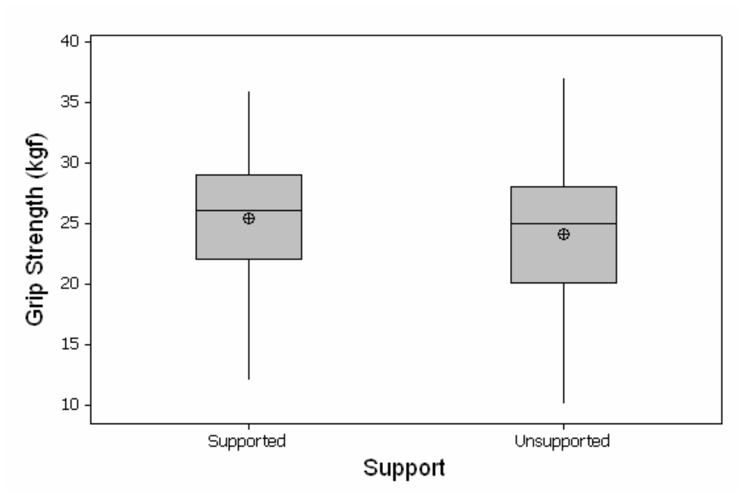


Figure 5.13. Boxplot of mean grip strength of females with dynamometer supported or unsupported

Table 5.14. Results of paired t-test for supported and unsupported dynamometer cases for males and females

Group	Item	Sample Size	Mean	SD	SE of Mean	T-value	P-value
Males	Supported (S)	129	44.79	7.86	0.69	13.06	0.000
	Unsupported (US)	129	42.85	7.68	0.68		
	S – US	129	1.94	1.68	0.15		
Females	Supported (S)	79	25.35	5.13	0.58	10.75	0.000
	Unsupported (US)	79	24.08	4.94	0.56		
	S – US	79	1.27	1.05	0.12		

Results show that the maximum average grip strength value for males were obtained with dominant hand, while the subjects sitting or standing and dynamometer supported by the experimenter. For females, the maximum grip strength were seen while the subject sitting or standing and gripping the dynamometer with their dominant hand when it was supported by the experimenter. Moreover, it should be noted that support effect has more importance than hand effect for males, since it increases the mean grip strength 4.52%, while hand affect does 3.01%. However, for females the two effects are approximately have the same importance, since hand effect increases the mean grip strength 5.4%, while support effect does 5.3%. On the other hand, gripping the dynamometer while sitting or standing has no significant effect on grip strength for both males and females.

5.3. Checking ANOVA Assumptions

5.3.1. Normality Test

To use ANOVA, residuals of grip strength values must fit to normal distribution. Therefore, normality of the residuals of the grip strength data were tested by using Anderson-Darling normality test (α = 0.05) in Minitab 15.0. According to Anderson-Darling normality test, the p-values of residuals of grip strength data are 0.259 for males and 0.054 for females. Since they are greater than 0.05, the null hypothesis, which says that data follow normal distribution, can be accepted. Therefore, the residual data for both males and females follow normal distribution.

Moreover, another procedure to prove normality is to investigate the normal probability plots of the residuals which were shown in Figure 5.14 and Figure 5.15. Since the plots approximately resemble a straight line, the underlying error distribution for males and females are normal.

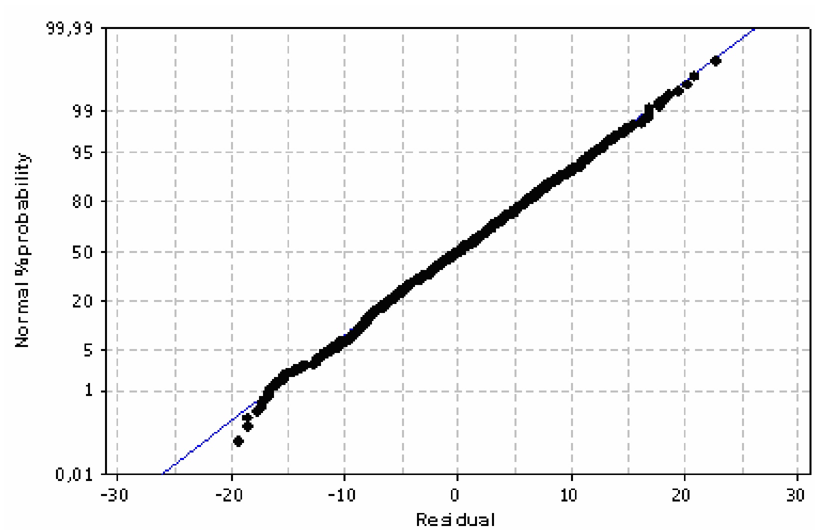


Figure 5.14. Normal probability plot of residuals of grip strength data for males

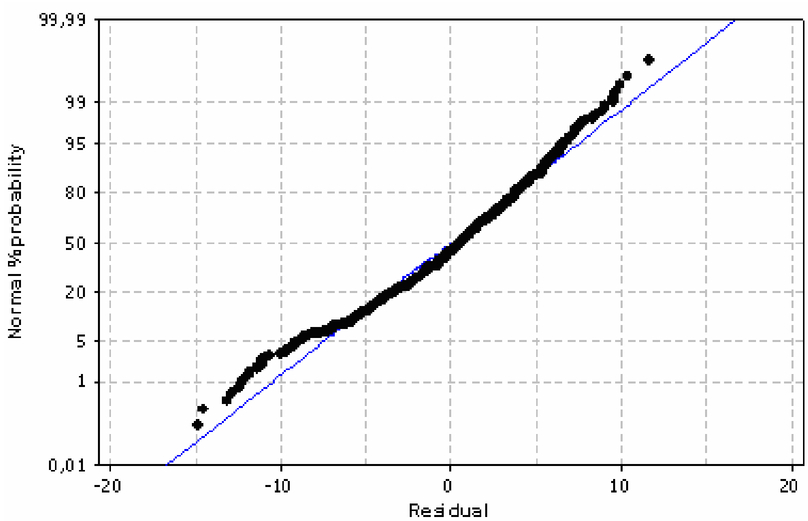


Figure 5.15. Normal probability plot of residuals of grip strength data for females

5.3.2. Independence Test

Another assumption about ANOVA is independence assumption. According to this assumption, there must not be any correlation between residuals (correlation of each value and the value before it) and correlation between independent variables and residuals. Plotting the residuals in observation order of data collection is helpful in detecting correlation between the residuals. A tendency to have runs of positive and negative residuals indicates positive correlation which would imply that the independence assumption on the errors has been violated (Montgomery, 2005).

Plots of the residuals versus observation order for males and females are shown in Figure 5.16 and 5.17. There is no reason to suspect any violation of the independence assumption.

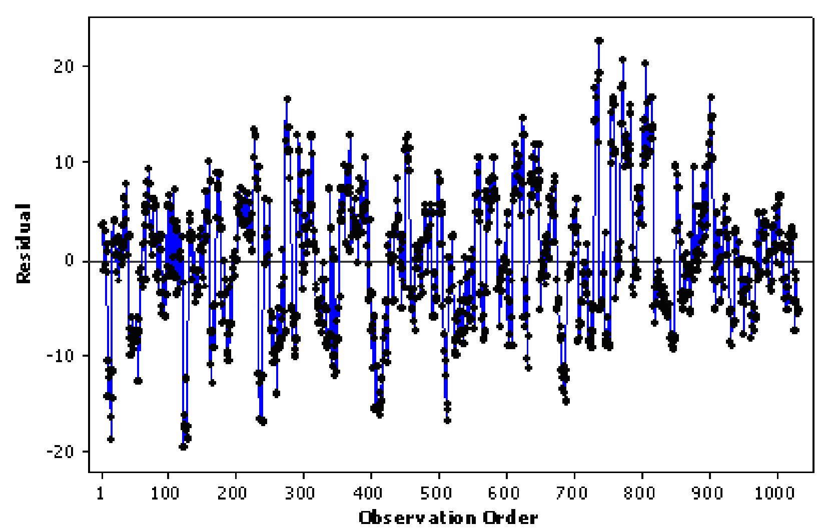


Figure 5.16. Plot of residuals versus observation order for males

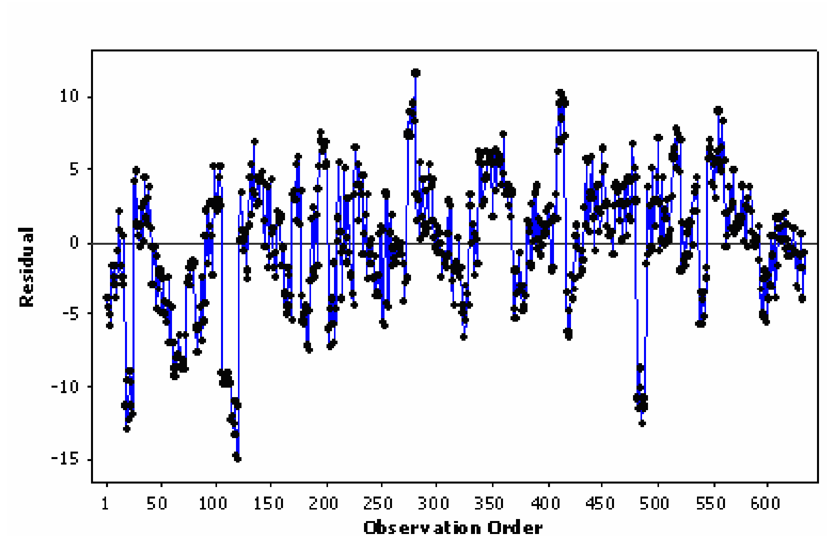


Figure 5.17. Plot of residuals versus observation order for females

Another way to prove independence is using autocorrelation function. There must not be correlation between each residual value and the value before it (lag 1). In Figure 5.18 and 5.19, autocorrelation function of residuals for males and females can be seen graphically. Since, the autocorrelation coefficients for lag 1 (0.03 for males and 0.038 for females) are not higher than critical autocorrelation value for significance level of 0.05, there is not any violation of the independence assumption.

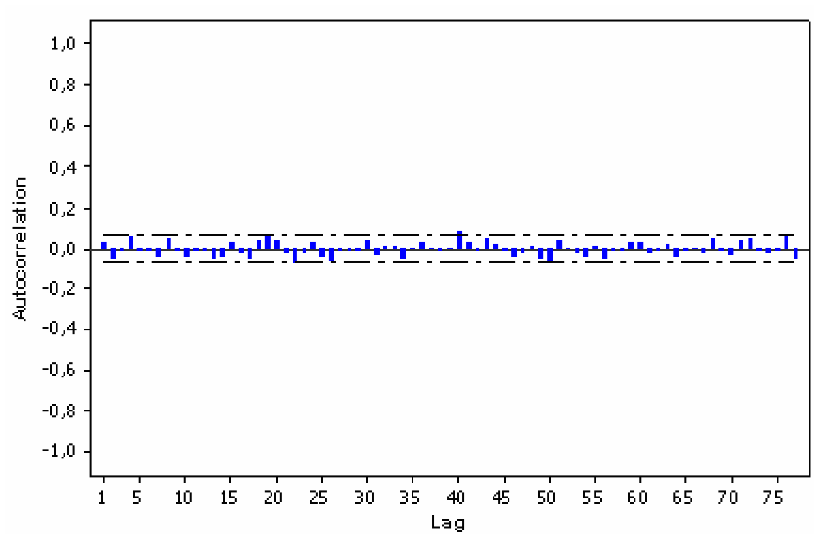


Figure 5.18. Autocorrelation function of residuals for males

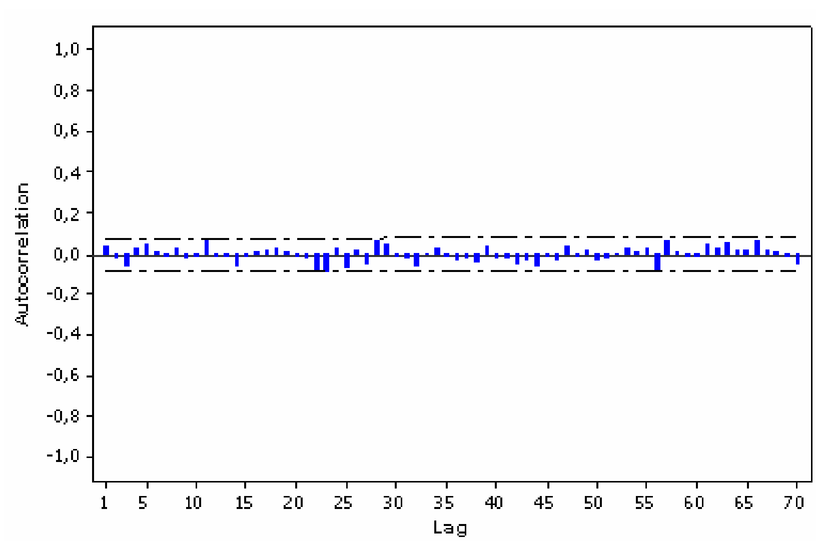


Figure 5.19. Autocorrelation function of residuals for females

Also, there must not be correlation between independence variables (age group, BMI prime group, occupation group, hand, support, and posture) and residuals, for independence assumption. In Table 5.15, Pearson's correlation coefficients between independence variables and residuals for males and females can be seen. The results show that there is not any significance correlation (p-value is one for all correlation coefficient) between independence variables and residuals for both males and females. Therefore, independence assumption was provided.

Table 5.15. Correlation coefficients between independent variables and residuals

Residuals	Age group	BMIP group	Occupation group	Posture	Support	Hand
Residuals for males	0.000	0.000	0.000	0.000	0.000	0.000
P-value	0.999	0.999	0.999	0.999	0.999	0.999
Residuals for females	0.000	0.000	0.000	0.000	0.000	0.000
P-value	0.999	0.999	0.999	0.999	0.999	0.999

5.3.3. Variance Equality Test

The last assumption about ANOVA is that variances of response variables for each treatment must not be different from each other (homogeneity assumption). Therefore, the residuals should be unrelated to any other variable including the predicted response. A simple check is to plot the residuals versus the fitted values. This plot should not reveal any obvious pattern (Montgomery, 2005). In Figure 5.20 and 5.21, plot of residuals versus fitted values for males and females can be seen. In these figures, no unusual structure is apparent. Therefore, equality variance assumption was satisfied.

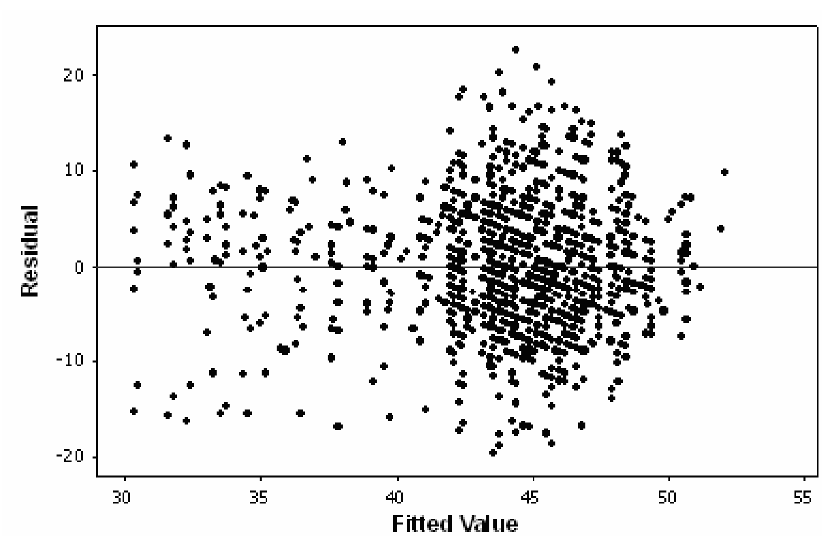


Figure 5.20. Plot of residuals versus fitted values for males

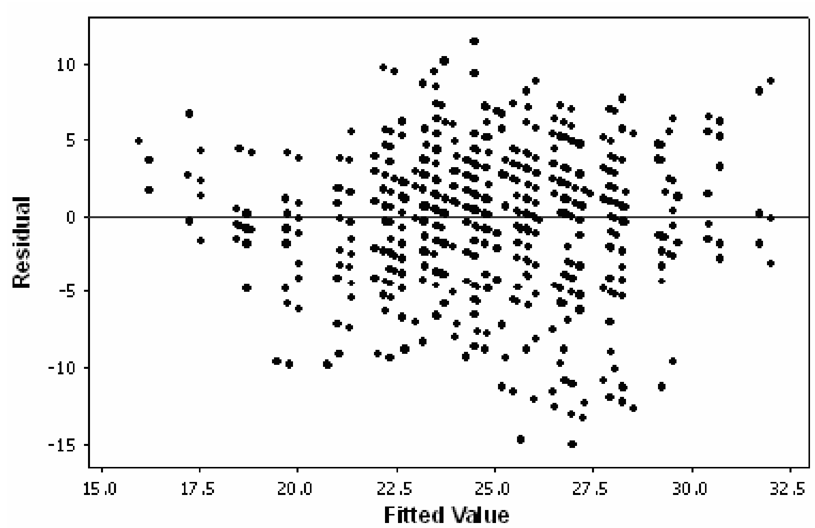


Figure 5.21. Plot of residuals versus fitted values for females

Although residual plots are frequently used to diagnose inequality of variance, when the normality assumption is satisfied, Bartlett's test may be viewed as a formal test of the hypotheses

$$H_0\text{: } \sigma_1^2 = \sigma_2^2 = \ldots = \sigma_n^2 \tag{5.1}$$

$$H_1\text{: } \sigma_i^2 \neq \sigma_j^2 \text{ for at least one pair } (i, j).$$

In Table 5.16 the results of Bartlett's test for males and females can be seen. Since p-values are higher than 0.05, the null hypothesis can be accepted. Therefore, both for males and females, variances are same for each treatment.

Table 5.16. The results of Bartlett's test for males and females

Test	**Test Statistic**	**P-Value**
Bartlett's Test for males	132.90	0.149
Bartlett's Test for females	121.92	0.067

Since all of the assumptions about ANOVA were satisfied, there is not any violation about using ANOVA. To this end, for both males and females, ANOVA procedure can be used for analyzing the data.

5.4. Regression Analysis of Grip Strength Values

The significant independent variables, which were found by ANOVA and correlation analysis, were used in building the regression models to predict grip strengths of males and females. After the diagnostics analysis, a no-interaction multiple linear regression model was determined as a suitable model for male grip strength, and a second order no interaction model for female grip strength.

For developing the best regression equation, Best Subsets Regression Analysis and Stepwise Regression techniques were used. Interaction effects were neglected and only the main effects were taken into consideration. Also, squares of quantitative factors were taken into consideration. Best subsets regression identifies the best-fitting regression models that can be constructed with the predictor variables. It is an efficient way to identify models with as few predictors as possible. Subset models may actually estimate the regression coefficients and predict future responses with smaller variance than the full model using all predictors. In best subsets technique, a statistic (Mallows' Cp) used as an aid in choosing between competing multiple regression models. It compares the precision and bias of the full model to models with the best subsets of predictors. A model with too many predictors can be relatively imprecise while one with too few can produce biased estimates. The best model is the minimizer of Cp. Stepwise regression is an automated tool used in the exploratory stages of model building to identify a useful subset of predictors. The process systematically adds the most significant variable or removes the least significant variable during each step. In this analysis, backwards elimination technique was used which starts with all predictors in the model and the least significant variable were removed for each step. Minitab stops when all variables in the model have p-values that are less than or equal to the specified Alpha-to-Remove value. In the analysis alpha was selected as 0.05.

5.4.1. Regression Equation of Grip Strength for Males

The general form of the male grip strength regression model is found as follows:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \varepsilon \quad (5.2)$$

Where,

β_0 : Constant

β_1 : Regression coefficient of age

β_2 : Regression coefficient of BMIP

β_3 : Regression coefficient of occupation group

β_4 : Regression coefficient of hand (gripping the dynamometer with dominant or non-dominant hand)

β_5 : Regression coefficient of support

ε : Error term

x_1 : Regressor variable of age

x_2 : Regressor variable of BMIP

x_3 : Regressor variable of occupation group (1 or 2)

x_4 : Regressor variable of hand (0 or 1)

x_5 : Regressor variable of support (0 or 1)

A test for significance of regression is performed to determine whether a linear relationship exists between the response variable and a subset of the regressor variables x_1, x_2,..., x_n (Montgomery, 2005). The appropriate hypotheses are,

$$H_0\text{: } \beta_1 = \beta_2 = ... = \beta_n = 0 \qquad (5.3)$$

$$H_1\text{: } \beta_j \neq 0 \text{ for at least one } j.$$

Rejection of H_0 in Equation 5.3 implies that at least one of the regressor variables contributes significantly to the model. To test this significance, an ANOVA table is used which takes into consideration total sum of squares, sum of squares due to regression model and sum of squares due to residual. If the p-value for the statistic F 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).

Table 5.17 presents analysis of variance table of regression model for males. At least one of the regressor variables contributes significantly to the model ($p < 0.05$).

In regression equation, some of the factor levels (e.g., students and light manual workers, sit and stand) were combined since differences between them were not significant. The interaction effects between factors and quadratic terms were neglected because p-values of them were less than significance level ($p < 0.05$). After that, some trials were done and the equation that has the maximum adjusted R^2 value was accepted as regression equation. The regression equation for males can be seen in Table 5.18.

Table 5.17. Analysis of variance table of regression model for males

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	6	13,389.9	2,231.7	57.32	0.000
Residual Error	489	19,037.5	38.9		
Total	495	32,427.4			

Table 5.18. Regression analysis results of grip strength for males

Predictor	**Coefficient**	**SE Coefficient**	**T**	**P**	**VIF**
Constant	-16.38	5.199	-3.15	0.002	
Age	-0.23	0.022	-10.76	0.000	1.055
Weight	0.16	0.024	6.75	0.000	1.224
Hand width	5.17	0.637	8.13	0.000	1.000
Occupation group	7.17	0.745	9.63	0.000	1.000
Hand	1.35	0.560	2.40	0.017	1.068
Support	1.90	0.560	3.39	0.001	1.212

Variance inflation factor (VIF) indicates the extent to which multicollinearity (correlation among predictors) is present in a regression analysis. Multicollinearity is problematic because it can increase the variance of the regression coefficients, making them unstable and difficult to interpret. Variance inflation factors measure how much the variance of the estimated regression coefficients are inflated as compared to when the predictor variables are not linearly related. If VIF = 1 predictors are not correlated. If $1 < \text{VIF} < 5$, predictors are moderately correlated. If $5 < \text{VIF} < 10$, predictors are highly correlated. VIF values greater than 10 may indicate multicollinearity is unduly influencing regression results. In this case, multicollinearity can be reduced by removing unimportant predictors from the model. However, in this model, small VIF values show that there is not any multicollinearity that influences the regression model.

Therefore, the regression equation for male grip strength is:

Grip strength = -16.38 – 0.23 * Age + 0.16 * Weight + 5.17 * Hand_width + 7.17 * Occupation_group + 1.35 * Hand + 1.90 * Support
(s = 6.24; R^2 = 0.413; R^2 (adj) = 0.406; Mallows' Cp = 12.5)

Where,

Age (in years), weight (in kgf) and hand width (in cm); and

Occupation Group = 1 for students and light manual workers, 2 for heavy manual workers,

Hand = 0 for non-dominant hand, 1 for dominant hand,

Support = 0 for unsupported dynamometer, 1 for supported dynamometer.

5.4.2. Regression Equation of Grip Strength for Females

Table 5.19 presents analysis of variance table of regression model for females. The p-value is less than 0.05. The regression equation for female grip strength is a second degree polynomial model.

Table 5.19. Analysis of variance table of regression model for females

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**
Regression	8	3,557.46	3,557.46	444.68	26.71	0.000
Residual error	291	4,864.11	4,864.11	15.90		
Total	299	8,521.33				

In regression equation for females, sit and stand factors were combined since the difference between them was not significant. After that, some trials were done to find the regression equation. The interaction effects between factors were neglected because p-values of them were less than significance level ($p < 0.05$). After that, some trials were done and the equation that has the maximum R^2 value was accepted as regression equation. In regression equation for females, there are some quadratic terms, unlike males. The reason of that is the fact that age and weight factor peak on a certain point and decrease thereafter. In Table 5.20, the regression coefficients for female grip strengths can be seen.

Table 5.20. Regression analysis results of grip strength for females

Predictor	Coefficient	SE Coefficient	T	P
Constant	-42.86	7.297	-6.29	0.000
Age	0.62	0.129	4.77	0.000
Age^2	-0.01	0.002	-6.45	0.000
Occupation Group	1.61	0.648	2.49	0.013
Weight	1.21	0.475	2.54	0.012
$Weight^2$	-0.007	0.001	-7.72	0.000
Hand	1.207	0.471	2.56	0.011
Support	1.24	0.471	2.63	0.009
Hand Length	1.13	0.371	3.03	0.003

Thus, the regression equation for female grip strength is:

$$\text{Grip strength} = -42.86 + 0.62 * \text{Age} - 0.01\ \text{Age}^2 + 1.61 * \text{Occupation\_Group} + 1.21 * \text{Weight} - 0.007 * \text{Weight}^2 + 1.21 * \text{Hand} + 1.24 * \text{Support} + 1.13 * \text{Hand\_ length}$$

($s = 4.08$; $R^2 = 0.423$; R^2 (adj) = 0.408; Mallows' Cp = 12.4)

Where,

Age (in years), weight (in kgf) and hand length (in cm); and

Occupation Group = 1 for students, 2 for light manual workers

Hand = 0 for non-dominant hand, 1 for dominant hand

Support = 0 for unsupported dynamometer, 1 for supported dynamometer.

5.5. Correlation between Preferred Grip Span and Hand Dimensions

In the grip strength tests, subjects used their preferred grip span of the dynamometer. Table 5.21 summarizes anthropometric dimensions of hands of the male and female subjects by preferred grip span.

Table 5.21. Hand anthropometry of the subjects by preferred grip span

Measurement Type	Preferred Grip Span	Male (n = 124*)			Female (n = 75**)		
		N	Mean ± SD	Range	N	Mean ± SD	Range
Right hand							
Hand length (cm)	2	37	18.19 ± 0.85	16.5 – 19.8	67	17.13 ± 0.62	15.6 – 18.5
	3	87	19.1 ± 0.82	16.8 – 20.8	8	18.03 ± 0.6	16.9 – 18.9
Hand width (cm)	2	37	8.53 ± 0.49	7.1 – 9.7	67	7.69 ± 0.35	6.9 – 8.4
	3	87	8.75 ± 0.47	7.7 – 9.8	8	7.96 ± 0.48	7.4 – 8.8
Wrist circumference (cm)	2	37	17.08 ± 1.14	15 – 20.1	67	15.59 ± 1.12	13.8 – 18.5
	3	87	17.65 ± 0.85	15.2 – 20	8	15.98 ± 1.34	14.6 – 19
Left hand							
Hand length (cm)	2	37	18.21 ± 0.88	16.4 – 19.9	67	17.14 ± 0.66	15.7 – 18.6
	3	87	19.1 ± 0.79	17 – 20.7	8	17.99 ± 0.55	17 – 18.8
Hand width (cm)	2	37	8.53 ± 0.49	7.1 – 9.7	67	7.69 ± 0.34	7 – 8.5
	3	87	8.73 ± 0.49	7.5 – 9.7	8	7.89 ± 0.52	7.3 – 8.9
Wrist circumference (cm)	2	37	17.05 ± 1.15	15 – 20	67	15.62 ± 1.14	13.7 – 18.7
	3	87	17.64 ± 0.88	15 – 20.5	8	16 ± 1.39	14.4 – 19

* Five male subjects did not participate to hand anthropometry study
** Four female subjects did not participate to hand anthropometry study

To determine whether any correlation occurs between preferred grip span and anthropometric dimensions of hands of the subjects, Pearson's correlation coefficients were calculated. Table 5.22 presents correlation coefficients between preferred grip span and anthropometric hand dimensions of the subjects. Results show that lengths of left and right hands and width of right hand are significant factors for selecting the grip span length, for males. For females, all hand length, hand width and wrist circumference factors significantly affect selecting the grip span. However, the most significant factor for choosing the grip span is the length of right and left hands, for both male and female subjects. There is a positive correlation between hand length and grip span. The longer the hand length a subject has, the longer the grip span he/she chooses.

Table 5.22. Correlations between preferred grip span and hand dimensions

Item	RHL	LHL	RHW	LHW	RWC	LWC
Preferred grip span of males	0.413	0.377	0.227	0.171	0.106	0.103
P-value	0.000	0.000	0.050	0.143	0.365	0.381
Preferred grip span of females	0.452	0.450	0.210	0.186	0.271	0.270
P-value	0.000	0.000	0.019	0.039	0.002	0.002

RHL: Right hand circumference
LHL: Left hand circumference
RHW: Right hand width
LHW: Left hand width
RWC: Circumference of right wrist
LWC: Circumference of left wrist

5.6. Percentile Calculation of Grip Strength Values

In this part, the percentiles of the measured values were calculated, for males and females in each testing position (Table 5.23). Moreover, percentiles of average of eight grip strength values and percentiles of height and weight of males and females were calculated for each occupation and age groups (Table 5.24, 5.25 and 5.26).

Table 5.23. Grip strength percentiles for males and females in each position

Position	Male Percentile							Female Percentile						
	1	**5**	**25**	**50**	**75**	**95**	**99**	**1**	**5**	**25**	**50**	**75**	**95**	**99**
DUU	25.6	30.8	38.2	43.4	48.5	56.0	61.2	13.1	16.5	21.4	24.8	28.2	33.1	36.5
NUU	23.6	29.0	36.6	42.0	47.3	54.9	60.3	10.8	14.5	19.8	23.5	27.2	32.5	36.2
DUS	27.2	32.6	40.2	45.4	50.7	58.3	63.6	14.0	17.6	22.7	26.3	29.9	35.0	38.6
NUS	25.8	31.2	38.8	44.1	49.4	57.0	62.4	12.0	15.8	21.1	24.9	28.6	34.0	37.7
DDU	24.7	30.3	38.2	43.6	49.1	57.0	62.6	12.9	16.4	21.2	24.6	28.0	32.9	36.4
NDU	23.3	28.9	36.9	42.4	48.0	56.0	61.6	11.4	15.0	19.9	23.4	26.9	31.8	35.4
DDS	25.6	31.4	39.7	45.4	51.2	59.5	65.3	13.8	17.3	22.3	25.7	29.2	34.2	37.7
NDS	24.9	30.6	38.6	44.2	49.8	57.8	63.4	11.9	15.6	20.8	24.5	28.2	33.5	37.2

DUU: Dominant handgrip test while standing and dynamometer unsupported
NUU: Non-dominant handgrip test while standing and dynamometer unsupported
DUS: Dominant handgrip test while standing and dynamometer supported
NUS: Non-dominant handgrip test while standing and dynamometer supported
DDU: Dominant handgrip test while sitting and dynamometer unsupported
NDU: Non-dominant handgrip test while sitting and dynamometer unsupported
DDS: Right handgrip test while sitting and dynamometer supported
NDS: Left handgrip test while sitting and dynamometer supported

Table 5.24. Grip strength percentiles for occupation and age groups

Group	Male Percentile							Female Percentile						
	1	**5**	**25**	**50**	**75**	**95**	**99**	**1**	**5**	**25**	**50**	**75**	**95**	**99**
Occupation														
Students	25.4	31.0	39.0	44.6	50.1	58.1	63.7	13.5	16.6	21.0	24.1	27.2	31.6	34.7
LMW	23.9	29.3	37.0	42.4	47.7	55.4	60.8	12.9	16.4	21.5	25.0	28.5	33.5	37.1
HMW	36.3	39.5	44.0	47.2	50.4	54.9	58.1							
Age Group														
18-29 yr.	26.9	32.1	39.6	44.9	50.1	57.6	62.9	15.1	17.9	21.9	24.7	27.5	31.5	34.3
30-39 yr.	30.4	34.8	41.0	45.3	49.7	55.9	60.2	16.0	19.7	24.9	28.5	32.2	37.4	41.1
40-49 yr.	33.1	36.5	41.3	44.6	48.0	52.8	56.2	12.1	16.0	21.7	25.6	29.5	35.2	39.2
50-59 yr.	26.9	31.0	37.0	41.1	45.2	51.1	55.2	11.5	14.9	19.7	23.1	26.5	31.3	34.7
60-69 yr.	13.4	19.2	27.3	33.0	38.7	46.9	52.6	13.9	15.4	17.6	19.1	20.7	22.9	24.4
Overall	25.8	31.1	38.6	43.8	49.0	56.5	61.8	13.1	16.5	21.3	24.7	28.1	33.0	36.7

LMW: Light manual workers
HMW: Heavy manual workers

Table 5.25. Height percentiles for occupation and age groups

Group	Male Percentile							Female Percentile						
	1	5	25	50	75	95	99	1	5	25	50	75	95	99
Occup.														
Students	164.0	168.7	175.4	180.1	184.8	191.5	196.2	154.9	158.1	162.7	165.8	169.0	173.5	176.7
LMW	157.6	162.9	169.9	175.0	180.0	187.2	192.3	147.6	151.4	156.6	160.3	164.0	169.3	173.0
HMW	162.0	165.7	170.9	174.6	178.2	183.5	187.2							
Age														
18-29	163.2	167.7	174.1	178.6	183.0	189.4	193.9	152.3	155.9	161.0	164.5	168.0	173.1	176.7
30-39	157.4	162.6	169.9	175.0	180.1	187.4	192.6	148.9	153.0	158.7	162.8	166.8	172.6	176.6
40-49	160.8	164.9	170.9	174.7	178.8	184.6	188.7	151.7	154.1	157.4	159.8	162.1	165.4	167.8
50-59	159.1	163.2	169.1	173.2	177.3	183.1	187.3	150.0	151.8	154.4	156.2	158.0	160.5	162.4
60-69	157.7	159.8	162.8	164.9	167.0	170.1	172.2	145.3	148.6	153.4	156.6	159.9	164.6	168.0
Overall	159.2	164.2	171.3	176.3	181.2	188.3	193.3	148.5	152.5	158.1	162.0	165.9	171.5	175.5

Table 5.26. Weight percentiles for occupation and age groups

Group	Male Percentile							Female Percentile						
	1	5	25	50	75	95	99	1	5	25	50	75	95	99
Occup.														
Students	43.5	54.4	69.8	80.5	91.2	106.6	117.4	37.3	42.8	50.7	56.2	61.6	69.5	75.0
LMW	50.6	58.8	70.5	78.7	86.8	98.5	106.7	32.9	41.9	54.7	63.6	72.5	85.4	94.4
HMW	55.6	61.2	69.2	74.7	80.2	88.2	93.8							
Age														
18-29	48.7	57.2	69.4	77.8	86.3	98.5	107.0	38.5	43.5	50.6	55.6	60.6	67.7	72.8
30-39	43.0	54.0	69.7	80.6	91.4	107.1	118.1	38.0	44.7	54.2	60.8	67.4	76.8	83.5
40-49	54.7	61.7	71.7	78.7	85.7	95.7	102.7	26.6	39.9	58.9	72.1	85.3	104.3	117.6
50-59	63.6	69.8	78.7	84.8	91.0	99.9	106.1	56.3	60.4	66.3	70.3	74.4	80.3	84.4
60-69	50.1	55.6	63.5	69.0	74.5	82.4	87.9	35.5	45.3	59.4	69.1	78.9	93.0	102.8
Overall	48.8	57.5	69.7	78.4	87.0	99.4	108.0	32.6	41.1	53.0	61.4	69.7	81.7	90.1

6. DISCUSSION

6.1. Discussion of the Current Study Results

Results indicate that the mean grip strength of males is significantly higher than that of females. Muscle strength is a function of size of related muscles. Therefore, grip strength depends on size of related muscles. Since males generally have bigger arm muscles than females, their mean grip strength is higher than that of females. Moreover, Slob (2000) reported that, men respond better to muscle training than women do; with the same kinds of muscle training, the strength of men increases faster and to a greater extent.

In sitting posture, people consume less energy than standing (Chaffin *et al.*, 2006). Sitting and standing posture did not affect grip strength, for both males and females. Although the postures of the body were different while sitting and standing, the posture of the arm muscle remained the same. Therefore, results indicate that sitting or standing does not affect grip strength while arm angle and wrist remains in the same position. This important result may eliminate the need to test the subjects in both postures; thus, reduces the time and effort needed. This result may also allow direct comparisons between different studies involved in the studied posture. Moreover, it is also possible to combine the different study data obtained from these two postures.

Support effect also increases the grip strength. In unsupported dynamometer case, the weight of the dynamometer has a negative effect on grip strength, since some components of the arm muscles use their strength to hold the dynamometer against the gravity. However, in unsupported case, the experimenter eliminates the affect of gravity by holding the dynamometer and thus the grip strength of the subject becomes greater than that for unsupported case. Here, it is should be noted that the differences are higher than the weight of the dynamometer (0.682 g) for both genders.

The mean grip strength value for dominant hand was significantly higher than that of non-dominant hand. Because a person uses his/her dominant hand more often than his/her non-dominant one, the arm muscles of dominant hand become bigger and thus stronger than those of non-dominant hand. Therefore, dominant hand is stronger than non-dominant hand.

There is also a relationship between hand strength and age. The data for females from the current study support a curvilinear relationship, with hand strength peaking somewhere between 30 and 39 years of age and decreasing thereafter. However for males there were not any significant differences among first three age groups [(18-29) yr., (30-39) yr., and (40-49) yr.], but it started to decline after age 50. Based on this, it can be said that the females start to lose their grip strength in earlier ages than males. However, Slob (2000) reported that strength increases rapidly in the teens, more slowly in the early twenties, reaches a maximum by the middle to late twenties, remains at this level for five to ten years, and thereafter declines slowly but continuously. Handgrip strength seem to continue to be relatively higher in later years than other types of muscular performances.

Another effect on grip strength is the type of occupation. Heavy manual workers have the highest grip strength value among occupational groups. The reason of this may be the fact that they use their hands and arms more often and forcefully than other occupation groups. Thus, their muscles get bigger, stronger and fit. Heavy manual workers also have the least difference between dominant and non-dominant hands since they use their non-dominant hands more than other occupation groups do.

According to body mass index prime, underweighted people have lower grip strength value than others. However, there is not a significant difference between normal weighted and overweighed people. This result indicates that as weight increases, muscle power increase, but after a certain point, it remains stationary. So, it does not change between normal weighted and overweighed people.

6.2. Comparison with Other Studies

Since there is not a study to determine grip strength relative to support, standing and sitting postures, the comparisons with other grip strength studies could be made only indirectly. For the comparisons with other studies, if the posture, support and hand effects are not known, the average mean strength values of eight different test combinations were used. On the other hand, for the cases that the posture, used hand and support effect of the study that would be compared with this study are known, the comparison of grip strength between the values was done for that special test combination. In Table 6.1, the information of some studies about grip strength which was compared with the current study was summarized. Except Xiao *et al.* (2005), and Bao and Silverstein (2006), in the grip strength studies, subjects were seated with shoulder adducted and neutrally rotated, the elbow flexed at 90°, with the forearm and wrist in neutral position. However in Xiao *et al.* (2005), the subject was seated and the grip dynamometer was held with the palm facing up while arm and dynamometer were supported. There was no information about posture in the study of Bao and Silverstein. The empty cells in the table mean that there is no information available.

Table 6.1. Information of some studies about grip strength

Source	**Sample type (n)**	**Dynamometer**	**Posture**	**Age mean and range (yr.)**	**Grip span**	**Measure used**
Mathiowetz *et al.* (1985)	Random (628)	Jamar	Sit (with support)	(20 – 94)	Fixed (Level 2)	Mean of three
Haidar *et al.* (2004)	Hospital workers (100)	Jamar	Sit (with support)	37 (23 – 63) (M) 34 (21 – 58) (F)	Preferred span	Best of three
Bao and Silverstein (2005)	Random (120)	A strain gauge (digital)		44 (19 – 60) (M) 43 (20 – 63) (F)	Fixed (2.5 cm)	Best of three
Xiao *et al.* (2005)	Students, industrial and office workers (193)	Lafayette	Sit (without support)	49.03 (M) 49.75 (F)	Fixed (2.5 cm)	Mean of two
Lau and Ip (2006)	Light and heavy manual male workers (64)	Jamar	Sit	35.7 (19 – 57)	Fixed (Level 2)	Mean of three
Anakwe *et al.* (2007)	Light and heavy manual workers (250)	Jamar	Sit	44.3 (18 – 83) (M) 41.6 (18 – 78) (F)	Fixed (Level 2)	Best of five

Mathiowetz *et al.* (1985) conducted a study to measure handgrip strength of both hands from a sample of 310 male (mean age: 49.03 yr.) and 328 female (mean age: 49.75 yr.) adults from USA population, ages 20 to 94. While conducting the tests, dynamometer was supported by experimenter and subjects were seated on a chair. They reported that the highest grip strength scores occurred in 25 to 39 age groups, for males and females. On the other hand, Anakwe *et al.* (2007) considered that the greatest grip strength data were indicated for 35 to 44 year old age group for both genders. However, for the present study, there were not any significant differences among mean male handgrip strengths of age group (18-29) yr., (30-39) yr. and (40-49) yr.. For females, the highest score were occurred in (30-39) yr. age group for the current study. They found a significant negative correlation between the grip strength and age, which is similar to the current study. In Table 6.2, the results of t-test to compare the mean strength values of Mathiowetz *et al.* (1985) and the current study can be seen. For two sample t-test, t statistic was used which is equal to (Montgomery, 2005):

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}} \tag{6.1}$$

where, $\bar{y}_1$ and $\bar{y}_2$ are means, S_1^2 and S_2^2 are sample variances, n_1 and n_2 are sample sizes of two samples.

Table 6.2. Comparison of results of Mathiowetz *et al.* (2004) with the current study

Study	**Gender**			
	Male		**Female**	
	DDS	**NDS**	**DDS**	**NDS**
Mathiowetz *et al.* (1985)	47.41 ± 12.84	42.23 ± 12.52	28.49 ± 7.71	24.45 ± 7.12
Present study	45.43 ± 8.54	44.18 ± 8.28	25.73 ± 5.14	24.52 ± 5.45
Difference	1.98	-1.95	2.76	-0.07
T	1.89	-1.90	3.84	-0.10
P-value	0.06	0.058	0.000	0.924
Significance	Marginal	Marginal	Significant	No significant

DDS: Handgrip strength of dominant hand in sitting posture and dynamometer supported
NDS: Handgrip strength of non-dominant hand in sitting posture and dynamometer supported

Bao and Silverstein (2005) were tested grip strength of 56 males (mean age: 44, range: 19-60 yr.), and 64 females (mean age: 43, range: 20-63 yr.) from the USA population, for only dominant hand. They found the mean dominant handgrip strength data 29.97 ± 6.72 kgf for females, and 47.91 ± 7.76 kgf for males. To compare the results of this study and the current study, a t-test was applied. For the current study, the mean grip strength for dominant hand for females was 25.36 ± 4.96 kgf and, for males was 44.47 ± 7.82 kgf which were significantly different from the previous study (with a p-value 0.007 for males and 0.000 for females).

Haidar *et al.* (2004) measured grip strength of 50 male (mean age: 34, range: 21-58 yr.) and 50 female (mean age: 37, range: 23-63) hospital workers from British population, for both hands. In the tests, the dynamometer was supported since the subjects were seated on an armchair. Table 6.3 presents the results of t-test to compare the mean strength values of this study and the current study.

Table 6.3. Comparison of results of Haidar *et al.* (2004) with the current study

Study	**Gender**			
	Male		**Female**	
	DDS	**NDS**	**DDS**	**NDS**
Haidar *et al.* (2004)	49 ± 9.9	46 ± 11.4	31 ± 8.3	30 ± 7.4
Present study	45.43 ± 8.54	44.18 ± 8.28	25.73 ± 5.14	24.52 ± 5.45
Difference	3.57	1.82	5.27	5.48
T	2.25	1.03	4.19	4.76
P-value	0.028	0.307	0.000	0.000
Significance	Significant	No significant	Significant	Significant

DDS: Handgrip strength of dominant hand in sitting posture and dynamometer supported
NDS: Handgrip strength of non-dominant hand test in sitting posture and dynamometer supported

Lau and Ip (2006) provided dominant and non-dominant grip strength data from a Chinese male population by occupation (32 heavy manual workers with age mean: 38.4, range: 19-57 yr.; and 32 light manual workers with age mean: 32.9, range: 20-53). They reported that grip strengths were different between hands within each group of subjects and heavy manual workers demonstrated a lesser difference between hands on handgrip strength (4.8%), like the current study (2.9%). Table 6.14 provides the results of t-test for comparison of the mean strength values of Lau and Ip (2006) and the present study. Results of t-tests indicate that the differences between mean grip strengths for dominant and non-dominant hands were significantly different between two studies for both light manual and heavy manual workers. These differences can be attributed to heredity, muscle size and fitness level of the subjects.

Table 6.4. Comparison of results of Lau and Ip (2006) with the current study

Study	**Occupation**			
	Light manual male workers		**Heavy manual male workers**	
	DD	**ND**	**DD**	**ND**
Lau and Ip (2006)	39.2 ± 5.9	34.8 ± 5.3	41.4 ± 5.9	39.5 ± 5.2
Present study	43.11 ± 8.32	41.76 ± 8.47	47.7 ± 5.2	46.35 ± 5.32
Difference	-3.91	-6.96	-6.3	-6.85
T	-2.72	-5.07	-4.19	-4.75
P-value	0.008	0.000	0.000	0.000
Significance	Significant	Significant	Significant	Significant

DD: Handgrip strength of dominant hand in sitting posture
ND: Handgrip strength of non-dominant hand in sitting posture

Xiao *et al.* (2005) provided dominant and non-dominant grip strength data from a Chinese population (146 male and 47 females). They reported that mean grip strength values for males were 43.92 ± 7.14 kgf for dominant hand and 42.07 ± 7.2 kgf for non-dominant hand. For females, these values were 23.26 ± 5.47 kgf and 21.29 ± 5.09 kgf. However for the present study, the mean grip strength values for males were 45.43 ± 8.54 kgf for dominant hand and 44.18 ± 8.28 kgf for non-dominant hand. For females, these values were 25.73 ± 5.14 kgf and 24.52 ± 5.45 kgf, for the present study. For males, results of t-tests indicated that, for non-dominant hand the mean grip strength difference between two studies was significant (p = 0.025); but not for dominant hand (p = 0.116). For females, the results of mean grip strength values of two studies were significantly different for dominant (p = 0.014) and non-dominant hand (p = 0.001). The reason of these differences can be the fact that they set the grip span at 2.5 cm (which is lower than the grip span of the current study), and they collected the grip strength values in a different test posture (dynamometer was held with the palm facing up). Xiao *et al.* (2005) also investigated occupational effects on grip strength, in the same study. They reported that the least handgrip strength differences between hands were in industrial workers, like the present study (heavy manual workers). They also provided handgrip strength of college students and office clerks. While college students were the strongest group for dominant hand, the strongest group for non-dominant hand was industrial workers. However, in the present study, the strongest group was heavy manual workers for both dominant and non-dominant hands.

Anakwe *et al.* (2007) conducted a study in Scotland, to depict the mean grip strength of dominant and non-dominant hands of 172 male (mean age: 44.3 with an age range of 18-83 yr.) and 78 female (mean age: 41.6, with an age range of 18-78 yr.) subjects. Forty nine males were heavy manual workers (age mean: 36.6 ± 16 yr.), and 123 males (mean age: 47.3 ± 17 yr.) were light manual workers. They reported that the mean grip strength value of heavy manual workers was 54.4 ± 10.6 kgf, and of light manual workers was 46.2 ± 10.2 kgf, for the dominant hand. For the present study, the value for the heavy manual occupation group was 47.7 ± 5.2 kgf and for light manual workers was 43.11 ± 8.32. For heavy manual workers, mean grip strength values were significantly different between two studies (p = 0.000). However, for light manual workers, the mean grip difference were not significant between two studies (p = 0.114).

In general, results showed that the mean grip strength values of this study are, depending on the study, similar to or lower than those of American and British populations. However they are generally higher than those of Chinese population, for each gender, occupation or posture and support group. Between these six studies mentioned above, Bao and Silverstein (2005), and Haidar *et al.* (2004), Anakwe *et al.* (2007) found the mean grip strength data higher than those of the present study (the differences were significant). However the mean grip data found by Mathiowetz *et al.* (USA) was statistically equal for each gender and hand (except the mean dominant grip strength of males in sitting posture while dynamometer supported). On the other hand, the mean grip strength data of the present study was higher (differences are significant) than those of Lau and Ip (2006), and Xiao *et al.* (2005), which was conducted for Chinese population, for different genders, hands and occupation groups.

7. CONCLUSIONS

The aims of this study were determining the maximal voluntary isometric grip strength distribution of a Turkish sample and analyzing the found grip strength data by using some statistical tools, to understand how grip strength changes as age, body mass index, occupation, hand, support and posture factors change. Correlation between preferred grip span and hand dimensions were calculated to understand whether the hand dimensions have an effect on preferred grip span. Some percentiles of measured and fitted grip strength values were also calculated for males and females. Finally, the grip strength data obtained through this study were statistically compared with those of some other studies.

The conclusions drawn from this study can be summarized as follows:

1. The mean male grip strength is 43.5% higher than the mean female grip strength.
2. For males, the grip strength remains relatively constant between ages of 18 to 49 years. It starts to decline after age 50. For females, grip strength peaks within the 30 to 39 years age group and gradually declines thereafter.
3. For males, heavy manual workers have higher mean grip strength than light manual workers and university students have. Grip strength is not significantly different in light manual workers and university students. However, for females, it is greater in light manual workers than in university students.
4. For both males and females, as body mass index prime increases, grip strength also increases. However, the mean grip strength of normal weighted and overweighed people are equal to each other.
5. For both males and females, grip strength is greater in dominant hand than in non-dominant hand for each occupation group.
6. For both genders, support effect increases the grip strength more than the weight of the dynamometer.
7. Sitting and standing posture did not affect grip strength, for both males and females.
8. Hand length is predictive for preferred grip span so that there is a positive correlation between hand length and grip span, for both hands.

9. Comparisons with other studies show that while the mean grip strength value of this study is, depending on the studies compared with, somewhat similar or lower than those of American and British population, it is generally higher than those of Chinese population.

APPENDIX A: FORMS

In this appendix, the prepared forms that were used in the study can be seen. These forms are personal consent form, brief medical history form, data collection form and the form of experimental design.

1. Personal Consent Form: It includes a detailed description of the aim and procedures of the study. The subjects signed the form to show that they are voluntarily participating to the study. In this form, it was reported that all information obtained during the study would be held in strict confidence. Since, this form were read and signed by Turkish people, it was prepared in Turkish.

2. Brief Medical History Form: This form was prepared for understanding that the subjects are healthy enough for the tests. The candidate subjects that were free from hypertension, heart diseases, diabetes, rheumatoid arthritis, arm pain and musculoskeletal disorders were accepted to participate in the tests. This form was also prepared in Turkish.

3. Data Collection Form: This form depicts descriptive (birth date, gender, occupation, dominant hand etc.) and anthropometric data (height, weight and hand dimensions) of the subjects and gives their handgrip strength data in each test combination. It was prepared for all subjects and filled by the experimenter. Namely, this form records all of the intended data about each participant.

A.1. Kişisel Kabul Formu

Bu çalışmada, Türk insanının sağ ve sol elin ayaktayken ve otururken dinamometrenin desteklenmesi ve desteklenmemesi durumunda maksimum sıkma kuvvetleri belirlenecektir. Bu çalışmaya engel olacak herhangi bir sağlık probleminizin olmamasından dolayı, çalışmaya uygun durumda bulunmaktasınız.

Bu çalışmadan elde edilecek kuvvet değerleri, manuel işlerin ve el aletlerinin Türk insanına göre tasarımlanmasına yardım edecektir. Bu verileri kullanarak yapılacak tasarımlar iş hastalıklarını azaltmaya ve çalışanların performansını artırmaya katkıda bulunacaktır.

Eğer katılmaya karar verdiyseniz, aşağıdaki hususlara lütfen dikkat ediniz.

1. Deneyden önce boyunuz, ağırlığınız, her iki elinizin eni, boyu ve bilek çapı ölçülecek, size doğum tarihiniz, mesleğiniz ve baskın elinizin hangisi olduğu gibi sorular sorulacaktır.
2. Caldwell protokolüne göre rassal sırayla yapılacak olan elle kavrama (sıkma) kuvveti testlerinde, el dinamometresine (size en uygun kavrama uzaklığı ayarında) maksimum kavrama kuvvetinizi uygulamanız gerekmektedir. Bu çalışma esnasında hazır olduğunuz an "başla" komutundan sonra yaklaşık 1-2 saniyede maksimum kuvvetinize çıkacak ve bu kuvveti 3-4 saniye boyunca tutacaksınız. Bu deney sağ ve sol ellere ayakta ve otururken ve dinamometre desteklenirken ve desteklenmeden olmak üzere her test kombinasyonunda asgari ikişer defa olmak üzere toplam 16 defa yapılacaktır. 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 ortalama ve maksimum değerler kaydedilecektir. Deney esnasında vücut pozisyonu deney yürütücüsü tarafından size gösterilecektir.

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

Katılımınız tamamen gönüllü olup, katılmanız için herhangi bir zorlamayla karşılaşmayacaksınız. Dilediğinizde, çalışmanın herhangi bir aşamasında çalışmayı terk edebilirsiniz. Elde edilecek kişisel bilgiler kimseyle paylaşılmayacak, tez çalışmasında ise 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 Baykar Silahlı veya Dr. Mahmut Ekşioğlu ile temasa geçebilirsiniz

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

Katılımcının İmzası: Tarih:

A.2. Personal Consent Form

In this study, maximum voluntary grip strength of a Turkish population for dominant and non-dominant hands will be determined for sitting and standing postures and for supported and unsupported dynamometer cases. You are selected as a participant in this study because you do not have any serious health problem that can adversely affect the performance of this study.

It is anticipated that the strength results from this study will aid engineers in designing hand tools and manual works according to Turkish population. This may lead to reduced risk of work related disorders and higher performance of workers.

If you decide to participate, you will be required to perform the following tasks.

1. Before the grip strength tests, your height, weight, length and width of your hands, and circumferences of your wrists will be measured. Moreover, you will be asked some questions such as your birth date, occupation and dominant hand.
2. The grip strength tests will be performed in predetermined random order. Utilizing Caldwell protocol, you will perform your maximum voluntary isometric grip force to the handles of a hand dynamometer at preferred grip span. After checking that you are ready for the tests, experimenter will say “start” and you will reach to your maximum exertion in 1-2 seconds and you will hold the maximum for 3-4 seconds. The tests will be done for both dominant and non-dominant hands while the subject is standing and sitting and dynamometer supported and unsupported. For each testing position, the tests will be done at least twice. Therefore the total number of the tests will be 16. To minimize fatigue effect, you will have a 2-minute rest between two successive experiments. Whenever the strength variation is more than 10 per cent 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 have less than 10 per cent differences between each other, will be recorded as your MVC for that test.

Before the tests, participants should not be full, hungry, 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.

If at any time you have questions regarding this research, you may contact either Baykar Silahlı or Dr. Mahmut Ekşioğlu 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.3. 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.4. 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.5. Data Collection Form

1. General Information about the Subject

Information	**Datum**
Birth date	Day: Month: Year:
Birthplace	
Birthplace of his/her parents	
Gender	
Occupation	
Dominant hand	
Preferred setting of the dynamometer	
Weight (kg)	
Stature (cm)	
Length of right hand (cm)	
Length of left hand (cm)	
Width of right hand (cm)	
Width of left hand (cm)	
Rigth wrist circumference (cm)	
Left wrist circumference (cm)	

2. Grip Strength Data of the Subject

Measure (kgf)	**Trial 1**	**Trial 2**	**Trial 3**
Right grip strength (sitting, supported)			
Right grip strength (standing, supported)			
Right grip strength (sitting, not supported)			
Right grip strength (standing, not supported)			
Left grip strength (sitting, supported)			
Left grip strength (standing, supported)			
Left grip strength (sitting, not supported)			
Left grip strength (standing, not supported)			

APPENDIX B: EXPERIMENTAL CONDITIONS FORM

		Posture															
		Stand								Sit							
		Unsupported				Supported				Unsupported				Supported			
		Right		Left		Right		Left		Right		Left		Right		Left	
Subject No.		Trials		Trials		Trials		Trials		Trials		Trials		Trials		Trials	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	Order																
	MVC																
2	Order																
	MVC																
3	Order																
	MVC																
4	Order																
	MVC																
5	Order																
	MVC																
6	Order																
	MVC																
7	Order																
	MVC																
8	Order																
	MVC																
9	Order																
	MVC																
10	Order																
	MVC																
11	Order																
	MVC																
12	Order																
	MVC																
13	Order																
	MVC																
14	Order																
	MVC																
15	Order																
	MVC																
. . .	Order																
	MVC																
208	Order																
	MVC																

REFERENCES

Anakwe, R. E., J. S. Huntley, and J. E. McEachan, 2007, "Grip strength and forearm circumference in a healthy population", *Journal of Hand Surgery (European Volume)*, Vol. 32E, No. 2, pp. 203–209

Bao, S., and B. Silverstein, 2005, "Estimation of hand force in ergonomic job evaluations", *Ergonomics*, Vol. 48, No. 3, pp. 288-301.

Bechtol, C. O., 1954, "Grip test: the use of a dynamometer with adjustable handle spacings", *The Journal of Bone and Hand Surgery*, Vol. 36-A, No. 4, pp. 820-824.

Bohannon R. W., A. Peolsson, N. Massy-Westropp, J. Desrosiers, and J. Bear-Lehman, 2006, "Reference values for adult grip strength measured with a Jamar dynamometer: a descriptive meta-analysis", *Physiotherapy*, Vol. 92, pp. 11-15.

Caldwell, S. L., D. B. Chaffin, F. N. Dukes-Dobos, K. H. E. Kroemer, L. L. Laubach, S. H. Snook, and D. E. Wasserman, 1974, "A proposed standard procedure for static muscle strength testing", *American Industrial Hygiene Association Journal*, pp. 201-206.

Carayon, P., M. J. Smith, and M. C. Haims, 1999, "Work organization, job stress, and work-related musculoskeletal disorders", *Human Factors*, Vol. 41, No. 4, pp. 644-663.

Chaffin, D. B., G. B. J. Andersson, B. J. Martin, 2006, *Occupational Biomechanics*, 4th Edition, John Wiley and Sons, USA

Chuang, M.-C., M. You, D. Cai, and C.-C. Chen, 1997, "Isometric muscle strength of Chinese young males in Taiwan", *Ergonomics*, Vol. 40, No. 5, pp. 576-590.

Devore, J. L., 2004, *Probability and Statistics: For Engineering and the Sciences*, 6th Edition, Thomson Learning, Belmont, CA, USA.

Ekşioğlu, M., 2004, "Relative optimum grip span as a function of hand anthropometry", *International Journal of Industrial Ergonomics*, Vol. 34, pp. 1-12.

Haidar, S. G., D. Kumar, R. S. Bassi, and S. C. Deshmukh, 2004, "Average versus maximum grip strength: which is more consistent?", *The Journal of Hand Surgery*, Vol. 29B, No. 1, pp. 82-84.

Hilmann T. E., Q. M. Nunes, S. T. Hornby, Z. Stanga, K. R. Neal, B. J. Rowlands, S. P. Allison, and D. N. Lobo, 2005, "A practical posture of hand grip dynamometry in the clinical setting", *Clinical Nutrition*, Vol. 24, pp. 224-228.

Hochberg Y., and A. C. Tamhane, *Multiple Comparison Procedures*, John Wiley and Sons, USA.

Hu, H., Z. Li, J. Yan, X. Wang, H. Xiao, J. Duan, and L. Zheng, 2007, "Anthropometric measurement of the Chinese elderly living in the Beijing area", *International Journal of Industrial Ergonomics*, Vol. 37, pp. 303-311.

Innes, E., 1999, "Handgrip strength testing: a review of the literature", *Australian Occupational Therapy Journal*, Vol. 46, pp. 120-140.

International Ergonomics Association, 2000, http://www.iea.cc.

Josty, I. C., M. P. H. Tyler, P. C. Shewell, and A. H. N. Roberts, 1997, "Grip and pinch strength variations in different types of workers", *The Journal of Hand Surgery (British and Europen Volume)*, Vol. 22B, No. 2, pp. 266-269.

Khalil, T. M., M. L. Goldberg, S.S. Asfour, E.A. Moty, R.S. Romosoff, and H.L. Romosoff, 1987, "Acceptable maximum effort (AME): a psychophysical measure of strength in back pain patients", *Spine*, Vol. 12, No. 4, pp. 372-376.

Lau, V. W.-S., and W.-Y. Ip, 2006, "Comparison of power grip and lateral pinch strengths between the dominant and non-dominant hands for normal Chinese male subjects of different occupational demand", *Hong Kong Physiotherapy Journal*, Vol. 24, pp. 16-22.

Mathiowetz, V., N. Kashman, G. Volland, K. Weber, M. Dowe, and S. Rogers, 1985, "Grip and pinch strength: normative data for adults", *Archives of Physical Medicine and Rehabilitation*, Vol. 66, pp. 69-74.

Minitab Inc., 2008, http:// www.minitab.com

Mital, A., and S. Kumar, 1998, "Human muscle strength definitions, measurement and usage: part I - guidelines for the practitioner", *International Journal of Industrial Ergonomics*, Vol. 22, pp. 101-121.

Montgomery, D. C., and G. C. Runger, 2003, *Applied Statistics and Probability for Engineers*, 3rd Edition, John Wiley and Sons, USA.

Montgomery, D. C., 2005, *Design and Analysis of Experiments*, 6th Edition, John Wiley and Sons, USA.

Montoye, H. J., and J. A. Faulkner, 1964, "Determination of the optimum setting of an adjustable grip dynamometer", *The Research Quarterly*, Vol. 35, No. 1, pp. 29-36.

Ng, G. Y. F., and A. C. C. Fan, 2001, "Does elbow position affect strength and reproducibility of power grip measurements?", *Physiotherapy*, Vol. 87, No. 2, pp. 68-72.

Nicolay, C. W., and A. L. Walker, 2005, "Grip strength and endurance: influences of anthropometric variation, hand dominance, and gender", *International Journal of Industrial Ergonomics*, Vol. 35, pp. 605-618.

O'Driscoll, S., E. Horii, R. Ness, T. D. Cahalan, R. R. Richards, and K.-N. An, 1992, "The relationship between wrist position, grasp size, and grip strength", *The Journal of Hand Surgery*, Vol. 17A, No. 1, pp. 169-177.

Peebles L., and B. Norris, 2003, "Filling 'gaps' in strength data for design", *Applied Ergonomics*, Vol. 34, pp. 73-88.

Schmidt, R. T., and J. V. Toews, 1970, "Grip strength as measured by the Jamar Dynamometer", *Archives of Physical Medicine and Rehabilitation*, Vol. 51, No. 6, pp. 321-327.

Slob, P., 2000, "The human power chart: sustained comfortable cranking", PhD Project, Delft University of Technology, The Netherlands.

Toothaker, L. E., 1993, *Multiple Comparison Procedures*, Sage University Papers, USA.

Turkish Official Newspaper, 16 June 2004, No. 25494, Ankara.

Vasu M., and A. Mital, 2000, "Evaluation of the validity of anthropometric design assumptions", *International Journal of Industrial Ergonomics*, Vol. 26, pp. 19-37.

Wikipedia, The Free Encyclopedia, 2008, http://en.wikipedia.org/wiki/Body_mass_index.

Xiao, G., L. Lei, P. G. Dempsey, B. Lu, and Y. Liang, 2005, "Isometric muscle strength and anthropometric characteristics of a Chinese sample", *International Journal of Industrial Ergonomics*, Vol. 35, pp. 674-679.