

ESTIMATION OF STATIC HAND TORQUE STRENGTH CAPACITY OF ADULT
MALE POPULATION OF TURKEY

by

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ABSTRACT

ESTIMATION OF STATIC HAND TORQUE STRENGTH CAPACITY OF ADULT MALE POPULATION OF TURKEY

Human muscle strength is still the main source of power for considerable number of industrial jobs and in many daily life activities. Strength norms are important for safe and efficient design of work, equipment and product. Most of these norms are not universal and are likely to show cross-national variations. The objective of this study are to establish the isometric (static) hand torque strength norms of healthy male population of Turkey, and investigate the effects of handle type, posture, age-group, job-group, BMI-group and several anthropometric variables on hand torque strength. A sample of 257 healthy adult male volunteers aged between 18 and 69 with family roots from all seven regions of Turkey participated in the study. Maximum voluntary hand torque strengths of dominant hand were measured both in sitting and standing postures with four different handles (ellipsoid, circular, key and cylindrical) by using a Torque Tester. The mean and standard deviation of maximum hand torque strength values (in Nm) are 6.97 ± 1.85 for cylindrical handle, 4.97 ± 1.21 for circular handle, 4.19 ± 1.1 for ellipsoid handle and 2.01 ± 0.42 for key handle. The hand torque strength peaked in (40-49) age group for both manual and non-manual job-groups in three handles (ellipsoid, circular and key). For cylindrical handle, hand torque strength peaked in (18-29) age group for both manual and non-manual job-groups. Manual workers, on average, were found stronger than non-manual workers. Slightly greater strength values were recorded in standing posture. Grip strength and some of the anthropometric variables were significantly correlated with torque strength. A comparison study was also made with torque strength data of some other populations. Through this study, static hand torque strength norms of adult male population of Turkey are established between the ages of 18 and 69 years. These norms can be a 'reference' in the design for torque strength for male population of Turkey. In addition, the norms can contribute to the development of the strength database for the population of the world.

ÖZET

TÜRKİYE YETİŞKİN ERKEK NÜFUSUNUN STATİK EL TORK KUVVET KAPASİTESİNİN TAHMİNLEMESİ

Kas kuvveti, endüstriyel işlerin önemli bir kısmında ve günlük aktivitelerin çoğunda hala ana güç kaynağıdır. Bu veriler güvenli ve etkili iş, takım ve el tork kuvveti gerektiren ürün dizaynı için önemlidir. Kuvvet verileri evrensel olmamakla birlikte uluslar arasında farklılık göstermektedir. Bu çalışmanın amacı, sağlıklı yetişkin Türkiye erkek nüfusunun maksimum statik el tork kuvveti standartlarını oluşturmak ve kulp çeşidinin, vücut duruşunun, yaşın, mesleğin, kilo/boy endeksinin ve bazı antropometrik değişkenlerin el tork kuvvetine etkilerini incelemektir. Aile kökenleri Türkiye'nin yedi farklı bölgesinden olan, 257 sağlıklı yetişkin erkek katılımcı çalışmaya katıldı. Kalibre bir tork ölçer cihaz kullanılarak dört kulp türüyle (elipsoid, dairesel, anahtar ve silindirik) oturarak ve ayakta, baskın elin maksimum el döndürme kuvveti ölçüldü. Maximum el tork kuvvetinin ortalama ve standart sapmaları kullara göre şu şekildedir: Silindirik kulp 6.97 ± 1.85 , dairesel kulp 4.97 ± 1.21 , elipsoid kulp 4.19 ± 1.1 ve anahtar kulp 2.01 ± 0.42 . El tork kuvveti elipsoid, dairesel ve anahtar tipi kulplar için ağır işlerde ve hafif işlerde çalışanlarda 40 ile 49 yaşlar arası maksimuma ulaşırken, silindirik kulpta 18 ile 29 yaşlar arasında maximum değerini almıştır. Ağır işlerde çalışanların, hafif işlerde çalışanlara göre daha güçlü oldukları tespit edildi. Ayakta iken ölçülen ortalama kuvvet değerleri, otururken ölçülenlerden daha yüksek çıktı. Statik el kavrama kuvveti ve bazı antropometrik değerlerin el tork kuvveti ile ilişkili olduğu gözlemlendi. Ayrıca diğer bazı ülkelerin tork kuvveti verileriyle de karşılaştırma çalışması yapıldı. Bu çalışmada 18-69 yaş arası Türkiye yetişkin erkek nüfusunun maksimum statik el tork kuvvet standartları belirlenmiştir. Bu standartlar Türkiye erkekleri için yapılacak tasarımlarda referans olarak kullanılabilir. Ek olarak bu veriler, dünya nüfusunun kuvvet veritabanının gelişimine katkıda bulunabilir.

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LIST OF SYMBOLS

H_0	Null hypothesis
H_1	Alternative hypothesis
R^2	Coefficient of determination
R_{adj}^2	Adjusted coefficient of determination
\bar{x}	Sample mean
y_{ij}	The observation in the j th block receiving the i th treatment
α	The percentage of relative accuracy desired
β_j	The effect of the j th block
δ_k	Effect of k th level for body mass index (BMI) group factor
ε_{klm}	NID $(0, \sigma^2)$ random error component
ε_{ij}	Random error
ϑ_m	Effect of m th level for age group factor
μ	Overall mean
τ_i	The effect of the i th treatment
φ_l	Effect of l th level for occupation group factor

LIST OF ACRONYMS/ABBREVIATIONS

ANOVA	Analysis of Variance
ASHT	The American Society of Hand Therapists
BMI	Body mass index
cm	Centimeter
DHB	Dominant hand breadth
DHL	Dominant hand length
DHFC	Forearm circumference of dominant hand
DHWC	Wrist circumference of dominant hand
DoF	Degrees of freedom
GS	Grip strength
ISCO	International Standard Classification of Occupations
ISO	International Organization for Standardization
kg	Kilogram
kgf	Kilogram force
m	Meter
mm	Millimeter
MS	Mean of squares
MW	Manual worker

N	Newton
n	Sample size
NID	Normally and independently distributed
Nm	Newton×meter
SD	Standard deviation
SE	Standard error
SS	Sum of squares
TS	Maximum voluntary hand torque strength
VIF	Variance inflation factor
yrs	Years

1. INTRODUCTION

Although the technological developments and automations in modern industrial society have contributed in the improvement of work efficiency and the ease of work method, there are still a lot of jobs that require physical strength of human being as the major source of power (Kim and Kim, 2000). In many industrial work situations, torque exertion and rotational forces are still required in various activities to fasten devices (Kong *et al.*, 2007). So, the knowledge of the capabilities of users and of using that knowledge as a base for product innovations has become really significant to improve human- machine interactions (Voorbij and Steenbekkers, 2002). In this sense, ergonomic data such as anthropometric and strength data are fundamental to the design of safe and usable products (Norris and Wilson, 1997), and the benefits of using these data properly in the early phases of the design process are widely recognized. The goal of equipment and work design therefore should be to optimize the relationship between the worker and the hand tool being used (Mital, 1986).

Knowledge on strength that can be applied to objects such as hand tools or handling loads is of great importance for ergonomic design (Kroemer, 1999). An atlas of human forces, containing possibly all information relevant to the use of products and equipment, would be valuable to designers (Daams, 1990). So, human strength assessment is required to form population norms for the better design of machines and tools (Chaffin, 1975). These norms are vital in industry so as to achieve productivity and safety of workforce and consumers (Ekşioğlu and Silahlı, 2009). The main objective of strength tests used for ergonomic purposes is often to generate data that enable predicting the strength capacity of a desired population percentile.

Assessment of strength is also necessary for predicting the capability of a person while performing a physical act in a job without incurring injurious strains (Chaffin, 1975). The use of hand tools accounts for approximately 10% of all industrial injuries (Mital and Sanghavi, 1986). If the strength capacity of worker is not enough to satisfy the strength requirements of the job, then it is more likely to undergo exertion related injuries. The

relationship between an operator and the hand tool thus directly affects occupational safety and health and, eventually, productivity (Mital and Sanghavi, 1986)

A number of studies have been conducted to model, measure, and predict hand grip torque strength under specified conditions (Adams, 2006). However, adequate information on force exertion in literature is very scarce because a situation in which force exertion is investigated seldom corresponds with the situation in which a product is expected to be used and even less with the real situation (Daams, 1990). Also, Kroemer (1970) emphasizes that there is a gap in the strength data because strength studies have been generally based on highly selected groups and there is very little information about the force capabilities of women or of elderly or of population in general. A majority of the population generally disregarded while setting the strength norms of that population. Therefore, further strength data collection studies must address each subgroup (e.g., age group, gender subgroup and occupation) of population with use of samples which are random, satisfactorily large, and representative of the population of interest (Portney and Watkins, 1993).

Muscular efforts have long been of interest in physiological, psychological, and biomechanical sciences for different purposes (Kroemer, 1999). Although, daily activities generally required dynamic forces, most of the studies related strength has been conducted with static forces, since the static condition is theoretically simple and experimentally well controllable. It allows rather easy measurement of muscular effort and therefore most of the information currently available on 'human strength' describes the outcomes of static (isometric) testing (Kroemer, 1999).

Strength data has been collected for limited number of different populations so far; however, these studies have been inadequate for the wider populations. Moreover, strength data may be time and generation dependent. Therefore, using strength data of one population for another population may lead to some problems due to cross-national variations. Up to date, for the population of Turkey, there is only a single study that established the hand torque strength norms of adult female population of Turkey. However, there is no study on hand torque strength of male population of Turkey. Thus, this study is

the first attempt to establish the hand torque strength characteristics of male population of Turkey.

A comprehensive experimental study was conducted to establish the hand torque strength norms of healthy male population of Turkey. A sample 257 healthy adult male people of Turkey aged from 18 to 69 years participated to this study. Maximum dominant hand torque strength was measured at the combinations of four different handles and two body postures. Boğaziçi University Ergonomics Laboratory was utilized to conduct the study, but for some subjects, strength tests were performed in different workplaces by providing similar conditions with the Ergonomics Laboratory.

The effects of handle-type, age, job-group, posture and BMI (body mass index) on torque strength were investigated in the study. In addition, the effects of some anthropometric measures that are hypothesized to have moderate to high correlations with hand torque strength were also investigated. Their handle type characteristics are unique for this study. And one of the four handles, ellipsoid handle, was never studied before. Moreover, job-group effect on torque strength was never studied before. The results of the study can be a significant guide to the designers and researchers.

The following chapters of the thesis are organized as follows: Chapter 2 includes a brief summary of literature about hand torque strength studies performed for various objectives on different populations all around the world. In Chapter 3, the rationale behind this study and the main objectives of the current study are presented. In Chapter 4, the methodology of this experimental study which includes description of subjects, equipments used, procedures while conducting the tests and statistical procedure followed to analyze the collected data. In Chapter 5, the results of the hand torque strength data and anthropometric data are presented in detail. In addition, the results of the statistical analysis of the study are presented. In Chapter 6, discussions about the results of the current study are presented and also comparisons of the results of the current study with the previous studies are presented. In the last chapter, conclusions of the current study and recommendations for the future researches are presented.

2. LITERATURE REVIEW

2.1. Overview

Literature review is one of the most critical parts of an experimental study. Before designing an experimental study, the studies done before must be investigated in detail. The main objective of the literature review is to determine the deficiencies of these studies to work on a subject that have never been investigated or find some gaps to fill. An important point is that human related scientific studies must be repeated in some time periods because human life conditions so their characteristics change over time.

There are so many studies in the literature related to hand torque strength. It is a popular subject because most of the occupational activities and daily activities are still performed by using hand torque strength. The aim of these studies is generally to determine the capabilities of human beings. Establishing the strength norms of a population is important to design hand tools, products, packages and many other hand torque required things according to strength capabilities of that population.

Since the application of strength data to human engineering problems is often hampered by ambiguities in the terminology (Kroemer, 1970), before starting to investigate the literature it is critical to explain the term “strength”, strength types and the strength measurements procedures.

2.2. Strength

An understanding of human strength and taxonomy for strength testing will provide for consistency in strength assessment (Kroemer *et al.*, 1990). Before describing different types of strength, the “strength” term must be defined. Strength can be defined as the capacity to produce force or torque with voluntary muscle contraction (Gallagher *et al.*, 1998). There are so many terms related to strength. Muscular strength is a primary determinant of the maximum amount of force that can be exerted, and is task specific (G.

Xiao *et al.*, 2005). Therefore, before designing an equipment engineers and designers must be determine the appropriate strength type.

Maximum strength is defined as the capacity to produce force or torque with a maximum voluntary muscle contraction (Gallagher *et al.*, 1998). “Voluntary” term here refers to willingness of the subject while performing the physical strength. Thus, measured maximum strength is not the actual maximum of the subject but some lesser value representing what he or she is comfortably expressing at the time with the existing equipment and environmental conditions (Gallagher *et al.*, 1998).

2.2.1. Strength types

From physiological perspective, generation of muscle strength is a complex procedure of myofilament activation under nervous control (Kroemer, 1999). It may involve substantial shortening or lengthening of the muscle, that is, either a concentric or eccentric effort, or there may be no perceptible change in length, that is, the effort is isometric. Mechanically, the main distinction between muscle actions is whether they are “dynamic” or “static” (Kroemer, 2006).

2.1.1.1. Static Strength. Static strength is defined as the capacity to produce force or torque with a voluntary isometric contraction (Gallagher *et al.*, 1998). In isometric exertion the length of the muscle stays constant during tension (Kroemer, 1970). Body posture does not change during the measurement.

The static condition is theoretically simple and experimentally well controllable. Moreover, it allows rather easy measurement of muscular effort, that’s why information currently available on ‘human strength’ describes the outcomes of static testing (Kroemer, 1999).

2.1.1.2. Dynamic Strength. Dynamic muscular efforts are more difficult to describe and control than static contractions. In dynamic activities, muscle length changes, and therefore the involved body segments move or rotate. This results in displacement (Kroemer, 2006). The difference between static and dynamic strength is that dynamic strength involves the

movement of the objects being held. From the biomechanical perspective, motion of body segments requires more muscle force to overcome inertia and accelerate the body segment masses (Chaffin *et al.*, 2006).

2.2.2. Strength measurement procedure

From the biomechanical viewpoint, the assessment of static muscular strength of a worker can provide a method of predicting whether the person is capable of performing a physical act in a job without incurring injurious strain (Chaffin, 1975). Human strength assessment is certainly needed to establish population norms for the better design of machines and tools (Chaffin, 1975). That's why, measurement of static muscle strength has been significant for many decades among physiologists, anthropologists, physical educationists and human factors engineers. However, in the real life, most of the force required activities are dynamic. The dynamic form of strength assessment, i.e., where body motion is involved, becomes much more complicated, and hence subject to many additional influences and potential errors (Chaffin, 1975). Most of the information currently available on "human strength" describes the outcomes of isometric (static) strength testing (Kroemer, 1999). Therefore, only the static strength was investigated in this study.

In order to reduce the variation of the measurement techniques, Cardwell protocol was accepted and applied. There are some other protocols give fundamentally the same information were written by Kroemer (1970) and Chaffin (1975). All of them emphasize to the importance of appropriate instructions, the duration of the measurement period, the resting time between two trails and extensive description of experimental methods.

Caldwell Regimen describes the experimental procedure in detail. The fundamental instruction is a slow build-up to maximal force in about one second and steady exertion sustained for four seconds. The strength datum is the mean score recorded during the first three seconds of the steady exertions. The strength variations during this period should be within $\pm 10\%$ to assume as a valid measurement. If not, the trial must be repeated once more. There should be at least two minutes break between the trials (Caldwell *et al.*, 1974).

According to Cardwell protocol, the subject should be informed about the objectives of the experimental study and the procedures before starting the testing session. The instructions should be kept factual and not include emotional appeals. In addition, other factors like rewards, goal setting, competition, spectators that can stimulate motivation should be avoided (Caldwell *et al.*, 1974).

According to Caldwell Regimen the results should include the data about the sample size, the subjects' characteristics and the testing conditions. Moreover, the statistical results such as mean, standard deviation, minimum and maximum values and skewness of the data should also be included (Caldwell *et al.*, 1974).

2.3. Hand Torque Strength

Many industrial work situations consist of high volume production or routine maintenance require transmission of torque to the work pieces (Mital and Sanghavi, 1986). Besides working life activities also in the daily life activities such as opening lids, turning knobs and so on hand torque strength exertion is required. The concept of openability has become a significant issue for designers and manufacturers (Rowson and Yoxall, 2011). Therefore, hand torque strength data has become really valuable for ergonomic purposes.

There are many internal and external factors that affect hand torque strength. Internal factors are related to the characteristics of human beings such as age, gender and so on. External factors are related to experimental conditions such as tool type, body posture and so on. Many factors affect hand and wrist strength as measured in laboratory or field studies (Adams, 2006). These include but are not limited to:

- Orientation to the work surface;
- Plane of rotation of hand;
- Reach distance;
- Type of tool;
- Resisting force dynamics;
- Repetition, duration of single grasp;
- Obstructions (barriers to motion);

- Grasp interference;
- Grasping method;
- Surface roughness or coefficient of friction;
- Use of gloves;
- Gender;
- Age;
- Handedness (use of preferred hand);
- Worker or subject.

Many other factors can be added to this list. For instance, weather conditions, time period in the day and psychology of the subject can affect hand torque strength. They may be tested in an experimental study but it is almost impossible to check all the factors in one experimental study. Therefore, before conducting the current study some factors which were considered as influential were determined.

2.4. Hand Torque Strength Studies

In the literature there are a great number of studies conducted to determine the hand torque capabilities of different populations. In these studies various experimental conditions have been performed to determine the influential factors. Moreover, in some studies regression models have been determined to find an equation to predict the hand torque strength. Some of the significant studies from the literature are investigated in detail before conducting the current study. The literature related hand torque strength is sequenced below according to their publishing years.

Swain *et al.* (1970) conducted a study to determine the maximum torque that men can apply to 0.375, 0.5 and 0.75 in diameter diamond knurled knobs in standing position with and without gloves in specific applications. The knobs were 0.5 in. long. They were operated by 96 civilian subjects and 24 military subjects in two age groups, one 29 years of age or under, the other over 29 years of age; a total of 120 subjects participated in the study and they were tested by using preferred hand to twist the knob, while steadying the apparatus with the other hand. The results of the study showed that the maximum torque

was influenced by the size of the knobs, gloved versus bare hands and knob orientation. Also it was concluded that torque increased with the knob size, decreased with usage of gloves and side knobs allowed more torque than front knobs. An interesting result of the study was that torque strength did not differ significantly between civilian and military personnel. And also the results show that there is no significant variability among subjects with age factor.

The effectiveness of the several daily activities depends ultimately on person's capabilities to grasp objects and turn them against resistance (Pheasant and O'Neill, 1975). In the study of Pheasant and O'Neill 1975, hand-handle linkage was studied to generate useful data for the optimal design of screwdrivers and other devices. Cylindrical handles were chosen for the first stage of the experiments due to their similarity to large number of practical devices use in the real world activities. Two experiments were conducted in this study. In the first experiment maximal steady voluntary torques were exerted by 24 subjects on various handles which were made of polished steel, and ranged in diameter from 1 to 7 cm. The result of the first experiment showed the clear relationship between torque and handle size. In the second experiment, ten subjects were required to exert maximal voluntary torques and maximal thrusts along the axes of the handles. Results of the study showed that the actual shape of the handle is unimportant for the forceful activities; however, the effectiveness of the activity is limited by the size of the handle and the quality of the hand/handle interface.

Rohles *et al.* 1983 conducted an experimental study to determine the wrist twisting strength capabilities of 100 elderly males and 100 elderly females with age ranged from 62 to 92 years; and 100 younger males and 100 younger females with age ranged from 44 to 58 months. The strength was exerted on 8 jar lids whose diameters ranged from 27 mm to 123 mm two times in both clockwise and counter clockwise directions. Besides the strength measurements anthropometric measures such as height, body weight, grasp, lateral prehension, hand length, hand breadth and hand spread were also measured. The results of the study indicated that males were stronger than females in both age groups. For older groups age was negatively correlated with torque, however in the younger groups it was positively correlated. Torque strength increased with the increase of diameter of the lid. Also the results showed that direction of twisting did not affect significantly the torque.

And hand measurements like grasp and lateral prehension, were significant indicators of wrist twisting strength for all subjects.

The effect of handle diameter on hand torque strength was analyzed in the study of Replegle (1983). During the experiments a series of smooth phenolic fiber cylinders ranging in diameter from 0.95 to 8.89 cm were used by ten male and ten female subjects. The participants applied turning force to each cylinder in both clockwise and counterclockwise direction with the preferred hand until the hand slipped. The results of the study were precisely that hand torque strength increases as the square of the diameter for handles which have a diameter less than 2.5 cm. For larger diameters the torque continuous increase, but at decreasing rate and reaches a maximum when the diameter is approximately 5 cm where the torque is 50 percent greater than the torque at 2.5 cm. The grip span and maximum torque diameters do not vary greatly between males and females. Another finding was that the torque capabilities of females are about 40 percent of torque capabilities of males.

Two experiments were conducted by Nagashima and Konz (1986) in their study. In the first experiment, they examined the influence of diameter, gripping material and knurling on torque strength. For this purpose, ten female university students participated voluntarily. Each of the subjects exerted twisting force to six jar lids which were smooth and knurled lid at each of three diameters (48, 67 and 86 mm). Each lid was opened with the bare hand, rubber jar opener and with 100% cotton cloth. At the end of the study, grip strength, hand length, hand breadth at the base of the thumb, and hand spread (distance from tip of thumb to tip of little finger of spread hand) were measured. Results of the experiment indicated that diameter and gripping material were highly significant but knurl was not significant. Moreover, from the anthropometric variables only hand length did not correlate significantly with torque. The second experiment was an attempt to repeat the experiment 1 with a larger and more varied group of subjects to see whether knurling was worthwhile. 29 visitors (17 male; 12 female) were tested with 5 jar lids. Age, gender and preferred hand grip strength was recorded for each subject. The results showed that there was a highly significant effect of gripper and dia. In addition it was found out that only for two pairs there were statistically significant differences.

Mital and Sanghavi (1986) examined the effects of several factors related with operator and task, on the human torque exertion capabilities with common nonpowered hand tools. These factors were sex, isometric strengths, posture, anthropometric variables, tool type, height of torque application, reach distance, and tool orientation. To examine these factors, maximum volitional torque was measured on 55 adult subjects (30 male, 25 female) in 540 treatment combinations (5 Tools \times 2 Postures \times 3 Heights \times 3 Reach distances \times 6 Angles). Result of the study related to gender showed that the operator sex was highly significant factor because peak torque exertion capabilities of female subjects average 66% of the male subjects' torques. It was found out that some factors like height of torque application and the angle of the arm holding the tool led to little differences on means of torques, however statistically different. Major differences were found among the mean torque values of 5 different hand tools, so hand tool type was most significant factor. The effect of posture and reach distance were also found statistically significant factors.

Adams and Peterson (1986) conducted an experimental study to determine the maximum hand grip torque that can be exerted during tightening or loosening of circular electrical connectors. As the strength criterion, three second static force was exerted by each of the subjects. Torque was applied to simulated connector rings with diameters of 0.9, 1.5 and 2 inches by twenty male (ages ranged from 18 to 32) and eleven female (from 19 to 40 years) subjects to test the effects of connector size, grip type employed, orientation of connector, the use of work gloves, the height of the connectors and the direction of rotation on hand grip torque. Results of the study showed that hand grip torque was directly affected by connector diameters and orientation of connector. The usage of gloves also resulted in higher torque exertions. Also it is found out that height and direction of rotation had little effect on torque strength. A common result of the study was that males were significantly stronger than females in both tightening and loosening.

Mital (1986) conducted an experimental study to examine the effects of body posture and effect of different types of non-powered hand tools on maximum volitional torque exertion capabilities of humans. For this purpose, thirty six male and 14 female civilians exerted isometric torque strength in 21 different body postures while using nine different non powered hand tools such as screwdrivers, wrenches, etc. Thus, 189 different torque measurements were recorded for each individual. Results indicated that males exerted 34%

more torque in overall torque than females. Analysis of the factors showed that the type of hand tool and posture assumed strongly influenced the magnitude of volitional torque for both males and females. Among these factors, hand tool type has strongest effect on torque and also has greatest correlation with volitional torque. On the other hand, there was no correlation between body posture and peak torque. The strength and anthropometric variables were weakly correlated with peak torque. Among the anthropometric variables, the body weight had the highest correlation.

With the rapid rise in the proportion of elderly people, the knowledge of their capabilities and limitations has been required by the designers to solve their problem openability. There was very little research related to this issue. One of them was conducted by Imrhan and Loo 1986, in which the effects of container lid variables on opening on circular lids in the elderly population were examined. Maximal voluntary opening force was applied to open circular lid containers by 42 subjects age ranged from 60 to 97 at standing posture except 4 subjects who preferred to apply force in sitting posture. During the experiments smooth and rough lid surfaces were investigated at four different diameters (31 mm, 55 mm, 74mm and 113 mm) for each. The results showed that diameter of the container lid had the greatest effect on torque. That is, the greater the diameter the greater the torque that can be applied. Age was the other factor that affects the torque exerted. Torque decreased by the increase of the age for elderly people. Although, stature and weight showed small positive correlations, none of the correlation coefficients were significant. On the other hand, hand breadth, hand length and hand circumference were all positively correlated with torque. Another result of the study was that female subjects were about 0.75 as strong as male subjects.

The objectives of the experimental study conducted by Adams and Ma (1988) were to determine the maximum, static hand grip torque strength that could be applied to circular electrical connectors under six different levels of interference and four different types of obstruction with and without using work gloves. Respectively, 0.9, 1.5 and 2 in diameters of connectors were used during the experiments. The hand grip strength of 16 male and 18 female participants were tested. Prior to serving in the experiments, subjects were required an isoinertial lift test. Besides the lifting test, subjects were given medical questionnaires and consent form. Results of the study indicated that torque strength and

required separation was a function of level of interference, condition of interference, connector size and glove usage. It was found that the greatest interference occurred when the connectors were located to the right, left, above and below the grasped connectors. It was also found out that large connectors permitted greater torque while requiring less surface-to-surface clearance than small connectors. And although the use of gloves increased torque slightly, as it could be understood easily required more clearance.

Daams (1990) was conducted an experimental study to investigate the influence of postures on maximal static force exertion. In the study, free postures that can be useful to designers were compared to standardized posture. In the first experiment, two women and three men of different age (ranging from 24 to 54) with mean 37 years were participated. For three different postures (free, standard 1 and standard 2), two different force directions (pull and push) were tested at two different exertion height (shoulder height and elbow height). Results indicated that the differences in average magnitude of force between the three types of posture are considerable and significant. Higher strength results were observed in free posture. In the second experiment, standard posture was replaced by the functional posture and same procedures were followed with the first experiment. Results showed that most of the variation may be explained by differences in posture. Highest strength values were observed in free posture, while the lowest values were observed in standard posture. Standardized posture was perceived as uncomfortable and unnatural and the forces measured in standard posture were less than half those exerted in free posture. Therefore, the data obtained using these standardized postures cannot be used to predict the forces exerted in unrestricted situations.

Imrhan and Jenkins (1999) tried to determine the effects of four variables with various levels on the torquing capabilities of male and female adults in simulated maintenance tasks. Ten male (28 - 43 years) and ten female (25 - 40 years) subjects were tested. During the experiments subjects were exerted static MVC torques on a 2.25 in diameter cylindrical handle with each hand over 24 different test conditions defined by combinations of levels among 4 variables which were surface finish, wrist action, arm position, and hand laterality. They were required to grip handles bare handed with power grip in a comfortable standing posture. The results of the study indicated that male torques were 2.04 as strong as female ones; extension torques were 1.18 as strong as flexion ones;

knurled handle torques were 1.15 as strong as smooth handle ones; and right-hand torques were 1.10 as strong as left hand ones. The interaction effects also investigated and it is found that male and female difference was greater for extension torquing compared to flexion one and from using the knurled handle compared with smooth handle. Also, extension- flexion difference was greater with the knurled handle than the smooth handle; and with the arm below the horizontal than at other positions.

Kim and Kim (2000) was conducted an experimental study to investigate the effects of body posture and of different types of common non-powered hand tools on maximum volitional torque exertion capabilities of Korean people. Fifteen healthy male and 15 female university students were participated in the experiments. They were free from any physical ailment especially in upper body and low back area. During the experiments, each subjects exerted maximum volitional torque in each of 15 postures by using 5 different hand tools. That is, each subject performed 75 torque exertions in a random order. Result of the study indicated that the magnitude of the torque exertion is significantly affected by the type of tool and posture for both males and females. Another result extracted from the analysis that females exerted only about 51.5% of torque of males exerted. The result is different with the findings that the muscular strength of female is usually 65% to 70% of male. When the percentage muscular strength of male considered, the strength of Korean females are quite different with western population.

The aim of the study of Voorbij and Steenbekkers (2002) is to determine, in as close to real life situation as possible, the maximum twisting force the elderly can apply when opening a jar. In this study 79 variables were measured on 750 subjects (123 of them were aged between 20 and 30 years and 627 of them were over 50 years of age). In order to make the measurements as realistic as possible a jar-shaped measuring unit that could be picked up and handled was used. The twisting force was measured while the subject was standing and also they were asked to adopt the posture normally used for opening jars. During the actual maximum force exertion, one attendant verbally encouraged the subject. Two minutes of rest was given between two consequent force exertions. All subjects used both hands in the force exertion. One hand was on the lid while the other grasped the jar. As a result of the study, it was concluded that the required torque for opening a jar should

not exceed 2Nm then 97.6% of users between 50 and 94 years of age and 100% of 20–30 year old users would have no difficulty opening a jar.

The increase in the numbers of older people living alone brings a challenge to those involved in design of products. In order to ensure that products are designed for use by all population, there is a requirement to provide strength data and information of the population (Crawford *et al.*, 2002). The aim of the study conducted by Crawford *et al.* (2002) was to examine the effect of shape, diameter and height of lid on wrist torque opening strength. Younger (10 males and 10 females) and older (10 males and 10 females) adults were participated in the experiments and they satisfied the requirements that no medical history of medical problems in the fingers and wrists; no current symptoms of joint problems; and to be able to perform while standing. During the experiments 12 nylon test pieces 9 of which were circular and others were square were used. Results of the analysis showed that increased torque can be exerted on square lids compared to those that are circular of the same diameter. As lid diameter and lid height increase, torque increases for the test pieces between 20 mm and 50 mm diameters. Also a linear relationship for torque exists for the test pieces between 20 mm diameter and 10 mm height and 50 mm diameter and 30 mm height.

One of the main deficiencies of existing studies related strength was that they were rarely measured across all age groups, especially older adults and children have been ignored in data collection. This is because these researches have focused on work place design. In the study of Peebles and Norris (2003), however around 150 subjects aged from 2 to 86 years were measured for six different strength exertion respectively, finger push strength, pinch-pull strength, handgrip strength, wrist twisting strength, opening strength, and push and pull strength. All subjects were free from any physical disability and were not selected to be representative of socio-economic criteria. For wrist twisting strength measurements, the subject stood in front of the measuring device applied force by adopting a free posture. A static twisting force was exerted with dominant hand in a clock-wise direction on a variety of knobs and handles such as, door lever, door knob, circular knob, ridged knob, butterfly nut and tap. All handles were positioned at elbow height. Results of the study indicated that age, sex, type of strength exertion lead to differences in response strength value. That is, the handle or control type, the direction of force, and the number of

hands used all significantly affected the amount of force that could be exerted. This difference can be explained by the diversity in the postures and grips used for each measurement.

Nayak and Queiroga (2004) conducted an experimental study to collect the data on hand grip and wrist twisting strength of healthy older adults to find a regression equation to estimate the pinch and power grip strength of community dwelling older adults in the United Kingdom. A torque meter was used to measure wrist twisting strength of 65 male and 85 female subjects within the age range of 55 to 85 years. Prior to the study, subjects were informed about the purpose of the study and methods to measure grip strength. The result of the study showed a high linear correlation between the pinch grip and power grip strengths. And a multiple regression equation was developed to predict the power grip strength by using age, hand area and mid arm circumference as predictor variables. Also many other regression equations were developed to predict the key grip and pinch grip strengths by using hand grip strength as a predictor. The result of the t-test between male and female wrist twisting strengths showed that males had significantly higher torque strength than females. It was calculated in the study that 1.3 Nm can be recommended as a removal torque for opening child-resistant bottle tops.

Nair and Baratz (2005) used a simple device to quantify twisting strength 64 normal subjects (46 females and 18 males) and 13 arthritic patients (9 females and 4 males) with arthritis of the thumb carpometacarpal joint. After determining the hand dominance, each subject adopted the testing position recommended by American Society of Hand Therapist in 1981 and applied a twisting force to each of the five disks (ranging in diameter from 2.5 to 12.5 cm) with each hand, in both the clockwise and counterclockwise directions, for three trails of each. In this experimental study, differences of gender, hand dominance, disk size, and pathology were all examined. Results indicated that males applied greater torques than females, the dominant hand applied greater torque, and subjects diagnosed with carpometacarpal arthritis could not apply normal levels of torque. This reduction in the strength with carpometacarpal arthritis also shows that the device can be useful in diagnosis, in quantification of rehabilitation and in comparison of surgical treatments. There were no differences in the test-retest group due to the day of testing. The torque

values found out are smaller than those reported by Voorbij (2002), Crawford (2002), and Peebles (2003).

None of studies have considered the effects of cylindrical handle diameters and handle orientation on the torque output, finger force capability/distribution, muscle activity, and subjective comfort rating in maximum torque exertion tasks. In order to fill this gap, Kong and Lowe (2005) conducted an experimental study to evaluate the effects of gender, handle diameter (25-50 mm) and handle orientation (horizontal and vertical) on torque, total finger force, efficiency of flexor and extensor electromyographic (EMG) activity, and subjective comfort rating in a maximum voluntary torque task. In the experiment twenty-four subjects (12 male and 12 female) were recruited. Each of the participants tested six cylindrical handles (diameters ranging from 25 to 50 mm) with two handle in both vertical and horizontal orientations. It is clear from the results of the study that the effects of handle diameter, orientation and also interactions of them on the maximum voluntary torque were statistically significant. However, gender and hand size were not statistically significant. As a general result of the study, the maximum torque increased as the handle diameter increased in both orientations; however there was an exception in the vertical orientation that the maximum torques between 45 mm and 50 mm diameter were not apparently different.

The main drivers behind packaging design used to be cost to the manufacturer and potential impact on consumers. However, more recently an additional factor has become significant is openability (Yoxall *et al.*, 2006). Since, in order to design effective packaging, understanding the ability of aged consumers is crucial (Yoxall *et al.*, 2006). The study of Yoxall *et al.*, 2006 was part of a study which tried to find low cost and easy to implement solutions to reduce opening force for difficult to open packaging. A torque measuring device was developed by using a jar that had a similar appearance and weight to the original product since; they tried to ensure that a subject's behavior would be as similar as possible to the real life experience. For this purpose, 138 male (aged from 8 to 93) and 97 female (aged from 8 to 95) subjects were tested and peak the peak applied torque was calculated. Each subject was tested individually, and asked to open the jar as they normally would. The results of the study showed that much of the female population will struggle to open some jars. Males were considerably stronger than females so, most of them will have

no trouble to open the bulk of jars. However, after 60 years old strength begins to decrease rapidly. Therefore, in order to that packaging can be opened by all of the population, it must be designed with regarding to the capabilities of the weakest consumers.

The objectives of the study conducted by Kong *et al.* (2007) were evaluation the effects of screwdriver handle shape, screwdriver handle surface and orientation of workpiece on torque output, total finger force and muscle electromyographic activity; and definition of the handle design characteristics achieving high task performance in a maximum screwdriver torque task. Twelve male subjects, recruited from a university population, performed maximum screw-tightening exertions using screwdriver handles with three longitudinal shapes (circular, hexagonal and triangular), four lateral shapes (cylindrical, double frustum, cone and reversed double frustum) and two surfaces (rubber and plastic). Each subject tested all 24 screwdriver handles, presented in a randomized order. Six of the subjects exerted their maximum torque exertion from the vertical orientation while other six subjects exerted from the horizontal orientation. Subjects used their dominant hand in each trial. Results of the study indicated that the effect of handle surface, longitudinal and lateral shapes were found to be statistically significant on torque output. Torque output with rubber handles was greater than plastic handles. Torque outputs with hexagonal and circular handles were statistically higher than triangular handles. And also result related lateral shape was that double frustum and cone handles exhibited statistically greater torque output than reversed double frustum and cylindrical handles.

Although interacting with knobs may be a simple task for humans to perform, the ability to manipulate these knobs is not as easily accomplished by a robot or human-machine system (Gugari and Okamura, 2007). Therefore, knob turning tasks are still being required to perform in the daily life. Gugari and Okamura (2007) conducted their studies in the area of knob turning and examined turning strategy, including arm motions used and number of grasps made, time used to complete the motion and maximum applied forces and torques. For this purpose, 6 male and 4 female right-handed, healthy subjects of ages ranging from 20 to 30 were tested. During the experiments, subjects were instructed to use only their right hand to turn the knob clockwise at least 270 degrees by using only wrist

and finger motion in sitting and standing positions. Results indicated that a more distal arm motion is used for a parallel angle of attack, decreased knob size and increased gain.

Seo *et al.* (2007) conducted an experimental study to develop a model to describe the relationship between grip and torque. For this purpose, twelve subjects (6 Female and 6 Male) with age ranging from 21 to 35 years (mean age 26.7) grasped a cylindrical object with diameters of 45.1, 57.8, and 83.2 mm in a power grip, and performed maximum torque exertions about the long axis of the handle in two directions: the direction the thumb points and the direction the fingertips point. Maximum torque, grip force, total normal force, and fingertip/ thumb force were measured. Subjects were seated with an elbow flexed about 90° and forearm horizontal, and grasped a vertical cylindrical handle with the right hand in a power grip. The results of the study showed that maximum torque exerted on the handles was less than each subject's wrist strength. Handle diameter had a significant effect on torque exerted. Also, hand torque is greater when the torque on a cylinder is applied in the direction the fingertips point. Maximum torque can be predicted by using cylinder diameter, normal force, and static coefficient of friction as predictors.

Seo *et al.* (2008) conducted an experimental study to investigate the relationship among friction, applied torque, and axial push force on cylindrical handles. Six female and 6 male healthy university students with age ranging from 21 to 35 participated in the experiments. All participants were right handed and were free of any upper- extremity disorders. Results indicated that axial push force was 12% greater for the rubber handle than for the aluminum handle. Participants exerted mean torques of 1.1, 0.3, 2.5 and -2.0 Nm and axial push forces of 94, 85, 75 and 65 N for the preferred, straight, inward and outward trails, respectively.

The aim of the experimental study of Wieszczyk *et al.* (2009) was to determine the effect of height of hand wheel on the maximum torque production and risk of injury to the shoulders and back of workers. During the experiments maximum torque exertions in the clockwise and counterclockwise directions at three heights (knee, chest, and overhead) were tested by 24 participants who were power plant mechanics or operators. Their ages range from 32 to 61 and average age was 46.3 years. Twenty three of participants were male and all of them were healthy and asymptomatic of any acute or chronic MSD or pain.

The results of the study indicated that the torque generated in the counterclockwise direction was greater than that of clockwise. It was found out that there was no interaction between direction and valve height. At least 10% greater torque was exerted at the overhead level than at the chest level. However, there was no difference in maximum torque between knee and overhead levels and between knee and chest levels.

A survey of 2000 people over the age of 50 by 'Yours' magazine (2004) found that 91% of respondents have had to ask for help in opening a package, whilst 71% of respondents had injured themselves trying to open packaging (Rowson and Yoxall, 2011). Therefore, 'openability' has become a significant issue for designers and manufacturers, and many researchers have interested in this issue. Rowson and Yoxall (2011) as well conducted a study to determine the effect of different hand grips on maximum torque. For this purpose, 19 female and 15 male participants were tested. They were also asked their occupation, age, gender and hand dominance. Each participant were asked to apply twisting force to open the jar with 7 different gripping type and 3 different jar diameters of closure were used, so 21 tests for each participants were applied. The required resting time was provided and each participant was tested separately in a randomized order. The results of the study indicated that female participants generally produce lower torques than males. Also the results indicated that female consumers were most likely to use a spherical grip on containers of this type, this grip choice leads to produce maximum torque for female consumers. Only a limited number of grip styles applied by women gave them a sufficient strength to be able to open the jar. However, for male participants, all of these grip styles produced maximum torques above the torque required for opening jars.

The aim of the study of Recep (2013) was to establish the static hand torque strength norms of healthy adult female population of Turkey, and investigate the effects of handle type, posture, age-group, job-group and several anthropometric variables on hand torque strength. A sample of 257 female volunteers aged between 18 and 69 participated in the study. Maximum voluntary torque strengths of dominant hand were measured both in sitting and standing with four types of handles (cylindrical, circular, ellipsoid and key). The results indicated that handle type, age-group and job-group significantly affect torque strength. The highest values were obtained with cylindrical handle followed by circular, ellipsoid and the lowest with key handle.

The torque strength peaked in (30-39) age group for nonmanual and in (40-49) age-group for manual workers. Manual workers were stronger than non-manual workers. Marginally higher strength values were recorded in standing posture and with overweight subjects.

The literature related to hand torque strength was investigated in detail. A summary of hand torque strength studies is given in Table 2.1. Studies have been conducted in various locations with various sample type, methodology and instrument. Also various factors were investigated in these studies. However, there are still some gaps in this field to be filled.

The significant results of the study showed that hand torque is greater when the torque on a cylinder is applied in the direction the fingertips point. Maximum torque can be predicted by using cylinder diameter, normal force, and static coefficient of friction as predictors.

2.4.1. Summary and Critics of Findings

Classifications of the studies according to posture, handle type, and population sample (age group) were done (Table 2.2, Table 2.3 and Table 2.4). However, there was not a classification according to job-group due to the absence of studies done on different job-groups. Classification is important to determine the deficiencies of the literature and summarize all the literature.

A great number of studies in the literature were concerned with posture because posture is an important factor that has effect on hand torque strength. Some studies in the literature had no restriction on body posture while applying hand torque strength. However, in many studies, posture is determined before the experiments. Table 2.2 shows the classification of the literature according to posture adopted during the experiments. Most common postures were relatively, sitting, standing, both sitting and standing, free posture and specific postures. Relatively few studies have focused on the sitting/standing postures as a factor. The influence of these two commonly used postures has not been quantified sufficiently and so fruitful areas remain for future hand torque strength research.

The effect of handle type on hand torque strength has been investigated most prevalently in the literature. Various hand tools such as cylindrical handles, circular knobs, jar lids, disks, screwdrivers, wrenches and circular electrical connectors were used in the experiments to determine the hand tool effect on hand torque strength. Table 2.3 shows hand tool/handle types used in the studies. None of the studies in the literature has investigated handle types like key handle and ellipsoid handle as used in the current study. Both of these handles are most commonly used in the daily life but almost never investigated in the literature. Door knob and butterfly nut was investigated in the study of Peebles and Norris (2002), but they are not exactly similar to ellipsoid handle and key handle respectively.

Table 2.4 shows the classification of the hand torque strength studies according to population sample. In general, hand torque strength studies were conducted on adult population. However, so limited studies were conducted on children and elderly people. In addition, really few of the studies in the literature were normative study.

Summary results of some TS studies in the literature were displayed in the Table 2.5.

Results of the studies in the literature related hand torque strength can be summarized as following:

- Gender has significant effect on hand torque strength. Males are approximately 60% stronger than females.
- Handle type, handle material, handle shape, handle diameter, handle surface and direction of force are all influential on hand torque strength. Various handle types were tried in the studies to determine the effect of handle type. In general, the effect of handle diameter was tested with different diameters and it was found that hand torque strength is proportional to the cylindrical handle diameter. Hand torque strength increases as the diameter of cylindrical handle increases and reaches maximum at 5 cm diameter, afterwards it slowly decreases.
- Body posture is another factor that has effect on hand torque strength. In general, the studies have found that higher torque strength was exerted in the standing posture compared with the sitting posture. But there are also some studies, finding this

difference statistically significant but practically insignificant. In addition, exertion height has effect on hand torque strength.

- The effect of age has been investigated in many studies. In general, strength increases throughout childhood, peaks in adulthood, and then decreases with age from around 50 years.
- Hand used in the experiment is also effective on hand torque strength. In general, dominant hand is stronger than non-dominant hand.
- Direction of torque exertion is another influential factor on hand torque strength. The results of the studies indicated that the torque generated in the counterclockwise direction was greater than that of clockwise. Also, for cylindrical handle inward torque strength values were found greater than outward torque strength values.

Table 2.1. Summary of studies in literature.

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Swain, Shelton, Rigby (1970)	USA	96 civilian M 24 military M (21-40)	Max of two measurements	<ul style="list-style-type: none"> • Dial indicating • Screw-driver type torque wrench • Indicator 	<ul style="list-style-type: none"> • Standing position, approximately in front of the device • Both feet on the floor • Not moving device • Twisting the knob with preferred hand, while steadying the apparatus with the other 	Maximum Torque for small knobs	Age	1 min	Until the hand slips	<ul style="list-style-type: none"> • Knob Size • Knob Orientation • Glove Condition
Pheasant, O'neill (1975)	UK	1. Exp - 24 subjects 2.Exp - 10 subjects	Mean value	Simple Lever and load cell device	Free posture	Maximum steady voluntary torques	NM*	NM	NM	<ul style="list-style-type: none"> • Screwdriver size • Screwdriver shape • Screwdriver shape quality
Replogle (1983)	USA	10 M and 10 F	Peak	Torque Meter	NM	Hand Torque Strength	Grip Span Diameter Hand Length	NM	NM	Diameter and Torque

*NM- Not mentioned

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Rohles, Moldrup, Laviana (1983)	USA	100 M and 100 F 100 boys and 100 girls	Mean value	<ul style="list-style-type: none"> • Torque meter (Snap-On Tools Corp., Model 6-FU) • Hand dynamometer (Lafayette Instrument Co. Model 78101) 	Free posture	Opening wrist twisting strength	<ul style="list-style-type: none"> • Age • Height • Weight • Grasp • Lateral prehension • Hand length • Hand breadth • Hand spread 	NM*	NM	<ul style="list-style-type: none"> • Age • Gender • Grasp type • Lid diameter • CW, CCW
Nagashima, Konz (1986)	USA	Exp.1 -10 F	Peak	Torque Meter	NM	Twisting Strength	<ul style="list-style-type: none"> • Grip Strength • Hand Length • Hand Breath • Hand Spread 	About 1 min	NM	<ul style="list-style-type: none"> • Grip strength • Lid radius • Gripping material
		Exp.2 - 17 M and 12 F	One trial		NM	Twisting Strength	<ul style="list-style-type: none"> Age Gender Preferred Hand Grip Strength 	15 sec	NM	<ul style="list-style-type: none"> • Grip strength • Lid radius • Gripping material

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Mital (1986)	USA	36 M and 14 F	Peak	VISHAY-20 digital strainmeter	21 different body postures	Maximum volitional torque	18 Anthropometric and strength measurements	5 min	5 sec	<ul style="list-style-type: none"> • Body • Posture • Hand Tool
Mital, Sanghavi (1986)	USA	30 M and 25 F	Peak	Special Torque Meter, VISHAY-20 digital strainmeter	Sitting Standing	Maximum Volitional Torque	<ul style="list-style-type: none"> • Age • Weight • Arm Strength • Shoulder strength • Standing height • Standing eye height • Standing shoulder height • Standing elbow height • Sitting Height • Sitting eye height • Sitting shoulder height • Sitting elbow height • Knee height 	1 min 5-10 min (after 30 min of data collection)	4-5 sec	<ul style="list-style-type: none"> • Gender • Posture • Isometric strength • Anthropometric variables • Tool type • Height of torque application • Reach Distance • Tool orientation

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Adams, Peterson (1986)	USA	20 M and 11 F	Mean of three trials	<ul style="list-style-type: none"> • Load cell (torque measuring) bridge • Amplifier; analog-to-digital converter • Digital computer-printer signal tone • Generator-test signal generator 	Standing	Maximum Hand Grip Torque	<ul style="list-style-type: none"> • Age • Height • Weight • Reach height • Maximum grip range 	2 min	3 sec	<ul style="list-style-type: none"> • Diameter • Type of grip • Orientation of the connector • The usage of gloves • The height of the connectors • Direction of rotation
Imrhan, Loo (1986)	USA	42 subjects	Mean value	Wrist twisting torque	The torque tester was placed on a table 33 cm high. Subjects standing in front of the tester and held the container lid with the preferred hand.	Maximum voluntary wrist twisting	<ul style="list-style-type: none"> • Age • Hand breadth • Wrist circumference • Hand circumference • Hand length • Stature • Body weight • Maximal strength of handgrip • Chuck pinch • Lateral pinch 	2-3 min	2-5 sec	<ul style="list-style-type: none"> • Age • Gender • Lid diameter • Lid surface

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Mital, Channaveeraiah (1988)	USA	15 M and 15 F	Peak	VISHAY-20 digital strainmeter	Standing posture for wrenches Sitting posture for screwdrivers	Maximum Torque	<ul style="list-style-type: none"> • Age • Weight • Height (Standing and sitting) • Eye height (Standing and sitting) • Shoulder height (Standing and sitting) • Elbow height (Standing and sitting) • Knee height (Standing) • Palm width • Palm length • Hand thickness • Hand circumference • Fist circumference • Grip diameter 	up to 5 min	4 sec	<ul style="list-style-type: none"> • Grip shape • Wrist orientation • Duration of repeated exertions

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Adams, Ma (1988)	USA	18 M and 16 F	Mean value	Torque measuring system	Frontal plane Connector located at 60% of the subject's max reach height	Static Hand Grip Torque for circular electrical connectors	NM*	2 min	5 sec	<ul style="list-style-type: none"> • Levels of interference • Condition of interference • Connector size • Glove usage
Daams (1990)	Netherlands	3 M and 2 F	Average of two trails	Force transducer with strain gauges, an amplifier and an xt-recorder	<ul style="list-style-type: none"> • Free • Standard 1 • Standard 2 	Push and Pull	N	2 min	5 sec	<ul style="list-style-type: none"> • Posture • Force direction • Height of handle above floor
		10 M and 10 F								
Steenbekkers (1993)	Netherlands	390 boys and 392 girls	Mean value	Metek torque measurement device	Sitting, forearm is almost horizontal in a sagittal plane and rest on the table. Upper arm and forearm are at the angle of about 150 degrees	Maximum static torque	<ul style="list-style-type: none"> • Age • Gender • Preferred Hand 	minimum 2 min	4 sec	<ul style="list-style-type: none"> • Laterality • Preferred Hand
Imrhan, Jenkins (1999)	USA	10 M and 10 F	Peak	Snapon-Tools model torque meter	Free posture	Torquing capabilities in maintenance tasks	Age	1,5 min	5 sec	<ul style="list-style-type: none"> • Handle surface • Wrist action • Arm position • Hand laterality

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Kim, Kim (2000)	Korea	15 M and 15 F	Max of two measurements	A work simulator and 5 attached tools	15 Different postures	Maximum volitional torque	<ul style="list-style-type: none"> • Age • Weight • Upper arm length • Forearm length • Arm length • Shoulder width • Forearm grip distance • Height • Eye height • Shoulder height • Elbow height • Knuckle height 	1 min 5-10 min (after 30 min of data collection)	4 sec	<ul style="list-style-type: none"> • Body posture • Type of hand tool
Chang, Wang (2001)	China	13 M	Mean of three trials	Pneumatic Screwdrivers with adjustable torque and a fast shut-off mechanism, OctoForce Sensor System	NM*	Torque	Age Hand Length Stature	20-30 min	5 sec	<ul style="list-style-type: none"> • Activation mode • Torque • Horizontal operating distance

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Voorbij, Steenbekkers (2001)	Netherlands	750 subjects (123 between 20 and 30 years, 627 over 50 years)	Mean of two measurements	Jar shaped force meter (force transducer)	Standing posture normally used for opening jars	Twisting force while opening jar	79 variables • Physical var. • Psychomotor var. • Sensory var. • Cognitive var.	2 min	Constant phase of 1 sec	• Age • Laterality • Position
Crawford, Wanibe, Nayak (2002)	UK	10 M and 10 F 10 boys and 10 girls	Mean value	• AFG 1000 N (Torque meter) • Dynamometer • Pinch gauge • AFG 1000 N Mecmesin force meter and a fixed jar holder	Standing	Wrist torque opening strength	• Stature • Weight • Hand breadth • Hand length • Chuck grip force • Grip force • Lateral grip force • Pinch grip force	NM*	NM	• Lid shape • Lid diameter • Height of lid

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Peebles, Norris (2003)	UK	Around 150 subjects	Peak	6 different devices for 6 different strength measurements	Free posture	<ul style="list-style-type: none"> • finger push strength; • pinch-pull strength; • hand grip strength; • wrist-twisting str.; • opening strength; • push and pull strength 	Age Gender	2 min	5 sec	<ul style="list-style-type: none"> • Gender • Age
Yang, Tan, Buttolo, Johnston, Pizlo (2003)	UK	6 M and 3 F	Peak	<ul style="list-style-type: none"> • Rotary motor (Maxon RE25 118752) • Optical Encoder (Computer Optical Product, CP950) • Power amplifier (Trust Automation 115) • Transformer (CUI MPS100-24) 	Resting the left elbow on the table in a comfortable position	Sinusoidal torque	NM*	NM	NM	Noise

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Nayak (2004)	UK	65 M and 85 F	Peak	<ul style="list-style-type: none"> • Strain-gauge hand-held dynamometer • torque meter 	<p>Sitting in a straight back chair with the feet flat on the floor. The elbow should be flexed to 90° with the forearm and wrist in neutral position.</p>	<ul style="list-style-type: none"> • Wrist twisting strength • Pinch and power grip strengths 	<ul style="list-style-type: none"> • Age • Gender • Weight • Height • BMI (Body Mass Index) • Hand length • Hand width • Hand area • Mid arm circumference (MAC) 	1 min	5 sec	<ul style="list-style-type: none"> • Age • Hand area • Mid arm circumference
Nair, Baratz (2005)	USA	46 F and 18 M and 13 arthritic patients	Mean of three trials	Special Torque Meter	Position recommended by American Society of Hand Therapists	Twisting Strength	<ul style="list-style-type: none"> • Age • Gender 	NM*	NM	<ul style="list-style-type: none"> • Age • Disease

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Kong, Lowe (2005)	USA	12 M and 12 F	Peak	<ul style="list-style-type: none"> • Force glove system • Electromyographic measurement system • LIDO WorkSET II 	The elbow angle about 90° in the vertical orientation, forearm and upper arm straight for holding the handle in the horizontal orientation.	<ul style="list-style-type: none"> • Maximum Volitional Torque • Finger Force • Muscle activity 	<ul style="list-style-type: none"> • Age • Height • Weight • Hand length 	2 min	5 sec	<ul style="list-style-type: none"> • Gender • Handle diameter • Handle orientation
Yoxall, Janson, Bradbury, Langley, Wearn, Hayes (2006)	UK	138 M and 97 M	Peak	Torque sensor was embedded into a modified glass jar	Free posture, opening the jar as subjects normally open	Maximum jar opening torque strength	Age Gender	NM*	NM	<ul style="list-style-type: none"> • Age • Gender
Kong, Lowe, Lee, Krieg (2007)	Korea	12 M	Mean of two measurements	<ul style="list-style-type: none"> • Handles • Torque measurement system 	Standing	Screwdriving Torque strength and Finger force	<ul style="list-style-type: none"> • Age • Height • Weight • Hand length • Hand thickness • Hand breadth • Palm lengthx 	2 min	4-5 sec	<ul style="list-style-type: none"> • Screwdriver handle shape • Surface material • Workpiece orientation

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Gugari, Okamura (2007)	USA	6 M and 4 F	Mean of two measurements	<ul style="list-style-type: none"> • Knob-turning device • Visual display • Video camera 	<ul style="list-style-type: none"> • Standing on a footstool • Sitting in a chair 	Knob Turning Torque	<ul style="list-style-type: none"> • Age • Hand Size • Self-reported experience 	NM*	No limit	<ul style="list-style-type: none"> • Turning strategy • Arm motions • Numbers of grasps • Time used to complete
Seo, Armstrong, Chaffin, Miller (2008)	USA	6 M and 6 F	Mean of two measurements	<ul style="list-style-type: none"> • Pressure Measurement System • EMG 	Free posture	<ul style="list-style-type: none"> • Axial push force • Torque • Grip force • Normal force • Finger flexor muscle activities 	<ul style="list-style-type: none"> • Age • Gender • Hand length • Grip strength 	2 min	5 sec	<ul style="list-style-type: none"> • Handle material • Push method
Wieszczyk, Marklin, Sánchez (2009)	USA	23 M and 1 F	Mean of two measurements	<ul style="list-style-type: none"> • Torque limiter • Hand wheel • Load cell 	Three heights <ul style="list-style-type: none"> • For knee height, participants squatted and bent their trunk forward • For the chest and overhead heights, the participant stood at the same horizontal distance to the hand wheel 	Maximum Torque	<ul style="list-style-type: none"> • Age • Height • Weight • Hand length • Work Experience 	2 min	5 sec	Height of a hand wheel

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009)	UK	18 young subjects 64 older subjects	Mean value	Instrumented jar with an embedded torque sensor	Free posture	Opening torque with jar opener	<ul style="list-style-type: none"> • Age • Gender 	2 min	5 sec	Tools
Su, Chiu, Chang, Lin, Hong, Kuo (2009)	China	4 M and 6 F	Mean of three trials	<ul style="list-style-type: none"> • Jar simulator with one torque sensor • Sixaxis force transducer 	Comfortable sitting position	<ul style="list-style-type: none"> • Twisting torque • Thumb forces 	<ul style="list-style-type: none"> • Age • Height • Weight • Hand length • Hand breadth 	3 min	NM*	Grip Patterns

Table 2.1. Summary of studies in literature (cont.).

Source	Location	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time	Factor
Wong, Moskovitz (2010)	USA	18 subjects	Mean of three trials	Portable forearm strength hydraulic dynamomete	Sittng, grasping the doorknob with both shoulder and elbow positioned in visually approximated 45 flexion	Forearm strength for doorknob handle	<ul style="list-style-type: none"> • Age • Height • Weight • BHD pronation • BHD supination • Cybex pronation • Cybex supination 	30 sec between three trials, 3 min between different assessors	NM*	Device
Rowson, Yoxall (2011)	UK	15 M and 19 F	Peak	Torque meter Jar resemble	<ul style="list-style-type: none"> • Lateral grip posture • Spherical grip, • Pulp grip • Tip grip • Cylindrical grip • Pronated cylindrical • Box grip 	Opening Torque	<ul style="list-style-type: none"> • Age • Gender • Occupation • Hand Size • Preferred Grip Choise 	Suitable rest periods	5 sec	Grip Choice

Table 2.2. Summary of studies classified according to the posture.

<i>Sitting</i>	<i>Standing</i>	<i>Sitting and Standing</i>	<i>Sitting and Standing (Free to choose)</i>	<i>Sitting, standing and some other postures</i>	<i>Studies where the posture is not mentioned</i>
<ul style="list-style-type: none"> • Yang, Tan, Buttolo, Johnston, Pizlo (2003) • Nayak (2004) • Miller, Nair, Baratz (2005) • Seo, Armstrong, Miller, Chaffin (2007) • Su, Chiu, Chang, Lin, Hong, Kuo (2008) • Wong, Moskovitz (2010) 	<ul style="list-style-type: none"> • Swain, Shelton, Rigby (1970) • Adams, Peterson (1986) • Imrhan, Loo (1986) • Adams, Ma (1988) • Adams, Peterson (1988) • Imrhan, Jenkins (1997) • Voorbij, Steenbekkers (2001) • Crawford, Wanibe, Nayak (2002) • Peebles, Norris (2003) • Kong, Lowe (2005) • Seo, Armstrong, Chaffin, Miller (2008) 	<ul style="list-style-type: none"> • Mital, Sanghavi (1986) • Gugari, Okamura (2007) 	<ul style="list-style-type: none"> • Rohles, Moldrup, Laviana (1983) • Daams (1990) • Yoxall, Janson, Bradbury, Langley, Wearn, Hayes (2006) • Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009) 	<ul style="list-style-type: none"> • Mital (1986) • Mital, Channaveeraiah (1988) • Kim, Kim (2000) 	<ul style="list-style-type: none"> • Pheasant, O’Neill (1975) • Replogle (1983) • Rowson, Yoxall (2010)

Table 2.3. Summary of studies classified according to handle/hand tool types.

<i>Cylindrical Handles</i>	<i>Circular knob</i>	<i>Jar lids</i>	<i>Screwdrivers</i>	<i>Circular electrical connectors</i>	<i>Wrenches</i>
<ul style="list-style-type: none"> • Pheasant, O'Neill (1975) • Replogle (1983) • Imrhan, Jenkins (1997) • Kim, Kim (2000) • Kong, Lowe (2005) • Seo, Armstrong, Ashton-Miller, Chaffin (2007) • Seo, Armstrong, Chaffin, Ashton-Miller (2008) 	<ul style="list-style-type: none"> • Swain, Shelton, Rigby (1970) • Kim, Kim (2000) • Peebles, Norris (2002) • Miller, Nair, Baratz (2005) (Disks) Designed device • Nair, Baratz (2005) • Gugari, Okamura (2007) 	<ul style="list-style-type: none"> • Rohles, Moldrup, Laviana (1983) • Nagashima, Konz (1986) • Imrhan, Loo (1986) • Voorbij, Steenbekkers (2001) • Peebles, Norris (2002) • Crawford, Wanibe, Nayak (2002) • Laxman, Nayak (2004) • Yoxall, Janson, Bradburry, Langley, Wearn, Hayes (2006) • Su, Chiu, Chang, Lin, Hong, Kuo (2008) • Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009) • Rowson, Yoxall (2011) 	<ul style="list-style-type: none"> • Mital, Sanghavi (1986) • Mital (1986) • Mital, Channaveeraiah (1988) • Kim, Kim (2000) 	<ul style="list-style-type: none"> • Adams, Peterson (1986) • Adams, Peterson (1988) • Adams, Ma (1988) 	<ul style="list-style-type: none"> • Mital, Sanghavi (1986) • Mital (1986) • Mital, Channaveeraiah (1988) • Kim, Kim (2000)

Table 2.4. Summary of studies classified according to the population sample.

<i>Children</i>	<i>Students</i>	<i>Adults</i>	<i>Elderly population</i>	<i>Normative Study</i>	<i>Not mentioned</i>
<ul style="list-style-type: none"> • Rohles, Moldrup, Laviana (1983) • Steenbekkers (1993) 	<ul style="list-style-type: none"> • Bradley (1969) • Nagashima, Konz (1986) • Adams, Ma (1988) • Kong, Lowe (2005) • Kong, Lowe, Lee, Krieg (2007) 	<ul style="list-style-type: none"> • Swain, Shelton, Rigby (1970) • Mital, Sanghavi (1986) • Mital (1986) • Cochran, Riley (1986) • Adams, Peterson (1986) • Adams, Peterson (1988) • Mital, Channaveeraiah (1988) • Daams (1990) • Imrhan, Jenkins (1999) • Kim, Kim (2000) • Chang, Wang (2001) • Crawford, Wanibe, Nayak (2002) • Miller, Nair, Baratz (2005) • Seo, Armstrong, Miller, Chaffin (2007) • Gugari, Okamura (2007) • Seo, Armstrong, Chaffin, Miller (2008) • Wieszczyk, Marklin, Sánchez (2009) • Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009) • Wong, Moskowitz (2010) 	<ul style="list-style-type: none"> • Rohles, Moldrup, Laviana (1983) • Imrhan, Loo (1986) • Voorbij, Steenbekkers (2001) • Crawford, Wanibe, Nayak (2002) • Nayak (2004) • Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009) • Rowson, Yoxall (2011) 	<ul style="list-style-type: none"> • Steenbekkers (1993) • Voorbij, Steenbekkers (2001) • Peebles, Norris (2003) • Nayak (2004) • Yoxall, Janson, Bradbury, Langley, Wearn, Hayes (2006) 	<ul style="list-style-type: none"> • Pheasant, O'Neill (1975) • Replogle (1983) • Yang, Tan, Buttolo, Johnston, Pizlo (2003)

Table 2.5. Summary result table of some TS studies in the literature.

Study	Country	Sample Size	Age (yrs)	Handle	Diameter	TS (Nm)			
						Male	Female		
Nagashima and Konz (1986)	USA	Exp.1 10F	NM*	Jar lid	48 mm		3.17		
					67 mm		5.02		
					86 mm		6.04		
		Exp.2 17M 12 F			67 mm	Rubber		Bare	Cloth
						smooth	9.8	7.8	6.3
					knurkled	8.9	7.9	6.3	
86 mm	smooth	11.3	10.4	8.7					
	knurkled	10.9	10.1	9.5					
Imrhan and Loo 1986	USA	42 subjects (M&F)	60-97	rough and smooth Lid with diameters:		Rough	Smooth		
					113 mm	5.01	3.29		
					74 mm	4.20	4.19		
					55mm	3.30	3.25		
31mm	1.62	1.53							
Imrhan and Jenkins (1999)	USA	10 M and 10 F	28-43	Cylindrical handle	57.2 mm	9.11±0.72	4.68±0.39		
Kim and Kim (2000)	Korea	15 M and 15 F	18-29	Cylindrical handle	34 mm	11.4±1.52	5.96±2.23		
						12.66±1.73	6.94±2.08		
Voorbij and Steenbekkers (2002)	Netherlands	750 subjects (123 between 20 and 30 years, 627 over 50 years)	20-30	Jar lid	66 mm	8.7±2.2	5.6±1.4		
			50-54			7.6±1.8	4.8±1.5		
			55-59			7.6±2.3	4.7±1.4		
			60-64			6.4±1.8	4.8±1.4		
			65-69			6.5±2.1	4±1.2		
			70-74			5.4±2.1	3.7±1.1		
			75-79			5±1.7	3.5±1.3		
			80+			4.9±1.7	3.4±0.9		
Peebles and Norris (2003)	UK	Around 150 subjects (21-30 yrs: 7, 31-50 yrs: 5, 51-60 yrs: 4, 61-70 yrs: 4)	21-30	Disk	4 cm	4.1±1.8	3.5±1.3		
			31-50			4.5±1.7	3±1.3		
						4.2±1.1	3.5±0.6		
			51-60	Butterfly nut		3.9±1	2.4±0.4		
						4.3±1.6	2.8±0.7		
						3.6±0.8	2.7±0.5		
61-70			3.2±0.5	2.3±0.6					
Nair and Baratz (2005)	USA	46 F and 18 M and 13 arthritic patients	19-74	Disk	5 cm	2.16±0.63	1.44±0.41		
					7.5 cm	3.37±0.86	2.20±0.63		
Seo <i>et al.</i> (2008)	USA	6 M and 6 F	21-35	Cylindrical handle (rubber)	57.8 mm	8.7±2.5	3.5±2.1		
				Cylindrical handle (aluminum)		6.9±1.3	2.8±1.7		
Recep (2013)	Turkey	257F (18-29 yrs: 53, 30-39 yrs: 54, 40-49 yrs: 50, 50-59 yrs: 50, 60-69 yrs: 50)	18-69	Ellipsoid handle	55.58 mm		Sitting 2.74±0.71 Standing 2.96±0.78		
				Circular handle	59.98 mm		3.30±0.86 3.51±0.88		
				Key handle			1.59±0.39 1.65±0.42		
				Cylindrical handle	50.7 mm		5±1.3 5.3±1.38		

3. RATIONALE AND OBJECTIVES OF THE STUDY

3.1. Rationale behind the Study

Even though, there is a great technological improvement in the industry, many activities are still required hand torque strength of human. Therefore, determining the strength norms of a population is necessary to design products and work stations within the strength capabilities of possible users. In order to apply strength data to human engineering problems, so many studies have been done. Measurements of static muscle force have, for many decades, been popular among physiologists, anthropologists, physical educationists, and human factors engineers (Kroemer, 1970).

Some developed countries have already established strength norms of their populations even though there are some gaps in the ergonomic data. However, there are many countries which are still using the strength data of other populations. Since geographical and hereditary differences among different nationalities may lead to variation in the strength data, hand torque strength norms should be developed specifically for the populations of different regions and nationalities. There have not been conducted any studies to investigate the hand torque strength capability of male population of Turkey. Therefore, this study would be an important step to form the hand torque strength data norms of male population of Turkey.

Four different hand tools were used in this experimental study with two different postures. There is no other study completely similar to this study. Especially, manual and non-manual classification has never been investigated. Relatively few studies have focused on relationship between body posture and hand torque strength.

The effects of various factors such as handle type, posture, age, BMI and occupation on hand torque strength was investigated in this study. Besides them also the effects of some anthropometric measures on hand torque strength were tested. This study combines the mentioned factors to study hand torque strength in addition to establish hand torque strength norms of adult male population of Turkey.

3.2. Objectives of the Study

Based on the rationale, the objectives of the study are as follows:

- (i) Estimating the maximum voluntary static (isometric) hand torque strength distribution of healthy (normal) adult male population of Turkey;
- (ii) Investigating the effects of body posture and handle type on hand torque strength;
- (iii) Investigating the effects of age, height, weight, job-group and hand dimensions on hand torque strength; and
- (iv) Comparing the hand torque strength data of the male population of Turkey with the hand torque strength data of male population of other countries.

4. METHODOLOGY

4.1. Overview

This part explains all the components of the study necessary to perform the experiments and analyze the results. In this part, the general characteristics of the participants, the details about the equipments utilized, the testing procedure followed, and finally the experimental design and statistical analysis procedure were explained.

4.2. Subjects

The sample of the study included 257 healthy male volunteers has family origin from different regions of Turkey. Subjects were recruited from a metropolitan city of Turkey (Istanbul) and its surrounding areas. Since, the population of this city is composed of people whose family origins are from every region of Turkey, it is assumed that the population of Istanbul approximately represents the population of Turkey. The sample also included a few foreign people who live in Turkey.

The data of birthplace, city of family origin, father and mother's birthplace of subjects were collected. The regional distribution of the family origin of the subjects is shown in Table 4.1 and Figure 4.1.

Table 4.1. Distribution of family origin regions of the subjects.

Regions	Subjects
Mediterranean	31
Eastern Anatolia	35
Agean	31
Southeastern Anatolia	32
Central Anatolia	33
Black Sea	38
Marmara	49
Other Countries	8
Total	257

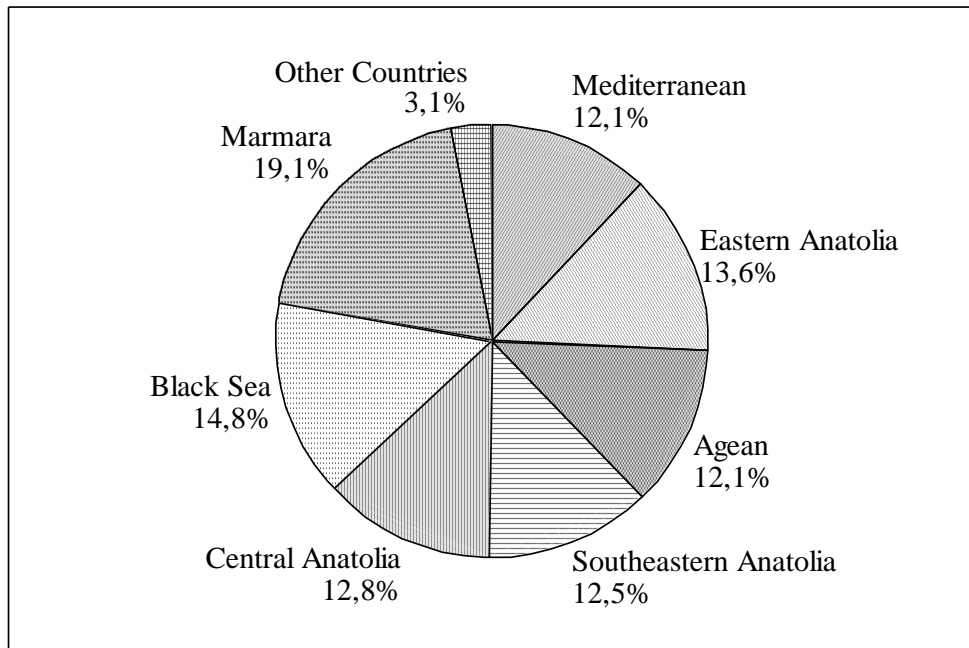


Figure 4.1. Distribution of family origin regions of the subjects.

Subjects were divided into two job groups; manual workers and non-manual workers according to jobs' power demand levels (ISCO-08; Crawley and *et al.*, 2009). This categorization was made by the help of "Regulation of Heavy and Dangerous Labors" which was published in the "Turkish Official Newspaper" on 16 June 2004.

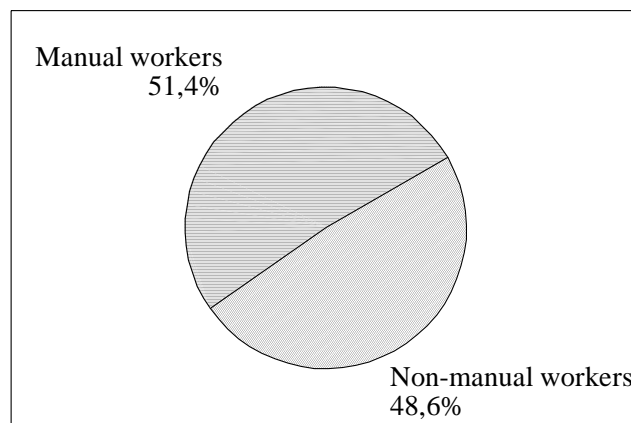


Figure 4.2. Distribution of job groups.

The distribution of job groups is displayed in the Figure 4.2 They were taken approximately close to each other to increase the reliability of the comparison. The occupations are displayed in detail in the Table 4.2.

In order to ensure the necessity that all subjects must be free from hypertension, heart disease, diabetes, rheumatoid arthritis, arm pain and musculoskeletal disorders; a medical history form was applied to the subjects before the experiments. The purpose of this form was to discover if the subjects had serious health problems which can lead to experimental errors. The subjects, who had health problems, were excluded from the experiments and the experimentation period was conducted only with the healthy subjects.

Table 4.2. Occupation Classification.

Manual workers (132)	Non-manual workers (125)
Assembly worker (9)	Accountant (7)
Auto electrician (1)	Architects (1)
Baker (4)	Building inspector (1)
Barber (4)	Business analyst (2)
Bus driver (7)	Chemist (1)
Canvas maker (1)	Clerk (23)
Carpet weaver (4)	Clerk (retired) (10)
Chef (1)	Clerk (transportation) (3)
Cleaner (6)	Computer programmer (7)
Construction (13)	Consultant (2)
Cook (6)	Editor (1)
Dressmaker (2)	Electrical technician (4)
Farmer (8)	Engineer (4)
Glass manufacturer (1)	Entrepreneur (1)
House keeper (1)	Information officer (2)
Machine operator (17)	Inspector (2)
Metal worker (1)	Interpreter(2)
Milling machine setter (1)	Luna park manager (1)
Painter (house) (3)	Officer (7)
Press operator (1)	Planning responsible (1)
Repairman (8)	Publisher (1)
Security guard (2)	Receptionist (2)
Service Driver (14)	Sale assistant (3)
Textile worker (4)	Sale representative (2)
Tool maker (1)	Store controller (1)
Waiter (8)	Street trader (3)
Warehouseman (1)	Student (12)
Welder (1)	Teacher (10)
Wood worker (2)	Telephone operator (2)
	Textile officer (1)
	Theater actor (1)
	Tourism personal (office) (2)
	Trade (import-export) (3)

The subjects were also categorized according to their BMI values. The body mass index (BMI) 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 square of their height (kg/m^2) (Wikipedia, 2008). The formula of the BMI Prime is stated below. The BMI categories were also shown in the Table 4.3.

$$\text{BMI} = \text{Weight} / (\text{Height}^2)$$

$$\text{BMI} = \text{kg} / \text{m}^2$$

Table 4.3. BMI categories.

Category	BMI Range (kg/m^2)	Subject Numbers
Underweight	< 18.5	-
Normal	$18.5 \leq x < 25$	79
Overweight	≥ 25	178

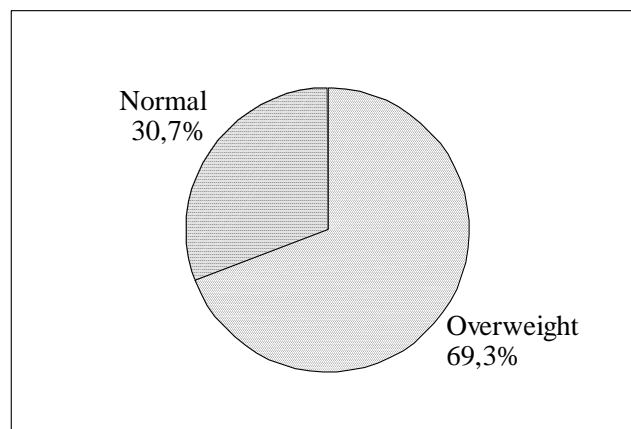


Figure 4.3 Distribution of BMI groups

A great number of subjects, approximately 69 % of them, were overweight. There were no underweight subjects. That is shown in the Figure 4.3.

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

Table 4.4. The number of subjects categorized by age, job groups and BMI.

Job group	BMI Category	Age Group					All
		18 - 29	30 -39	40 -49	50 - 59	60 - 69	
Manual	Normal	16	9	9	5	6	46
	Overweight	9	16	16	27	19	89
	All	25	25	25	32	25	132
Non-manual	Normal	13	5	3	5	8	34
	Overweight	12	20	22	20	17	91
	All	25	25	25	25	25	125
Total		50	50	50	57	50	257

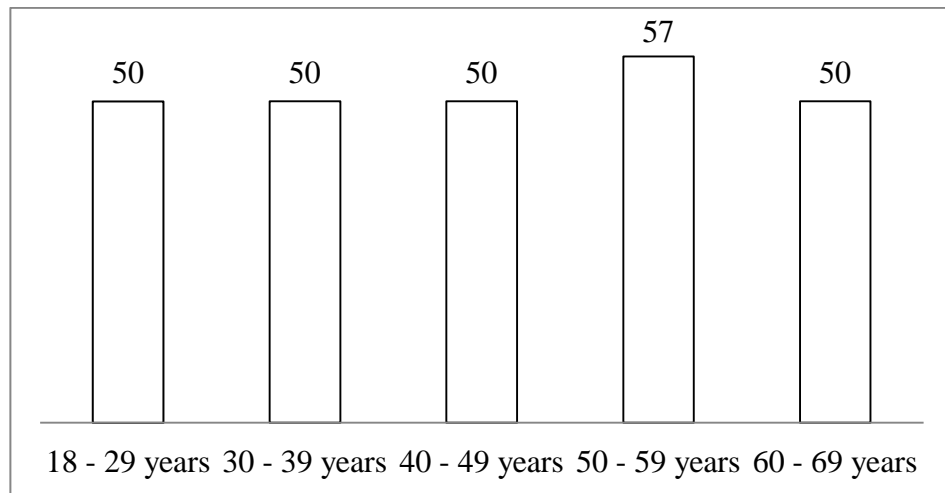


Figure 4.4. Distribution of Age groups.

4.3. Equipment

The equipment used to measure hand torque strength, and anthropometric dimensions are described below.

4.3.1. Torque Tester

Hand torque strength was measured with the CAP-TT01-250 Digital Cap Torque Tester which is a special high-capacity version calibrated for a range up to 250 lb-in / 2880 kg-mm / 2825 N-cm. The torque tester was a specially modified for the current study by Electromatic Equipment Co., Inc., in the USA. Its female rectangular block was specially designed according to the "tongue" end of the handles. The equipment was calibrated

before starting the experiments through the calibration kit. The CAP-TT01-250 Digital Cap Torque Tester is displayed in the Figure 4.5. The four handles that were used are described below:

- Ellipsoid handle – major axis(a): 55.58 mm; minor axis(f): 41.95 mm; depth(b): 35.41 mm; total height(c): 90.08 mm; tongue depth(d): 14 mm; tongue width(e): 37.5 mm (Figure 4.7)
- Circular handle – diameter(a): 59.98 mm; depth(b): 20.10 mm; total height(c): 79.05 mm, tongue depth(d): 14 mm, tongue width(e): 37.5 mm (Figure 4.8)
- Key handle – length(a): 30.87, (b):55.58 mm, total height(c): 55.58 mm, tongue depth(d): 25 mm, total width(e): 37.5 mm (Figure 4.9)
- Cylindrical handle – diameter(a): 50.7 mm, length(b): 112.97 mm, total height(c): 126.97 mm, tongue depth(d): 14 mm, tongue width(e): 37.5 mm (Figure 4.10)

The materials of handles are as following: Ellipsoid and circular handles are made of plastic; key handle is made of natural anodized coated aluminum; cylindrical handle is made of black anodized coated aluminum.



Figure 4.5. The CAP-TT01-250 Digital Torque Tester (Electromatic Equipment Co., Inc., USA).

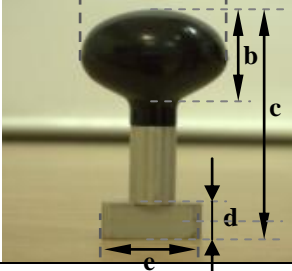
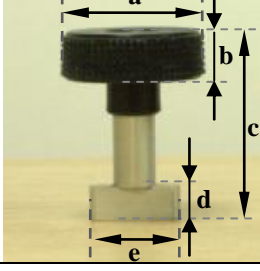
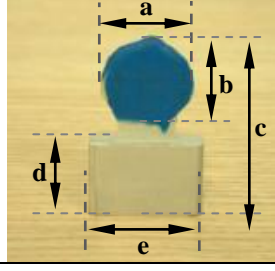
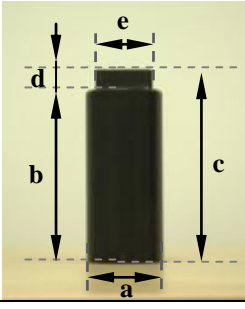
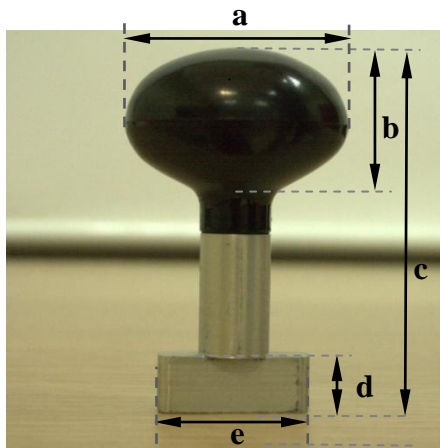
Ellipsoid Handle	Circular Handle	Key Handle	Cylindrical Handle
			
<p>a=55.58 mm, b=35.41 mm, c=90.08 mm, d=14 mm, e=37.5 mm</p>	<p>a= 59.98 mm, b= 20.10 mm, c=79.05 mm, d=14 mm, e=37.5 mm</p>	<p>a= 30.87 mm, b= 30.08 mm, c=55.58 mm, d= 25 mm, e=37.5 mm</p>	<p>a= 50.7 mm, b= 112.97 mm, c=126,97 mm, d=14 mm, e=37.5 mm</p>

Figure 4.6. Handles.



a=55.58 mm, b=35.41 mm, c=90.08 mm, d=14 mm, e=37.5 mm, f=41.95 mm

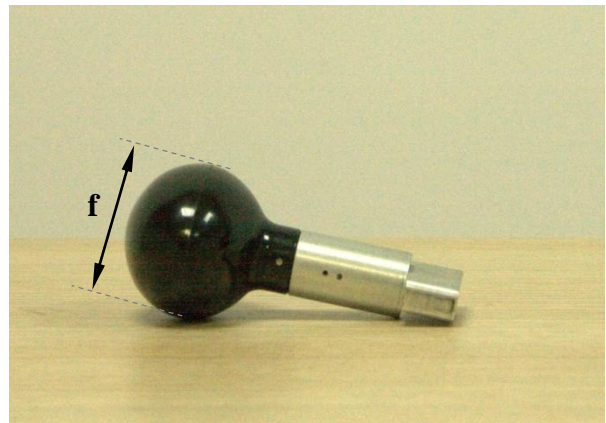
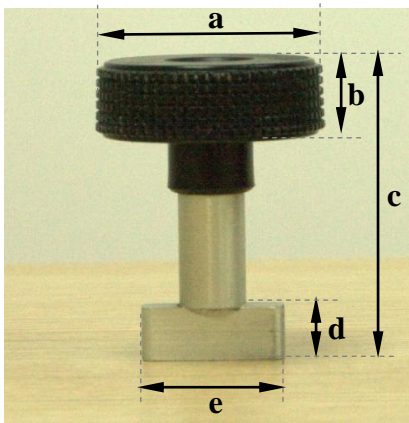


Figure 4.7. Ellipsoid Handle.



a= 59.98 mm, b= 20.10 mm, c=79.05 mm, d=14 mm, e=37.5 mm

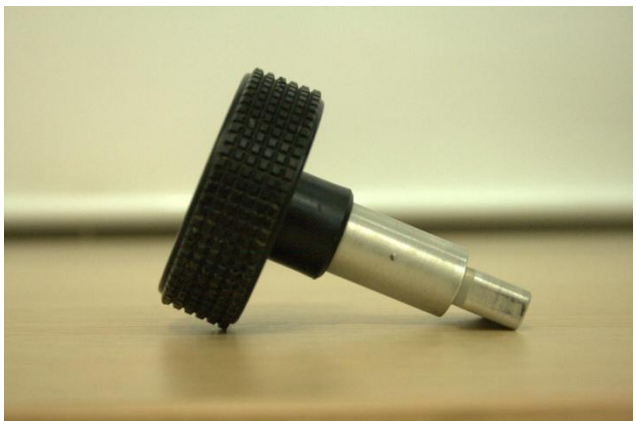
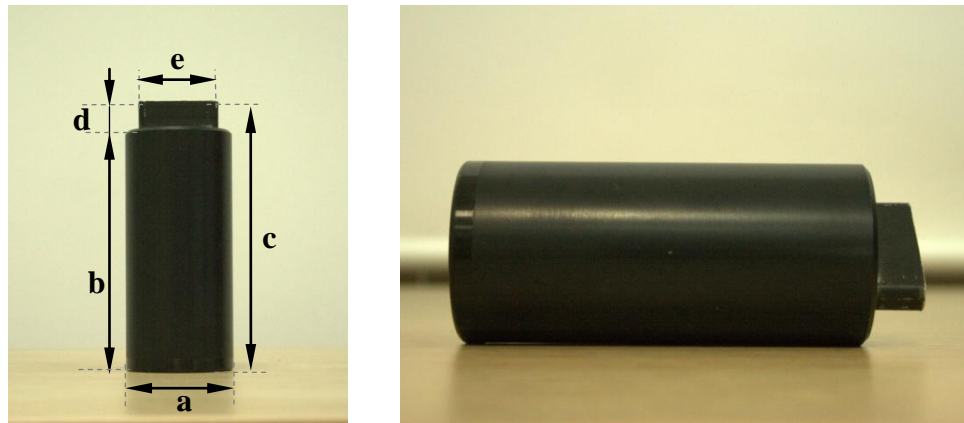
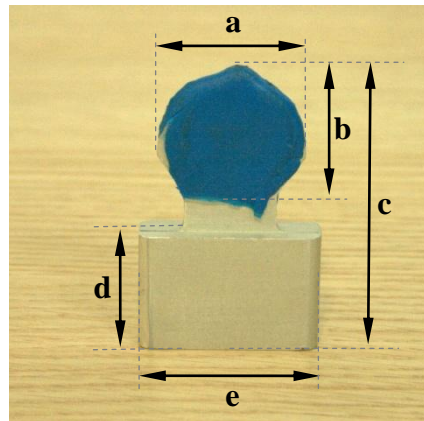


Figure 4.8. Circular Handle.



a= 50.7 mm, b= 112.97 mm, c=126,97 mm, d=14 mm, e=37.5 mm

Figure 4.9. Cylindrical Handle.



a= 30.87 mm, b= 30.08 mm, c=55.58 mm, d= 25 mm, e=37.5 mm

Figure 4.10. Key Handle.

4.3.2. Holtain Harpenden Stadiometer

Holtain Harpenden Stadiometer was used to measure the height of the subjects in the Ergonomics Laboratory. It gives an accurate and direct reading of a subject's height. The stadiometer is a counter recording instrument, with an effortless counter balanced movement. The structure of the Harpenden Stadiometer, which is made of light alloy angle, can be moved easily. There is a wooden piece on it, and it is provided with adjustable wall brackets for mounting purposes. Therefore, it can be moved up and down in a quick way. The stadiometer head-block operates via miniature ball-bearing rollers in order to ensure a movement which is free yet without cross-play. Then, most of standing measurements can be taken through a high speed Veeder-Root counter on this stadiometer. It counts approximately 1500 mm length. Figure 4.11 shows the stadiometer.

4.3.3. Weighing Scale

Weighting scale was used to measure body mass of the subjects. A spring scale measures weight by the distance a spring deflects under its load. A balance compares the unknown weight to a standard weight using a horizontal lever. It is used in the laboratory study to determine the weights of the subjects.

4.3.4. The Measuring Tape

Anthropometric measurements such as circumferences of wrist and forearm of the participants were measured with measuring tape which is flexible form of ruler. It consists of a ribbon of cloth, plastic, fiber glass, or metal strip with linear-measurement markings.

4.3.5. Sliding Caliper

Sliding caliper was used to measure hand length and hand breadth measurements. The caliper used in this study is designed to measure the external size of an object. There is a high degree of accuracy and repeatability about reading the result on this equipment Figure 4.12 shows the caliper used in this study.

4.3.6. Jamar Handgrip Dynamometer

Hand grip strength was measured while sitting on an adjustable chair by a hydraulic Jamar handgrip dynamometer (Model 5030J1, Sammons Preston Royle, and Chicago, USA), which is considered a standard isometric grip strength testing device (Figure 4.13). This dynamometer displays two different strength parameters, namely, pounds and kilograms. The maximum strength value can be measured is 200 pounds or 90 kilograms. The Jamar hand dynamometer has an analog display screen and it has a peak-hold needle that automatically retains the highest reading until reset. The dynamometer accommodates various settings 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. During the experiments third setting is heavily preferred by male subjects while a few of the subjects felt comfortable with second setting.

4.3.7. Adjustable height table and adjustable chair

In order to ensure the required body posture for all subjects, a remote controlled adjustable height table and an adjustable chair were used (Figure 4.14 and Figure 4.15). For sitting and standing postures, the height of table was adjusted proper to the height of subjects. In addition, for strength measurements with sitting posture, the height of adjustable chair was adjusted to ensure that the upper legs of subjects were almost horizontal and their feet were flat on the ground.



Figure 4.11. Stadiometer (a) Front view (b) Indicator.



Figure 4.11. Stadiometer (a) Front view (b) Indicator (Cont.).



Figure 4.12. Sliding caliper.

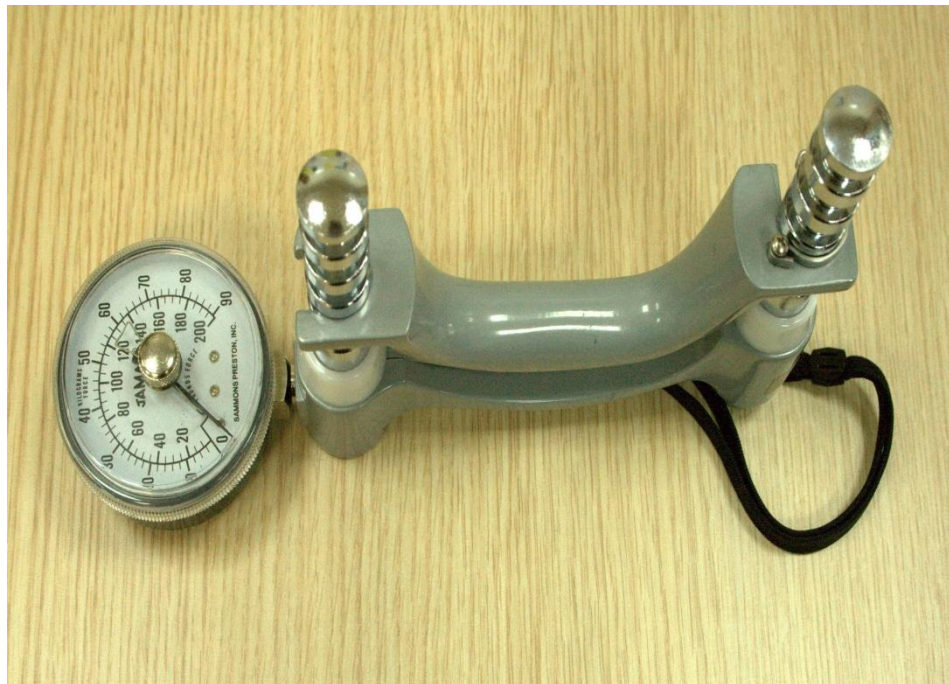


Figure 4.13. Hydraulic Jamar handgrip dynamometer.



Figure 4.14. Remote-controlled height adjustable table.



Figure 4.15. Adjustable chair (a) Front view (b) Lateral view.

4.3.8. The calibration check of Torque Meter

The calibration of the equipments is an important factor for the reliability of the experiments. The calibration of the CAP-TT01-250 Cap Torque Tester was checked before starting the experiments. In order to check the calibration, previously determined weights was used. In order to check the calibration of the torque tester, a special calibration kit was used. This special calibration kit is designed to permit the field calibration of the CAP-TT01-250 Cap Torque Tester. The kit contains a complete set of attachments required to mount the tester to a bench, as well as the necessary brackets and cable to mount weights. The calibration kit without weight held is displayed in the Figure 4.16.

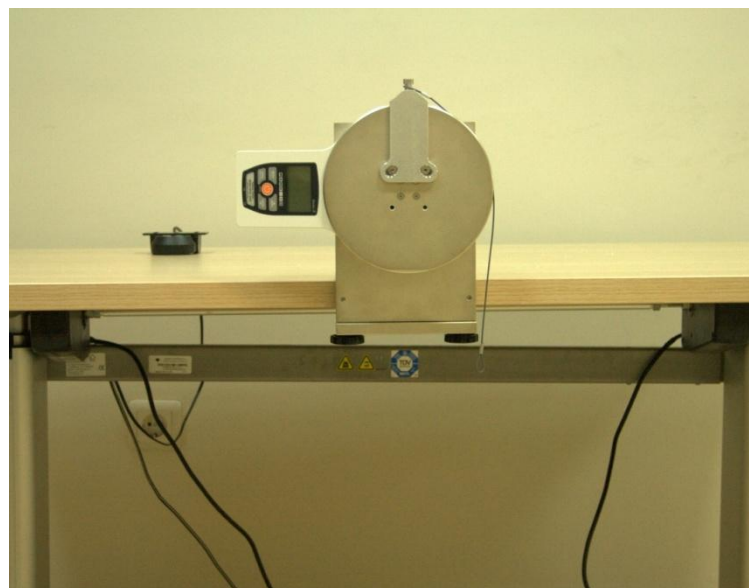


Figure 4.16. Checking calibration, before mounting weight.

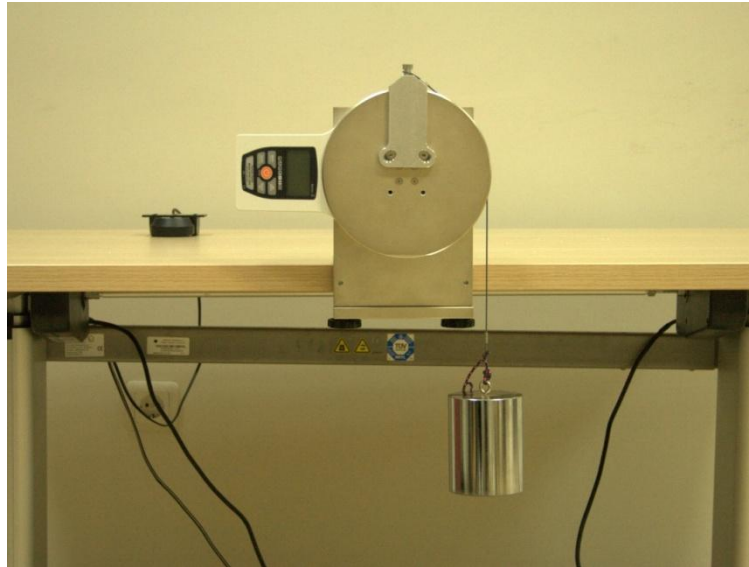


Figure 4.17. Checking calibration, after mounting weight.

In order to increase the sensitivity of the calibration, previously determined weights were used. They were hanged with the calibration kit (Figure 4.17). Then the result was read from the scale and compared with the determined real weights of the objects being held. The readings from the scale were exactly the same as the actual weights of the objects, so the calibration of the device is accurate.

The calibration procedure is done according to the procedure described in the CAP-TT01-250 Cap Torque Tester Manual (Appendix D).

The calibration of the Torque tester was calculated by the following formula:

$$\text{Moment (Nm)} = \text{Force (N)} \times \text{Distance (m)}$$

$$\text{Force} = \text{mass (kg)} \times \text{gravity (m/s}^2\text{)}$$

Then,

$$\text{Force} = 4 \times 9.81 = 39.24 \text{ N}$$

$$\text{Distance} = 8.5 \text{ cm} = 0.085 \text{ m}$$

$$\text{Moment} = 39.24 \times 0.085 = 3.34 \text{ Nm}$$

The torque tester was displayed 3.34 Nm, so the torque tester was ready for the experiments. This means that the calibration of the torque tester is okey.

4.4. Testing Procedure

First of all, people from different age and job groups were convinced to be a candidate for the experiments. Potential subjects were told that a series of basic body dimensions and hand torque strengths were going to be measured. Prior to any evaluation, each subject was given a detailed description of the objectives and requirements of the experiment. After this, all the candidate subjects filled “Medical History Form” and the ones who were free from diseases such as musculoskeletal disorders were accepted to participate in the study (Ekşioğlu and Silahlı, 2009). The participants then signed the “Personal Consent Form”, which includes a detailed description of the aim and procedures of the study, to show that he/she was voluntarily participating in the study. In the personal consent form, it was also reported that all information obtained during the study would be held in strict confidence. The “Personal Consent Form” and “Medical History Form” were prepared both in English and Turkish (Appendix A).

Before performing the tests, the subjects filled a “Personal Data Form” (Appendix A), that provided information including birthdate, birthplace, occupation, family origin, and mother and father’s birthplace.

4.4.1. Anthropometric measurements

The following anthropometric measurements were taken.

- Height
- Weight
- Wrist circumference
- Forearm circumference
- Hand length
- Hand breadth

(i) Measurement of Height: Stature (body height) was measured by wall-mounted meter while subject stood fully erect with feet together and head was oriented in the Frankfurt plane (ISO 7250) (Figure 4.18).



Figure 4.18. Measurement of height with stadiometer.

(ii) Measurement of Weight: In order to measure weight a mechanical scale was used (Figure 4.19). This mechanical scale had been checked for accuracy with known weights before the tests. The subjects wore light clothes and did not wear any accessories which cause extra weight. In addition, the participant was not very hungry or full.



Figure 4.19. Measurement of weight with mechanical scale.

(iii) Measurement of Hand length: To measure hand length, which is distance from the crease of the wrist to the tip of the middle finger with the hand held straight and stiff; the sliding caliper was used and subject held the forearm horizontal with hand stretched out flat, palm up (ISO 7250) (Figure 4.20).

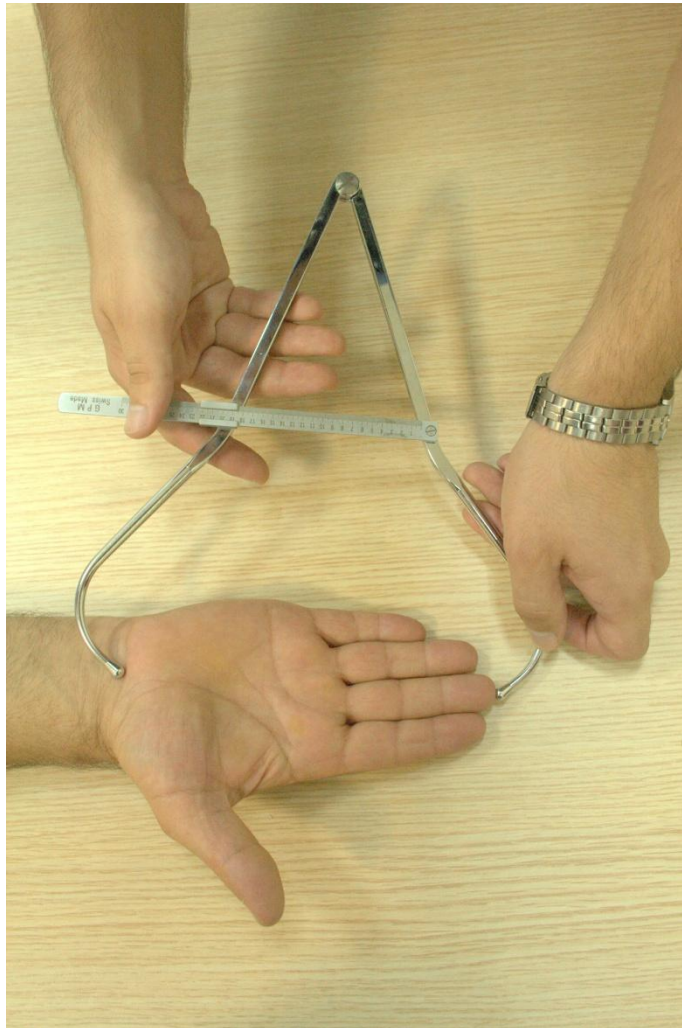


Figure 4.20. Measurement of hand length with sliding caliper.

(iv) Measurement of Hand breadth: Hand breadth was measured by sliding caliper; subject held forearm horizontal with hand stretched out flat, palm up (ISO 7250) (Figure 4.21).



Figure 4.21. Measurement of hand breadth with sliding caliper.

(v) **Measurement of Circumference of Wrist:** A tape measure is going to be used to measure circumferences of wrists of the participants and while measurements subject is going to hold forearm horizontal with outstretched and fingers extended (ISO 7250) (Figure 4.22).



Figure 4.22. Measurement of circumference of wrist with tape measure.

(vi) **Measurement of Circumference of Forearm:** Forearm circumference of the participants was measured with a tape measure, while person sits with the forearm bent upwards, thumbs side of hand toward the face and hand held flat (Peoplesize, 2008) (Figure 4.23).

All anthropometric hand measurements were taken from the dominant side of the subject.



Figure 4.23. Measurement of circumference of forearm with tape measure.

4.4.2. Grip Strength Measurement

(i) **Determination of preferred grip span:** Preferred grip span changes according to the hand dimensions of subjects. Therefore, before actual grip strength tests, subjects performed trial tests with different dynamometer grip span setting to determine their “preferred span”, for which they felt they could produce their maximal strength,

comfortably. While 243 males preferred third setting, 14 males preferred second setting of the Jamar hand grip dynamometer.

(ii) Grip Strength Measurements: Grip strength of subjects was measured only at sitting posture. The subjects were comfortably sitting on an adjustable chair with shoulder adducted naturally with 90° elbow angle. The upper legs of subjects were almost horizontal and their feet were firmly flat on the ground. Jamar grip strength dynamometer was supported by the experimenter. Hand grip strength was measured according to Caldwell *et al.*'s Protocol (1974) at the preferred span determined before, subjects were instructed to hold the handles of the dynamometer and squeeze as hard as they can, without jerking. They were instructed to reach their maximum exertion in about one second and hold it for about four seconds". 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 grip strength test once more. To eliminate fatigue effect on grip strength, the subjects were allowed to rest about two minutes between trials. During the testing, any feedback was provided about the strength values to the subjects. Verbal encouragements, rewards, goal setting, competition and noise were also avoided. Also, laboratory was kept in normal room temperature.



Figure 4.24. Measurement of grip strength.

4.4.3. Hand Torque Strength Measurement

After all anthropometric measurements were taken the following hand torque strength measurements were taken. All of them are shown in the Table 4.5.

Table 4.5. Hand torque strength measurements with different handle types.

Number	Treatment Combinations
1	Hand torque strength while sitting with ellipsoid handle
2	Hand torque strength while standing with ellipsoid handle
3	Hand torque strength while sitting with circular handle
4	Hand torque strength while standing with circular handle
5	Hand torque strength while sitting with key handle
6	Hand torque strength while standing with key handle
7	Hand torque strength while sitting with cylinder handle
8	Hand torque strength while standing with cylinder handle

Before performing the tests, there was a demonstration and practice period. The objective of this period was make the subjects get familiarized with the equipment and procedures for collecting hand torque strength data. Before the actual tests, the subjects were instructed shook their hands and fingers to speed up their blood circulation, as a warm-up period.

The purpose of the experiments and procedures were described to subjects clearly. They were only permitted to use their dominant hand. Subjects were instructed to increase to maximum exertion (without any jerk) in about one second and maintain this effort during a four second count (Caldwell *et al.*, 1974). These instructions were kept factual and did not include any emotional appeals (Caldwell *et al.*, 1974). Subjects performed two strength exertions, lasting around 5 sec for each experimental condition. If the difference between the two measurements was more than 10%, the test was repeated as many times as needed to meet this 10% variation criterion. The maximum value of the successive two trials was recorded as the subject's maximum voluntary strength and 2- min rest intervals were given between each exertion, again in accordance with Caldwell *et al.* (1974) and Kroemer (1970). The subjects were not given any feedback during the exertion and

anything that can affect the subject's motivation and performance like rewards, competition etc. were avoided (Caldwell *et al.*, 1974).

(i) Hand Torque Strength Measurements in Sitting Posture: For the sitting posture, to minimize effects of the body positions on strength measurements, each subject adopted the testing position recommended by American Society of Hand Therapists (ASHT), where a subject sat upright of the measuring device. By using an adjustable chair, body posture was standardized for each subject. The shoulder was adducted and neutrally rotated, elbow was flexed at 90 degrees, forearm in a neutral position, wrist was between 0 and 30 degrees extension and between 0 and 15 ulnar deviation and in all cases the arm was not supported by the examiner or by an armrest. The legs hung down freely or are directed forward (Figure 4.25 and Figure 4.26).



Figure 4.25. Measurement of hand torque strength while sitting (cylindrical).



Figure 4.26. Measurement of hand torque strength while standing (Ellipsoid, circular, key).

(ii) Hand Torque Strength Measurements in Standing Posture: For the standing position, subjects stood during tests in free posture in order to replicate realistic scenarios (Daams, 1990). The testing device was positioned at each subject's elbow height via height adjustable table. Subjects were encouraged to exert maximal effort during testing, and they did not obtain any visual feedback from the testing device, because visual feedback affects the strength performance (Jung and Hallbeck, 2004). In the Figure 4.27 and Figure 4.28 the position of the subject while exerting hand torque strength was displayed.



Figure 4.27. Measurement of hand torque strength while standing (cylinder).



Figure 4.28. Measurement of hand torque strength while standing (Ellipsoid, circular, key).

The grip methods for each handle are shown in Figures 4.29, 4.30, 4.31 and 4.32.

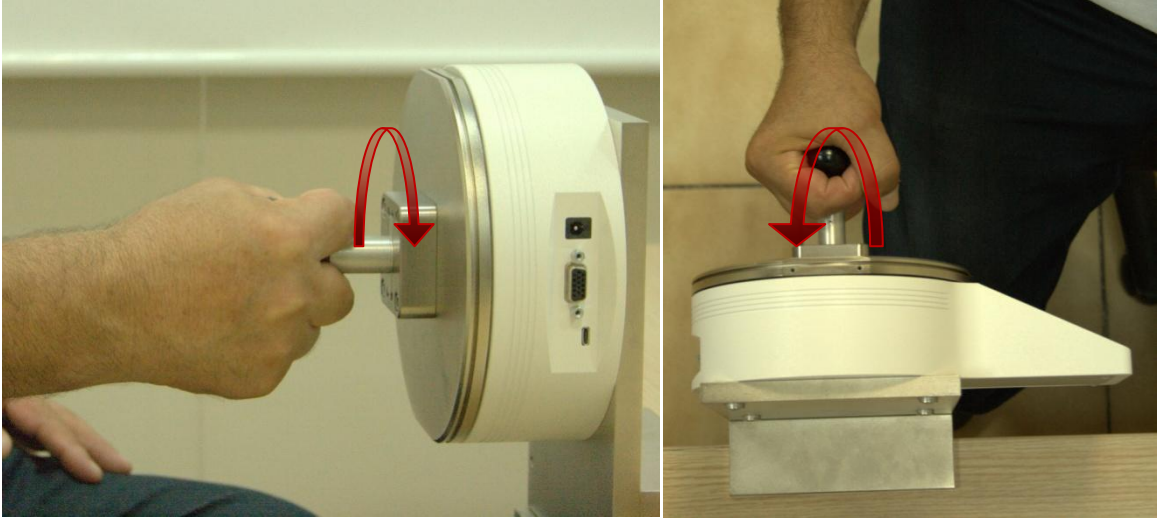


Figure 4.29. Grip method used when manipulating ellipsoid handle (Clockwise).

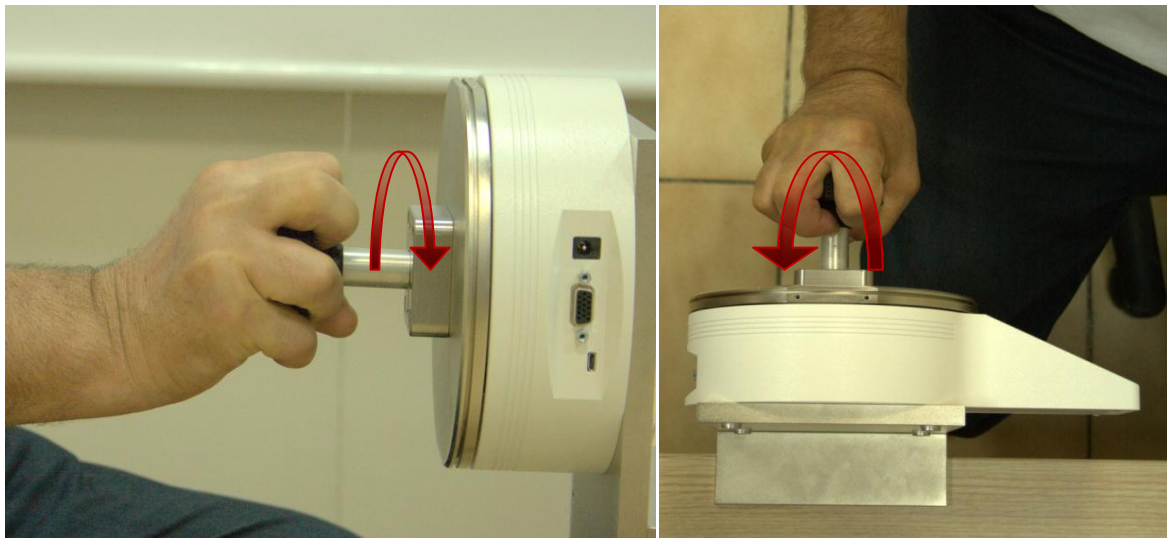


Figure 4.30. Grip method used when manipulating circular handle (Clockwise).

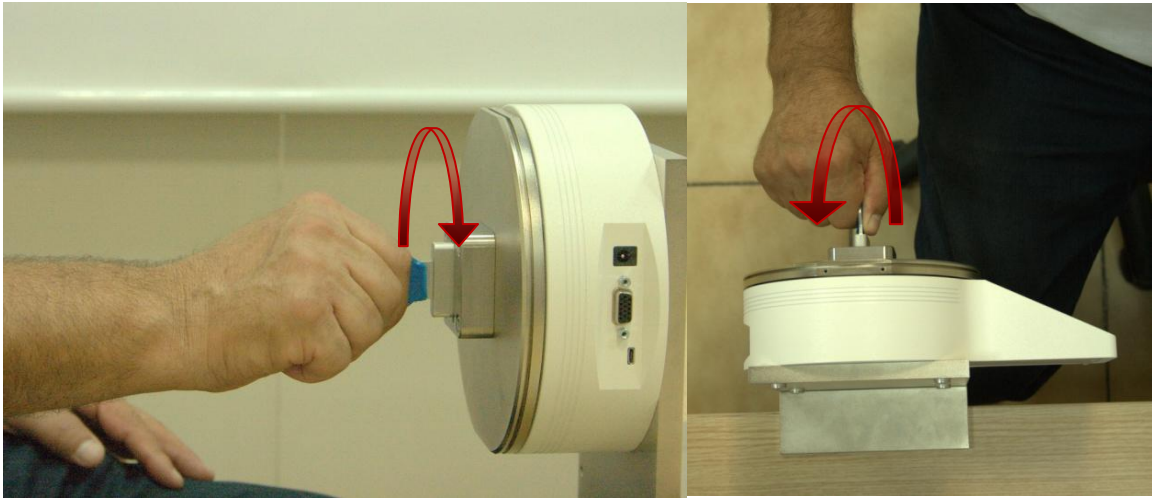


Figure 4.31. Grip method used when manipulating key handle (Clockwise).

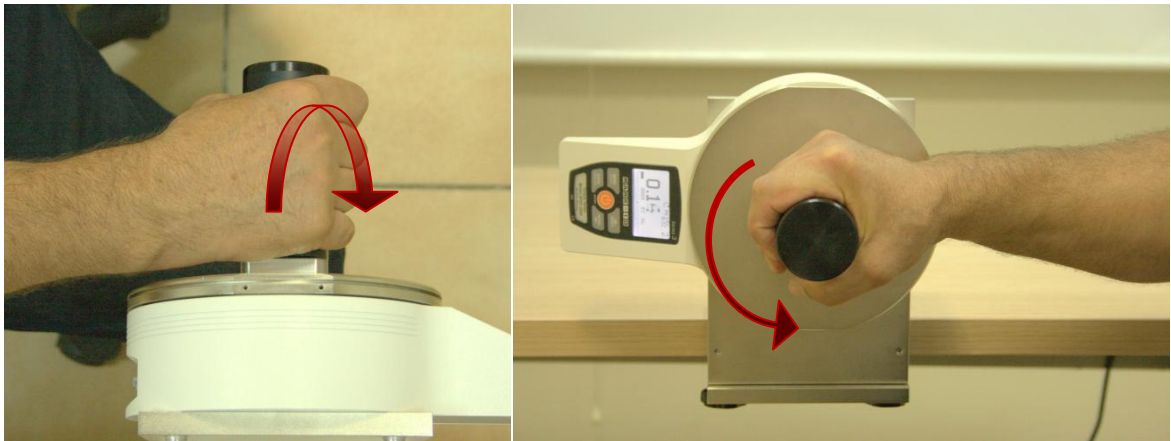


Figure 4.32. Grip method used when manipulating cylindrical handle (Counterclockwise)

The flow chart of the experimental procedure was shown in the Figure 4.33.

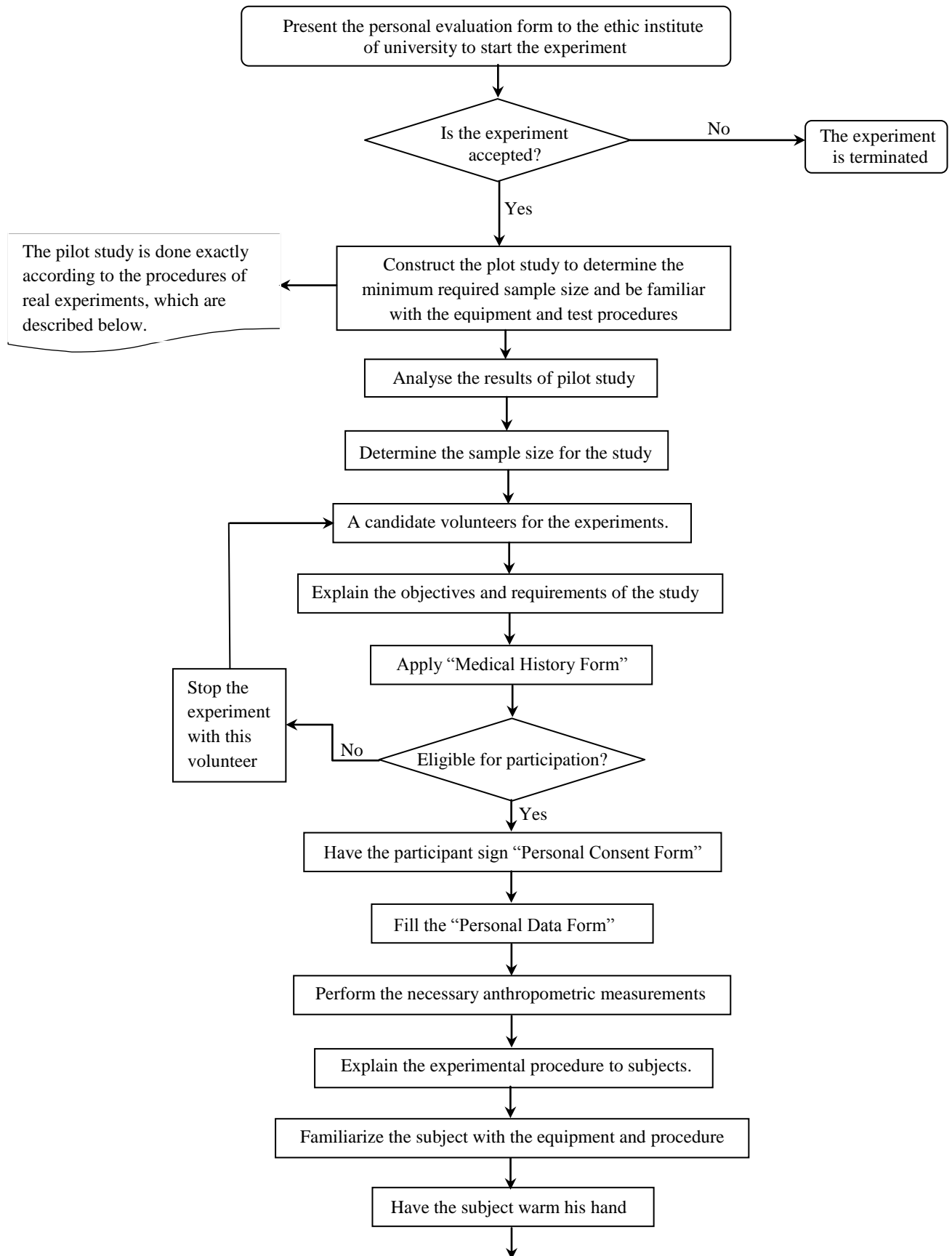


Figure 4.33. Flow chart of the experimental procedure.

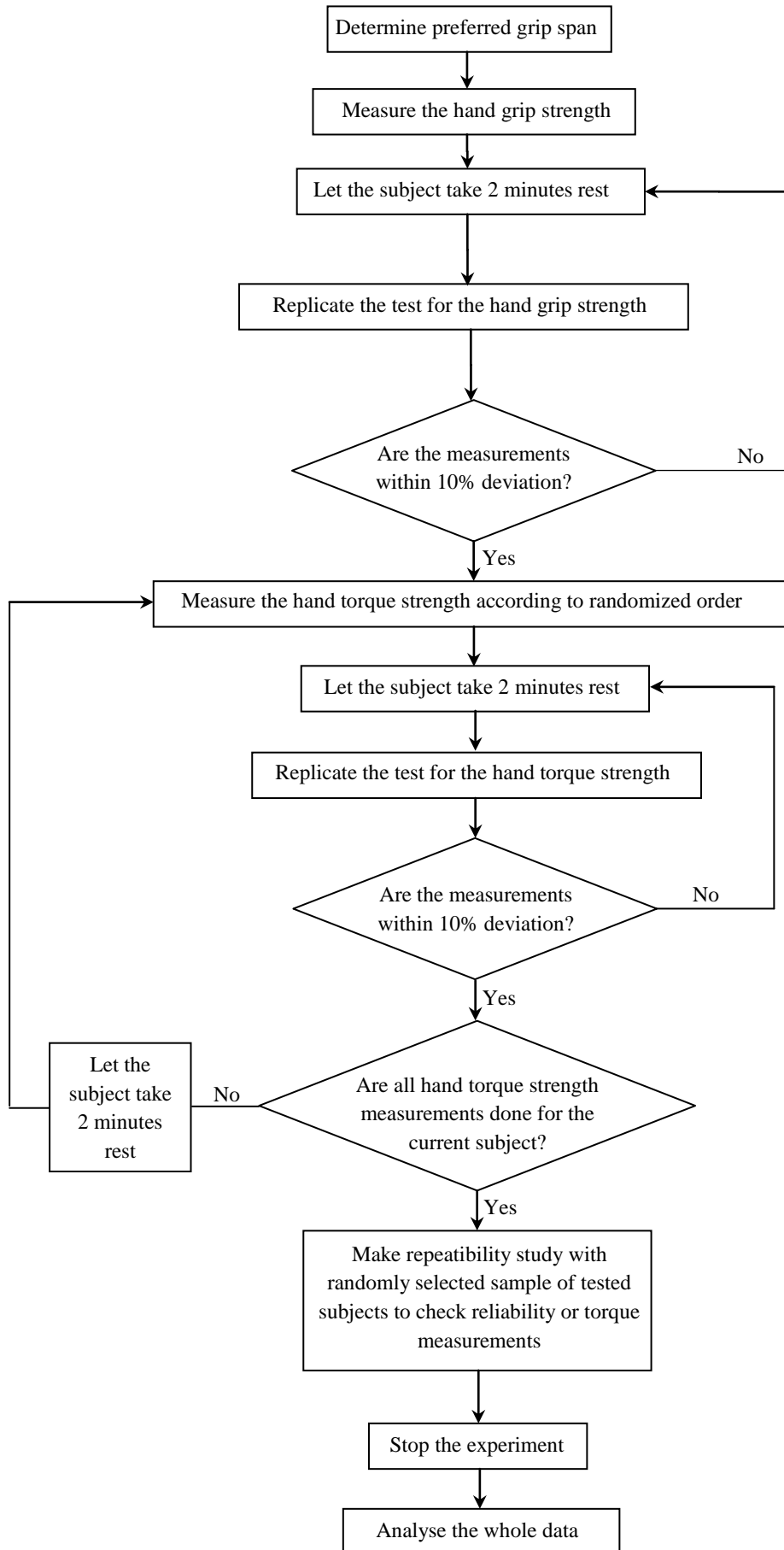


Figure 4.33. Flow chart of the experimental procedure (Cont.).

4.5. Experimental Design and Statistical Analysis

4.5.1. Experimental Variables

The dependent (response) variable for the current study is maximum voluntary static hand torque strength. There are two experimental factors (independent variables) in this study. These factors are posture and handle type. Levels of the factors can be seen in Table 4.6. Characteristics of the subjects like; age-group, job-group and BMI group, are classification factors.

Table 4.6. Design factors and levels of these factors.

	Design Factors	Number of Levels	Levels
Experimental	Posture	2	(1) Sitting (2) Standing
	Hand Tool	4	(1) Ellipsoid Handle (2) Circular Handle (3) Key Handle (4) Cylinder Handle
Classification	Job group	2	(1) Manual worker (2) Non-manual worker
	Age Group	5	(1) 18-29 yrs. (2) 30-39 yrs. (3) 40-49 yrs. (4) 50-59 yrs. (5) 60-69 yrs.
	BMI group	3	(1) Underweight (2) Normal (3) Overweight

4.5.2. Experimental Conditions

Eight different treatment combinations (4 handle type \times 2 postures) were performed by each subject to measure dominant hand's maximum voluntary hand torque strength. Each strength test was performed at least twice according to the Caldwell protocol. For each test, each subject performed eight different test conditions randomly. There were 257 male subjects. Therefore the number of recorded hand torque strength data points (test

runs) was at least $257 * 8 * 2 = 4112$ (Table 4.7). However, the number of strength data points considered for analysis is $4112 / 2 = 2056$. The orders and response data for each condition were recorded in Experimental Conditions Form that can be seen in Appendix B.

Table 4.7. Experimental conditions.

	Posture															
	Sitting								Standing							
	Ellipsoid		Circular		Key		Cylinder		Ellipsoid		Circular		Key		Cylinder	
Subject no	Trails		Trails		Trails		Trails		Trails		Trails		Trails		Trails	
	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
.
.
.
256	4081	4082	4083	4084	4085	4086	4087	4088	4089	4090	4091	4092	4093	4094	4095	4096
257	4097	4098	4099	4100	4101	4102	4103	4104	4105	4106	4107	4108	4109	4110	4111	4112

4.5.3. Experimental Model

4.5.3.1. Randomized complete block design. The randomized complete block design with subjects serving as blocks was considered convenient for this experimental study. Randomization is necessary to avoid the effects of uncontrolled and unknown nuisance factors in the experiments. When nuisance source of variability is known and controllable, blocking can be used to eliminate its effect on the statistical comparisons among treatments (Montgomery, 2005). The power of the test can be increased by removing the effects of different subjects on hand torque strength by blocking on the subjects. By doing this blocking, smaller differences between factor effects can be detected (Montgomery, 2005). In the model, interaction effects between treatments were neglected and only main effects were taken into consideration. Because after running ANOVA for males, all interaction effects were found non-significant since their p-values were higher than the significance level of 0.05. Therefore, for this case, the reduced statistical model for randomized block design with no interaction is:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \tau_k + \varepsilon_{ijk} \quad (4.1)$$

- y_{ijk} : ijk^{th} maximum voluntary hand torque strength
- μ : The overall response mean (Mean of max. voluntary hand torque strength mean)
- α_i : The effect of i^{th} level of posture
- β_j : The effect of the j^{th} level of handle type
- τ_k : The effect of the k^{th} block (subject)
- ε_{ijk} : Random sampling error NID $(0, \sigma^2)$

for

$i = 1,2$ (posture)

$j = 1,2,3,4$ (handle type)

$k = 1,2,3,4, \dots, 257$ (subject)

The hypothesis of interest is:

$$H_0 = \mu_1 = \mu_2 = \dots = \mu_8$$

$H_1 =$ at least one μ_{ij} is different

4.5.3.2. Completely randomized design. For classification factors (age group, job group and BMI group) a separate ANOVA was conducted so as to determine their effects on hand torque strength. After running ANOVA in Minitab, all interaction effects were also found non-significant with p-values higher than significance level. Thus, in the regression model, interaction effects were neglected and only main effects were considered.

Therefore, the model for complete randomized design was determined as following:

$$y_{klm} = \mu + \delta_k + \varphi_l + \vartheta_m + \varepsilon_{klm} \quad (4.2)$$

where,

- y_{klm} : klm^{th} Response (maximum voluntary hand torque strength: TS)
- μ : The overall response mean (Mean of max. voluntary hand torque strength mean)
- δ_k : Effect of k^{th} level of body mass index (BMI) group factor

φ_l : Effect of l^{th} level of job group factor
 ϑ_m : Effect of m^{th} level of age group factor
 ε_{klm} : Random error component NID $(0, \sigma^2)$

for

$k = 1, 2, 3$ (1: Underweight; BMI < 18.5)
 (2: Normal; $18.5 \leq \text{BMI} \leq 25$)
 (3: Overweight; BMI > 25)

Not: There was no underweight group, so k is taken 2 levels for the analysis.

$l = 1, 2$ (1: Manual workers)
 (2: Non-manual workers)

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

The hypothesis of interest is:

$$H_0 = \mu_1 = \mu_2 = \dots = \mu_{30}$$

$H_1 =$ At least one μ_{klm} is dif.

4.5.4. Pilot Study

A pilot study study with randomly selected 50 male subjects (5 subjects from each age-occupation category) was conducted prior to main experiments. Purposes of the pilot study were as follows:

- (i) Get familiar with equipment and experimental procedures,

- (ii) Obtain the necessary statistical parameter values (mean, standard deviation) in order to determine the required minimum sample size.

The results of the pilot study are shown in Table 4.8.

Table 4.8. Sample Statistics.

	Experimental cond.	\bar{x}	SD	CV
Sitting	Ellipsoid	3.86	0.70	18.13
	Circular	4.65	0.82	17.63
	Key	1.93	0.34	17.62
	Cylindrical	6.42	1.23	19.16
Standing	Ellipsoid	4.11	0.71	17.27
	Circular	4.85	0.81	16.70
	Key	1.97	0.39	19.80
	Cylindrical	6.71	1.11	16.54

4.5.5. Sample Size Determination

In order to make a reliable study in a feasible time period, sample size of the study has to be determined carefully. The sample size must be large enough to receive reliable results and on the other hand it must be small enough to complete the study in a reasonable time.

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

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

where, 1.96 is the critical Z value from a standard normal distribution for a 95% confidence interval, CV is the coefficient of variation, a is the percentage of relative accuracy desired (CI is to be no larger than \pm some percentage of the mean).

CV is defined as the following:

$$CV = \frac{SD}{\bar{x}} \times 100 \quad (4.4)$$

where, \bar{x} is the sample mean and SD is the sample standard deviation.

In the current study, true mean and standard deviation of the population are unknown, so these values are estimated by using the results of the pilot study. Relative accuracy is decided to be at least 5%. Therefore, sample size for males is calculated as in equation 4.1.

In the current study there are eight different treatment combinations which give different strength results from each other. Each of them requires different minimum sample size because of their different coefficient of variation. In practice, however, it is desirable to calculate the minimum sample size for the study using the hand torque strength having the largest CV. When this approach is taken, the calculated sample size will be sufficient for a certain percentage of relative accuracy and 95 % confidence in the worst case, and it will be more than sufficient for all the other hand torque strengths (ISO 15535).

CV values of maximum voluntary torque strength vary for each eight test combinations (Table 4.8), thus, the calculation of required minimum sample sizes vary accordingly (Table 4.9).

In the current study, the maximum CV calculated for Ellipsoid handle with standing posture. Entering these data into equation above, the sample sizes are calculated (Table 4.9).

The highest minimum sample size value is calculated at key handle and standing position as 142 subjects. As can be seen in Table 4.9 by measuring 142 male subjects, it can be ensured that the desired levels of relative accuracy and confidence are achieved for all the variables.

Table 4.9 Minimum sample size for 95 % confidence and 5 % relative accuracy

Sitting	Ellipsoid	$N = \left(\frac{1.96 \times 18.13}{5} \right)^2 \times 1.534^2 = 118.92 \approx 119$
	Circular	$N = \left(\frac{1.96 \times 17.63}{5} \right)^2 \times 1.534^2 = 112.45 \approx 113$
	Key	$N = \left(\frac{1.96 \times 17.62}{5} \right)^2 \times 1.534^2 = 112.22 \approx 113$
	Cylindrical	$N = \left(\frac{1.96 \times 19.16}{5} \right)^2 \times 1.534^2 = 132.73 \approx 133$
Standing	Ellipsoid	$N = \left(\frac{1.96 \times 17.27}{5} \right)^2 \times 1.534^2 = 107.91 \approx 108$
	Circular	$N = \left(\frac{1.96 \times 16.70}{5} \right)^2 \times 1.534^2 = 100.86 \approx 101$
	Key	$N = \left(\frac{1.96 \times 19.80}{5} \right)^2 \times 1.534^2 = 141.72 \approx \mathbf{142}$
	Cylindrical	$N = \left(\frac{1.96 \times 16.54}{5} \right)^2 \times 1.534^2 = 98.95 \approx 99$

4.5.6. Repeatability Study

Repeatability or test-retest reliability is another significant issue for an experiment. Repeatability can be determined by calculating the maximum deviation between measurements under the same conditions and with the same measuring instrument. A repeatability study was done to ensure the reliability of measurements.

In order to test the repeatability, 20 subjects from different age and job groups performed the strength tests once more at least a week later from the first trial. For repeatability, it was tested whether the difference between the means of first and second

trails is smaller than 0.5 Nm. The result of the paired t-test indicated that the difference between the means of first and second trails is smaller than the determined limit 0.5 Nm.

Table 4.10. Result of paired t-test for repeatability study.

	N	Mean	St Dev.	SE Mean	T-value	P-value
1. Trails	160	4.35	1.79	0.14	-49.12	< 0.001
2. Trails	160	4.44	1.78	0.14		
Difference	160	-0.09	0.15	0.01		

The hypothesis was: H0: Difference = 0.5, H1: Difference < 0.5

So the null hypothesis was rejected and alternative hypothesis was accepted. This result confirmed that difference between the means of two trails is smaller than 0.5 Nm.

4.5.7. Statistical Analysis

Statistical Analysis was performed using Minitab 16.0. In the analysis, p-values ≤ 0.05 were accepted as significant and $0.05 < \text{p-values} \leq 0.1$ were accepted as marginal. For descriptive statistics: mean, standard deviation, range, confidence intervals, percentages and and correlation coefficients were calculated. For inferential statistics: Analysis of variance (ANOVA) was used to investigate the effects of age, handle type, job, BMI range and posture factors on hand torque strength. However, in order to use ANOVA, the following three assumptions must be satisfied:

4.5.7.1. ANOVA Assumptions.

(i) Normality assumption: The error terms (residuals) of the model must follow a normal distribution centered at zero ($\varepsilon \sim \text{NID Normal}(0, \sigma^2)$). Check of normality can be made by plotting a histogram of the residuals. If the NID $(0, \sigma^2)$ assumption on the errors is satisfied, this plot should look like a sample from a normal distribution centered at zero. Moreover, in order to be sure quantitatively from normality Anderson Darling normality test was used. The hypotheses for the Anderson Darling test are:

$$\begin{aligned} H_0 &: \text{The data follow normal distribution} \\ H_1 &: \text{The data do not follow normal distribution} \end{aligned} \tag{4.5}$$

If the p-value for the Anderson Darling test is lower than significance level (0.05), conclude that the data do not follow the normal distribution.

(ii) Independence assumption: Independence assumption requires no correlation between error terms and no correlation between independent variables and error terms. In order to examine the correlation between the residuals, the plot of residuals versus time order can be helpful. A tendency to have runs of positive and negative residuals indicates positive correlation. This would imply that the independence assumption on the errors has been violated. This is potentially serious problem and one that is difficult to correct, so it is important to prevent the problem if possible when the data are collected. Proper randomization of the experiment is an important step in obtaining independence. (Montgomery, 2005)

Moreover, autocorrelation between residuals, and Pearson's correlation coefficients between independent variables and residuals were calculated for males in order to determine the independence. The plot of the residuals versus observation order for males is investigated to determine whether there is any correlation between residuals. According to the plots there is no correlation between residuals. Also, the results of the Pearson correlation between independent variables and residuals indicated that there is no correlation.

(iii) Homogeneity of variance assumption: The variances of response variables for each treatment must be equal to satisfy this assumption. Any violation of this assumption may lead to serious problems with the results of analysis. If the model is correct and if the assumptions are satisfied, the residuals should be structureless; in particular, they should be unrelated to any variable including the predicted response. A simple check is to plot the residuals versus the fitted values. (Montgomery, 2005)

Firstly, normality of the residuals of hand torque strength data of male subjects were tested by using Anderson-Darling normality test which is one of the three general

normality tests designed to detect all departures from normality. With p value 0.01 normal probability plot of the residuals for males is found following approximately normal distribution.

Secondly, autocorrelation between residuals, and Pearson's correlation coefficients between independent variables and residuals were calculated for males, to check the independence assumption. The plot of the residuals versus observation order for males is investigated to determine whether there is any correlation between residuals. According to the plots there is no correlation between residuals. In addition, the results of the Pearson correlation coefficients between independent variables and residuals show that there is no correlation between them.

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 males. According to the plots and the result of Bartlett's test this assumption is also satisfied for four different handle types.

Since the three assumptions of ANOVA are approximately meeting, it was used to investigate whether the independent variables have an influence on hand torque strength of males.

4.5.7.2. Multiple Comparisons. For the significant ANOVA, 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):

$$\begin{aligned} H_0: \mu_i &= \mu_j \\ H_1: \mu_i &\neq \mu_j \end{aligned} \tag{4.6}$$

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):

$$q = \frac{\bar{y}_{max} - \bar{y}_{min}}{\sqrt{MS_E/n}} \quad (4.7)$$

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):

$$T_\alpha = \frac{q_\alpha(a,f)}{\sqrt{2}} \sqrt{MS_E \left(\frac{1}{n_i} + \frac{1}{n_j} \right)} \quad (4.8)$$

where $q_\alpha(a, f)$ is the upper α percentage points of studentized range statistics (q), f is the number of degrees of freedom associated with the MS_E , α is the number of groups will be compared, n_i and n_j are the sample sizes of the groups.

Two sample t-test was used to compare the results of the current study with the results of the studies done before.

4.5.7.3. Regression Analysis. Following the ANOVA and multiple comparison tests, regression analysis was made to develop prediction equations for hand torque strengths of males. In the ANOVA analysis, the interactions between independent variables were found non-significant. That's why, a no-interaction multiple linear regression model was determined as a suitable model for the analysis. Stepwise approach was adopted during the statistical analysis. Stepwise regression approach is a method which systematically adds the most significant variable to the model and removes the least significant variable in each step. 0.01 was selected for the level of significance. Moreover, Best subsets approach was used as a second check of the model developed by stepwise regression. In the Best subsets approach, it gives many different alternative sub-models with Mallows' cp statistics to compare them. The general form of the multiple regression equation is as the following (Montgomery, 2005):

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \cdots + \beta_kx_k + \varepsilon \quad (4.9)$$

where, y is the response (Hand torque strength), β_0 is constant, β_1, β_2, \dots , are the regression coefficients for independent variables, x_1, x_2 are the regression variables and ε is the error term (normally and independently distributed, $\approx \text{NID}(0, \sigma^2)$)

Regression Assumptions: In order to set a reliable regression models, some assumptions must be satisfied. Before starting the regression analysis, the following assumptions must be checked (Montgomery, 2005):

- *Linearity:* The relationship between the dependent and independent variables must be linear. This assumption can be checked by utilizing fitted line plots. Multiple regression procedures are not greatly affected by minor deviations from this assumption.
- *Normality:* The residuals of the independent variables must be normally distributed. This assumption can be checked by looking at the normal probability plots of residuals.
- *Multicollinearity:* Multicollinearity must not exist because if exists, it means that there are redundant variables in the regression. This can be checked by looking at the variance inflation factor (VIF). VIF is desired to be smaller than 5.
- *Variance homogeneity:* The variances within groups must be equal. Bartlett's test and residual analysis can be used to check this assumption.
- *Autocorrelation:* There must not be correlation between the errors because correlation affects the estimation of coefficients for the regression. Durbin-Watson statistic is used to verify this assumption. It is desired to be between 1.5 and 2.5.

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

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

$$\begin{aligned} H_0: \beta_1 = \beta_2 = \dots = \beta_n = 0 \\ H_1: \beta_j \neq 0 \text{ for at least one } j (j = 1, \dots, n) \end{aligned} \tag{4.10}$$

The hypothesis above checks the significance of regression coefficients. If the p-value is less than α significance level, the null hypothesis H_0 is rejected, which implies that at least one of the regressor variables contributes significantly to the model (Montgomery, 2005). Moreover R^2 and R_{adj}^2 values were examined to see the goodness of fit of the regression model. While determining the appropriate regression model, R_{adj}^2 values and Mallows' cp statistics were used.

5. RESULTS

5.1. Overview

In this section the collected data were analysed and documented. Respectively, descriptive statistics of subjects, descriptive statistics of hand torque strength, correlation analysis, analysis of variance results and multiple comparisons, and regression analysis were covered in detail.

5.2. Descriptive Statistics

5.2.1. Summary Statistics

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

Table 5.1. Characteristics of male participants.

Measurements	Mean \pm SD	Min-Max
Age (years)	44.46 \pm 14.36	18 - 69
Stature (cm)	173.98 \pm 6.37	155 - 195
Weight (kg)	81.77 \pm 12.56	53.4 - 130
Dominant Hand Length (cm)	18.58 \pm 0.85	16.5 - 21
Dominant Hand Breadth (cm)	9.10 \pm 0.51	8.0 - 10.7
Dominant Hand, Circumference of Wrist (cm)	18.11 \pm 1.03	15.5 - 21
Dominant Hand, Circumference of Forearm (cm)	28.64 \pm 2.12	23 - 36.5

Table 5.2 represents descriptive statistics (mean, standard deviation (SD) and range (min - max)) of males of the maximum voluntary static hand grip strength (in N) and maximum voluntary hand torque strength (in Nm) (for eight different test combinations) by age and occupation for dominant hand.

Table 5.3 represents descriptive statistics (mean, standard deviation (SD) and range (min - max)) of males of the maximum voluntary static hand grip strength (in N) and maximum voluntary hand torque strength (in Nm) (for eight different test combinations) by age for dominant hand.

Table 5.4 represents 95% confidence intervals for mean of the maximum voluntary static hand grip strength (in N) and maximum voluntary hand torque strength (in Nm) (for eight different test combinations) by age and occupation for dominant hand.

Results indicate that manual workers are stronger than non manual workers in all handles at both sitting and standing postures.

It can be seen from Table 5.2 that the hand torque strength peaks between 40-49 years for both non-manual and manual workers for all handles except cylindrical handle. For cylindrical handle peak torque strength was obtained at 18-29 age group. However, the oldest age group (60-69 years) has lower hand torque strength than other age groups for all four handles.

Table 5.2 and 5.3 indicate that mean values of hand torque strength for cylindrical handle are the highest while mean values of hand torque strength for key handle is the lowest.

Figure 5.1 shows hand torque strength distributions for eight different test combinations. The distributions are fairly normal.

Table 5.2. Descriptive statistics of Hand Grip Strength (in N*) and eight different Hand torque strengths (in Nm *) by age and occupation.

Occupation by age group	n	Grip Strength	Sitting				Standing			
			Ellipsoid	Circular	Key	Cylindrical	Ellipsoid	Circular	Key	Cylindrical
All	257	370.06 ± 93.74 166.71 - 804.15	4.12 ± 1.09 1.52 - 8.06	4.83 ± 1.12 2.16 - 8.02	1.97 ± 0.38 0.79 - 3.42	6.87 ± 1.82 2.81 - 11.7	4.25 ± 1.12 1.37 - 7.34	5.10 ± 1.28 2.15 - 9.43	2.05 ± 0.45 0.94 - 4.06	7.07 ± 1.87 3.07 - 12.20
Manual	132	385.95 ± 95.50 196.13 - 804.15	4.43 ± 1.14 1.52 - 8.06	5.15 ± 1.08 2.24 - 7.92	2.06 ± 0.39 1.14 - 3.42	7.31 ± 1.65 3.96 - 11.00	4.49 ± 1.19 1.37 - 7.34	5.45 ± 1.31 2.74 - 9.43	2.12 ± 0.45 0.97 - 4.06	7.49 ± 1.74 4.28 - 12.20
18-29 yrs.	25	469.54 ± 104.37 333.43 - 804.15	4.02 ± 1.16 1.86 - 6.27	4.92 ± 1.17 2.24 - 7.92	1.99 ± 0.43 1.14 - 2.86	8.28 ± 1.37 5.50 - 10.97	4.09 ± 1.45 2.12 - 7.34	5.20 ± 1.21 2.76 - 8.58	2.10 ± 0.54 1.22 - 3.14	8.96 ± 1.57 5.82 - 12.20
30-39 yrs.	25	427.96 ± 85.95 323.62 - 686.47	4.45 ± 1.20 1.52 - 6.49	5.23 ± 0.95 3.61 - 6.80	2.11 ± 0.46 1.30 - 2.74	8.25 ± 1.54 5.38 - 11.00	4.60 ± 1.29 2.10 - 6.78	5.65 ± 1.42 3.68 - 9.43	2.22 ± 0.38 1.37 - 2.76	8.38 ± 1.54 4.96 - 11.00
40-49 yrs.	25	379.32 ± 79.71 196.13 - 529.56	4.90 ± 1.33 2.12 - 8.06	5.58 ± 1.27 2.82 - 7.72	2.13 ± 0.39 1.53 - 3.42	7.07 ± 1.41 4.64 - 9.56	5.00 ± 1.01 2.65 - 7.32	5.71 ± 1.45 2.74 - 8.72	2.24 ± 0.53 1.25 - 4.06	7.42 ± 1.57 4.62 - 10.40
50-59 yrs.	32	347.83 ± 58.15 225.55 - 480.53	4.34 ± 1.05 2.31 - 6.31	5.03 ± 0.91 2.69 - 6.66	2.05 ± 0.37 1.2 - 2.76	7.01 ± 1.72 4.11 - 10.63	4.46 ± 1.15 1.37 - 6.35	5.48 ± 1.09 3.35 - 7.53	2.12 ± 0.42 0.97 - 2.90	6.94 ± 1.27 4.58 - 10.70
60-69 yrs.	25	315.77 ± 67.41 205.94 - 451.11	4.46 ± 0.85 2.82 - 6.49	5.03 ± 1.05 3.65 - 7.33	1.99 ± 0.32 1.37 - 2.78	6.04 ± 0.98 3.96 - 8.10	4.32 ± 0.87 2.65 - 6.35	5.2 ± 1.42 3.14 - 8.59	1.94 ± 0.32 1.33 - 2.63	5.93 ± 1.04 4.28 - 8.47
Non-manual	125	353.28 ± 89.18 166.71 - 725.69	3.80 ± 0.93 1.63 - 6.74	4.50 ± 1.07 2.16 - 8.02	1.88 ± 0.36 0.79 - 2.80	6.41 ± 1.89 2.81 - 11.70	3.99 ± 0.98 1.65 - 6.24	4.74 ± 1.13 2.15 - 8.56	1.97 ± 0.45 0.94 - 3.74	6.63 ± 1.91 3.07 - 12.20
18-29 yrs.	25	423.26 ± 98.42 274.59 - 725.69	3.57 ± 1.14 1.63 - 6.74	4.36 ± 1.29 2.16 - 7.09	1.93 ± 0.28 1.41 - 2.71	7.88 ± 2.17 4.76 - 11.18	3.63 ± 1.22 1.65 - 5.97	4.50 ± 1.27 2.15 - 6.52	2.00 ± 0.45 1.11 - 3.32	7.89 ± 2.23 4.44 - 12.20
30-39 yrs.	25	387.56 ± 62.99 294.20 - 519.75	3.86 ± 0.89 2.12 - 6.12	4.61 ± 1.00 2.98 - 7.29	1.84 ± 0.42 0.79 - 2.80	6.55 ± 1.7 3.98 - 9.20	4.04 ± 0.83 2.72 - 5.83	4.81 ± 1.08 3.12 - 6.81	1.94 ± 0.40 1.25 - 2.90	6.71 ± 1.92 4.15 - 11.20
40-49 yrs.	25	373.83 ± 59.54 254.97 - 529.56	4.29 ± 0.90 2.33 - 5.66	4.80 ± 0.98 3.51 - 8.02	2.03 ± 0.29 1.58 - 2.63	7.18 ± 1.64 4.72 - 11.70	4.44 ± 0.85 3.00 - 6.16	5.40 ± 1.24 3.90 - 8.56	2.20 ± 0.56 1.53 - 3.74	7.33 ± 1.73 4.56 - 12.20
50-59 yrs.	25	305.58 ± 70.07 166.71 - 470.72	3.74 ± 0.73 2.41 - 5.59	4.48 ± 1.01 2.53 - 7.10	1.85 ± 0.36 1.22 - 2.53	5.62 ± 1.05 4.04 - 8.66	4.10 ± 0.96 2.51 - 6.24	4.70 ± 1.08 2.74 - 6.92	1.95 ± 0.36 0.94 - 2.67	5.95 ± 1.04 4.34 - 8.38
60-69 yrs.	25	276.16 ± 60.43 205.94 - 392.27	3.52 ± 0.79 1.96 - 5.21	4.24 ± 1.00 2.80 - 6.74	1.76 ± 0.37 1.14 - 2.71	4.82 ± 0.97 2.81 - 7.04	3.74 ± 0.81 2.36 - 5.04	4.29 ± 0.62 3.31 - 5.72	1.75 ± 0.34 1.08 - 2.33	5.25 ± 1.2 3.07 - 8.54

*N: Newton, *Nm: Newton meter

Table 5.3. Descriptive statistics of dominant hand static grip strength (in N*) and dominant hand static torque strength (in Nm **) by age.

	n	GS	Sitting				Standing			
			Ellipsoid	Circular	Key	Cylindrical	Ellipsoid	Circular	Key	Cylindrical
All	257	370.06 ± 93.74 166.71 - 804.15	4.12 ± 1.09 1.52 - 8.06	4.83 ± 1.12 2.16 - 8.02	1.97 ± 0.38 0.79 - 3.42	6.87 ± 1.82 2.81 - 11.7	4.25 ± 1.12 1.37 - 7.34	5.10 ± 1.28 2.15 - 9.43	2.05 ± 0.45 0.94 - 4.06	7.07 ± 1.87 3.07 - 12.2
18-29 yrs.	50	446.4 ± 103.09 274.59 - 804.15	3.79 ± 1.16 1.63 - 6.74	4.64 ± 1.25 2.16 - 7.92	1.96 ± 0.36 1.14 - 2.86	8.08 ± 1.81 4.76 - 11.18	3.86 ± 1.35 1.65 - 7.34	4.85 ± 1.28 2.15 - 8.58	2.05 ± 0.5 1.11 - 3.32	8.43 ± 1.98 4.44 - 12.2
30-39 yrs.	50	407.76 ± 77.32 294.2 - 686.47	4.16 ± 1.09 1.52 - 6.49	4.92 ± 1.02 2.98 - 7.29	1.97 ± 0.46 0.79 - 2.80	7.4 ± 1.82 3.98 - 11	4.32 ± 1.11 2.1 - 6.78	5.23 ± 1.32 3.12 - 9.43	2.08 ± 0.41 1.25 - 2.90	7.54 ± 1.92 4.15 - 11.2
40-49 yrs.	50	376.58 ± 69.68 196.13 - 529.56	4.6 ± 1.17 2.12 - 8.06	5.19 ± 1.19 2.82 - 8.02	2.08 ± 0.34 1.53 - 3.42	7.12 ± 1.52 4.64 - 11.7	4.72 ± 0.97 2.65 - 7.32	5.56 ± 1.35 2.74 - 8.72	2.22 ± 0.54 1.25 - 4.06	7.37 ± 1.64 4.56 - 12.2
50-59 yrs.	57	329.3 ± 66.51 166.71 - 480.53	4.08 ± 0.97 2.31 - 6.31	4.79 ± 0.99 2.53 - 7.1	1.96 ± 0.38 1.2 - 2.76	6.4 ± 1.61 4.04 - 10.63	4.3 ± 1.08 1.37 - 6.35	5.14 ± 1.15 2.74 - 7.53	2.04 ± 0.4 0.94 - 2.9	6.51 ± 1.27 4.34 - 10.7
60-69 yrs.	50	295.97 ± 66.44 205.94 - 451.11	3.99 ± 0.94 1.92 - 6.49	4.63 ± 1.09 2.80 - 7.33	1.87 ± 0.36 1.14 - 2.78	5.43 ± 1.15 2.81 - 8.10	4.03 ± 0.88 2.36 - 6.35	4.74 ± 1.18 3.14 - 8.59	1.84 ± 0.34 1.08 - 2.63	5.59 ± 1.16 3.07 - 8.54

*N: Newton, *NM: Newton meter

Table 5.4. 95% confidence interval for mean Hand Grip Strength (in N*) and for mean hand torque strengths (in NM*) statistical by posture, handle, job-group and age-group.

Age	n	Grip Strength	Sitting				Standing			
			Ellipsoid	Circular	Key	Cylindrical	Ellipsoid	Circular	Key	Cylindrical
All	257	358.54 - 381.57	3.99 - 4.26	4.70 - 4.97	1.92 - 2.02	6.65 - 7.10	4.11 - 4.39	4.95 - 5.26	1.99 - 2.10	6.84 - 7.30
Manual	132	369.51 - 402.40	4.23 - 4.63	4.96 - 5.34	1.99 - 2.12	7.03 - 7.60	4.29 - 4.70	5.22 - 5.68	2.04 - 2.20	7.19 - 7.79
18-29 yrs.	25	426.46 - 512.63	3.54 - 4.50	4.43 - 5.40	1.82 - 2.17	7.71 - 8.85	3.49 - 4.68	4.70 - 5.70	1.88 - 2.32	8.31 - 9.61
30-39 yrs.	25	392.48 - 463.44	3.96 - 4.95	4.84 - 5.63	1.92 - 2.30	7.62 - 8.88	4.07 - 5.13	5.07 - 6.24	2.06 - 2.38	7.74 - 9.01
40-49 yrs.	25	346.42 - 412.22	4.36 - 5.45	5.06 - 6.10	1.97 - 2.29	6.48 - 7.65	4.59 - 5.42	5.11 - 6.31	2.02 - 2.45	6.77 - 8.06
50-59 yrs.	32	326.87 - 368.80	3.96 - 4.72	4.71 - 5.36	1.92 - 2.19	6.39 - 7.63	4.05 - 4.88	5.09 - 5.87	1.97 - 2.27	6.48 - 7.40
60-69 yrs.	25	287.95 - 343.60	4.10 - 4.81	4.59 - 5.46	1.85 - 2.12	5.64 - 6.45	3.97 - 4.68	4.61 - 5.78	1.81 - 2.07	5.50 - 6.36
Non-manual	125	337.49 - 369.06	3.63 - 3.96	4.31 - 4.69	1.82 - 1.94	6.08 - 6.75	3.82 - 4.16	4.54 - 4.94	1.89 - 2.05	6.29 - 6.97
18-29 yrs.	25	382.63 - 463.88	3.10 - 4.04	3.83 - 4.89	1.81 - 2.04	6.99 - 8.78	3.13 - 4.14	3.98 - 5.03	1.82 - 2.19	6.97 - 8.81
30-39 yrs.	25	361.56 - 413.56	3.50 - 4.23	4.20 - 5.02	1.67 - 2.01	5.85 - 7.25	3.70 - 4.38	4.37 - 5.26	1.77 - 2.10	5.92 - 7.51
40-49 yrs.	25	349.25 - 398.41	3.92 - 4.66	4.39 - 5.21	1.91 - 2.15	6.50 - 7.86	4.08 - 4.79	4.89 - 5.91	1.97 - 2.43	6.62 - 8.05
50-59 yrs.	25	276.65 - 334.50	3.44 - 4.05	4.06 - 4.90	1.70 - 2.00	5.18 - 6.05	3.70 - 4.50	4.25 - 5.15	1.80 - 2.10	5.52 - 6.38
60-69 yrs.	25	251.21 - 301.10	3.20 - 3.85	3.83 - 4.65	1.61 - 1.91	4.42 - 5.22	3.40 - 4.07	4.03 - 4.54	1.61 - 1.89	4.76 - 5.75

*N: Newton, *NM: Newton meter

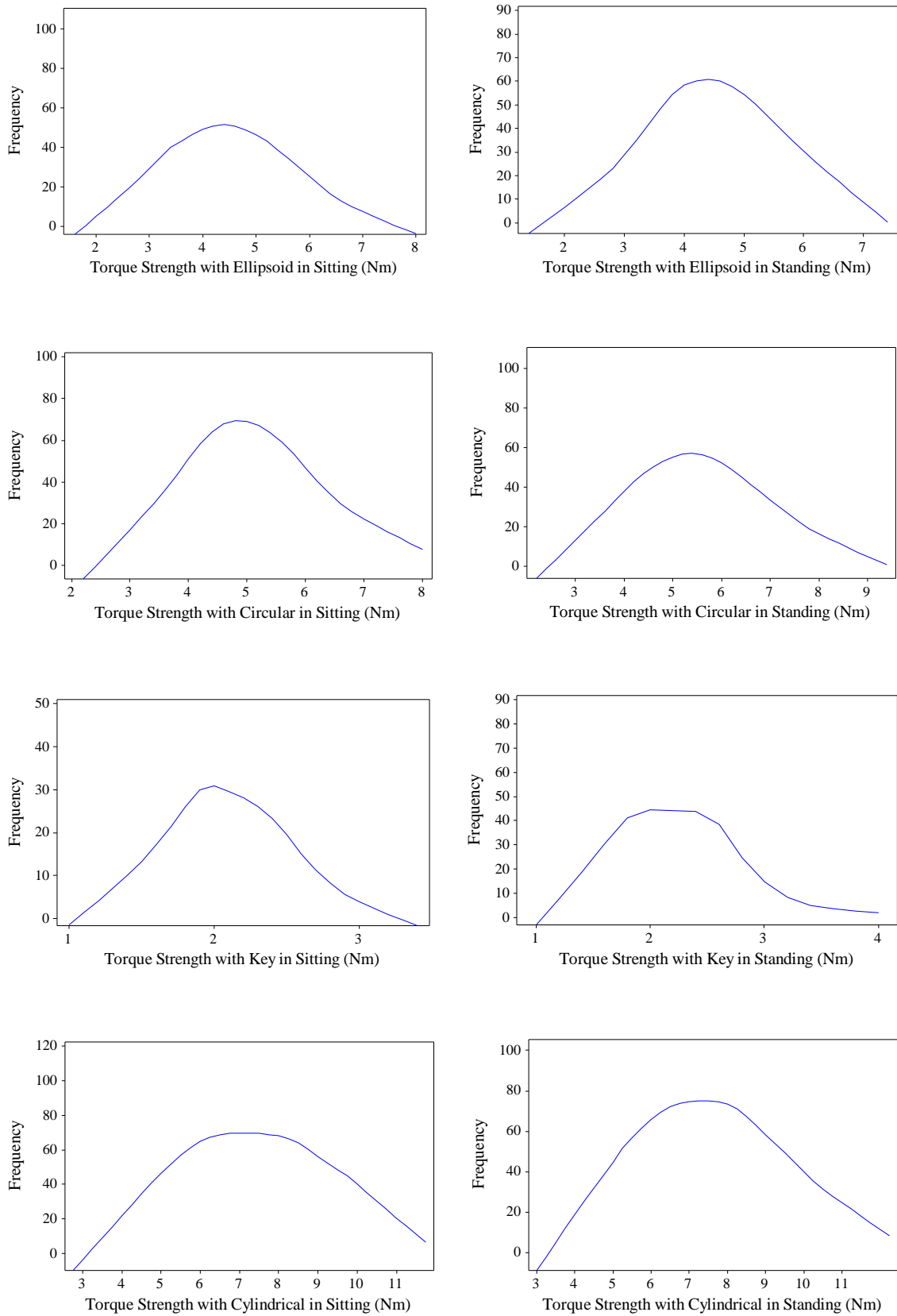


Figure 5.1. Distribution of strength data for eight different strength treatments.

Graphical summary of results for different levels of independent variables are shown by boxplots in Figure 5.2 – 5.32.

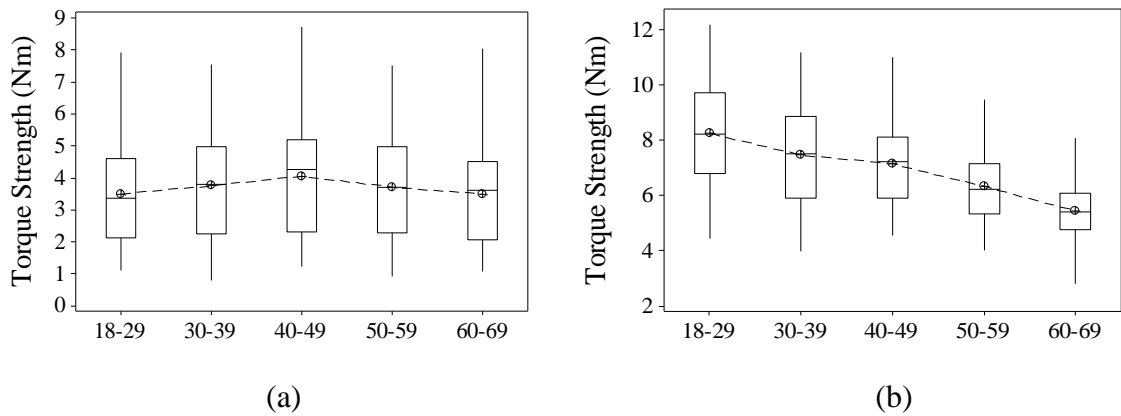


Figure 5.2. Box plot of overall TS for different age groups (a) Ellipsoid, Circular and Key (b) Cylindrical.

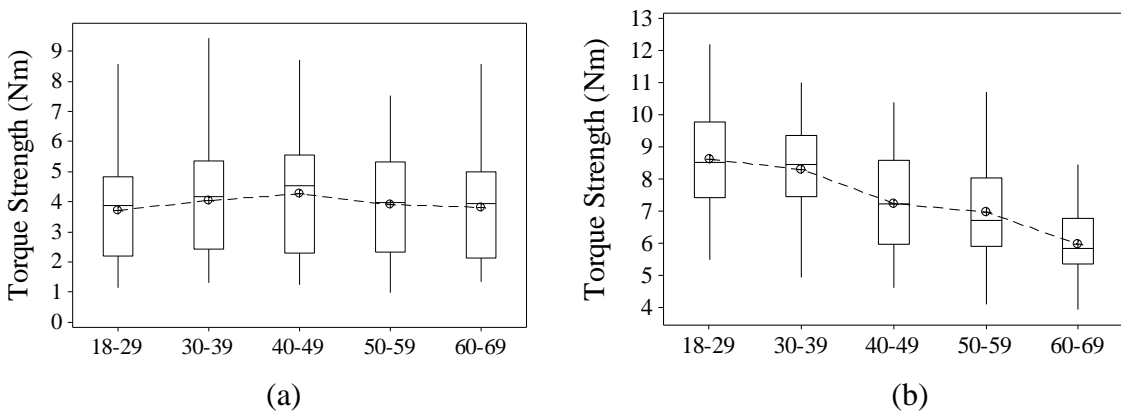


Figure 5.3. Box plot of overall TS of manual workers for different age groups (a) Ellipsoid, Circular and Key (b) Cylindrical.

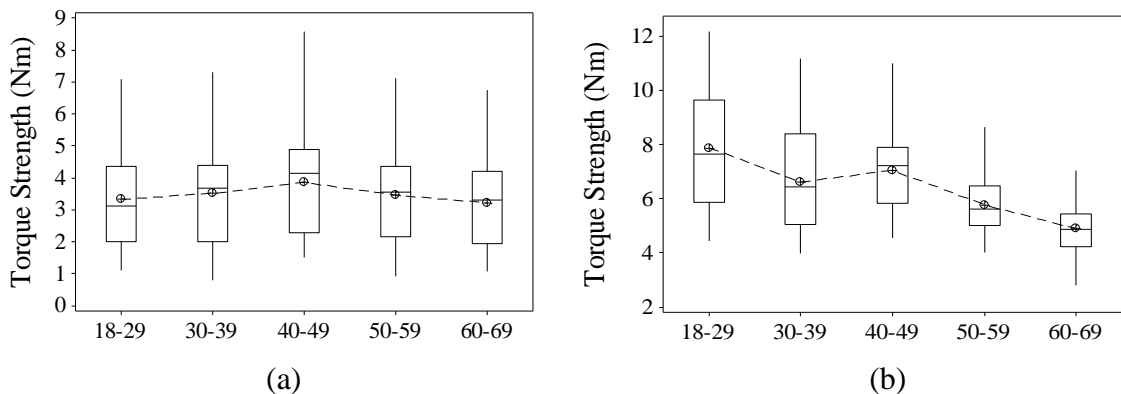


Figure 5.4. Box plot of overall TS of non-manual workers for different age groups (a) Ellipsoid, Circular and Key (b) Cylindrical.

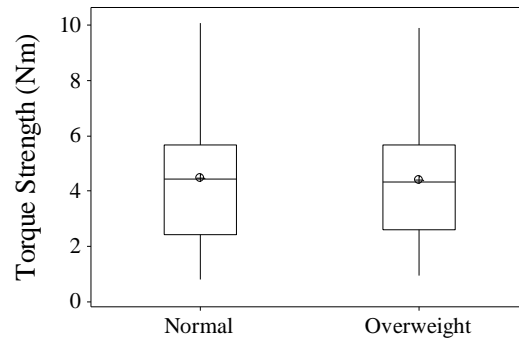


Figure 5.5. Box plot of overall torque strength for BMI groups.

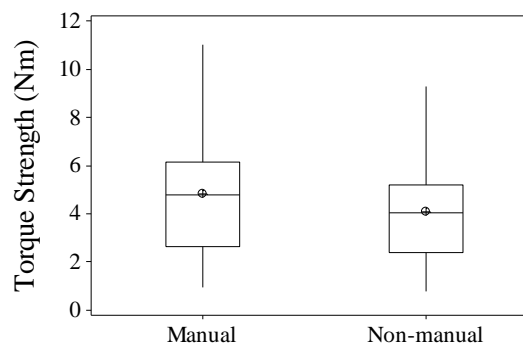


Figure 5.6. Box plot of overall torque strength for job groups.

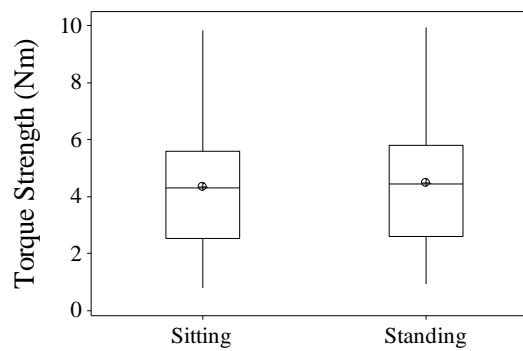


Figure 5.7. Box Plot of overall torque strength for posture groups.

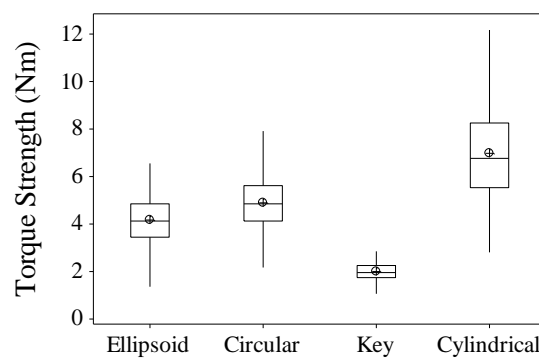


Figure 5.8. Box plot of overall torque strength for different hand tools.

Box plots for eight treatment combinations for different levels of independent variables:

(i) TS with Ellipsoid in Sitting:

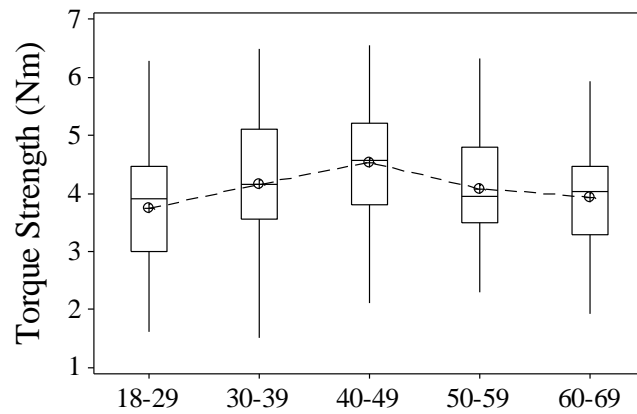


Figure 5.9. Box plot of overall TS with Ellipsoid in sitting for different age groups.

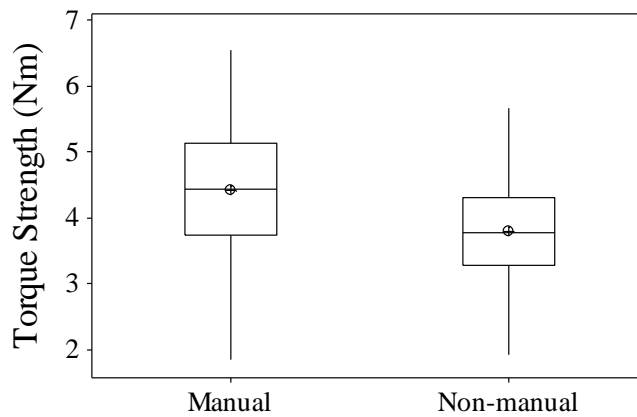


Figure 5.10. Box plot of overall TS with Ellipsoid in sitting for different job groups.

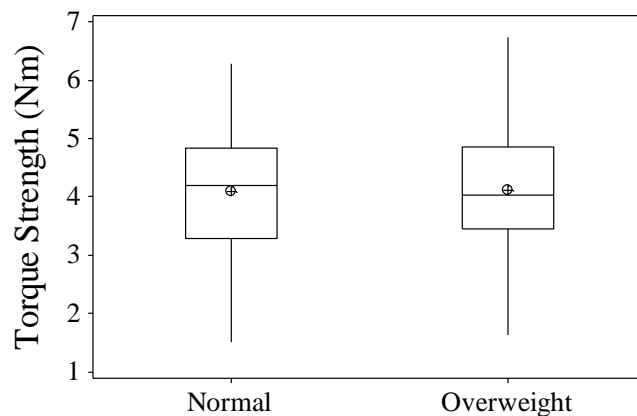


Figure 5.11. Box plot of overall TS with Ellipsoid in sitting for different BMI groups.

(ii) TS with Circular in Sitting:

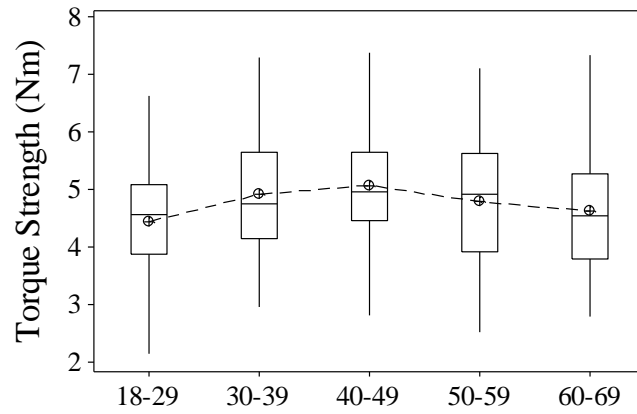


Figure 5.12. Box plot of overall TS with Circular in sitting for different age groups.

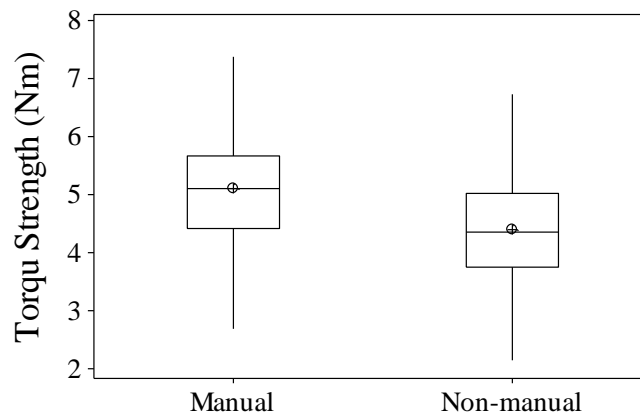


Figure 5.13. Box plot of overall TS with Circular in sitting for different job groups.

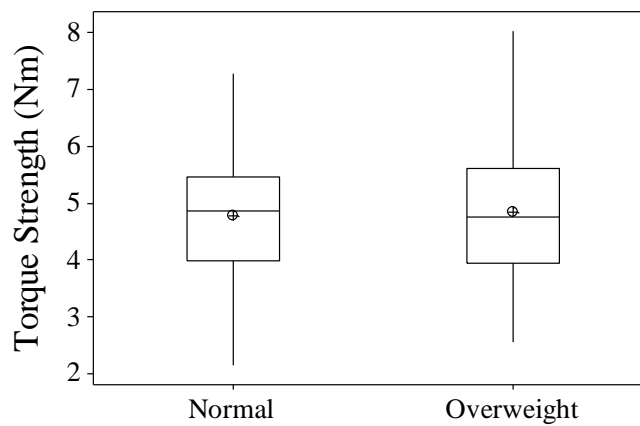


Figure 5.14. Box plot of overall TS with Circular in sitting for different BMI groups.

(iii) TS with Key in Sitting:

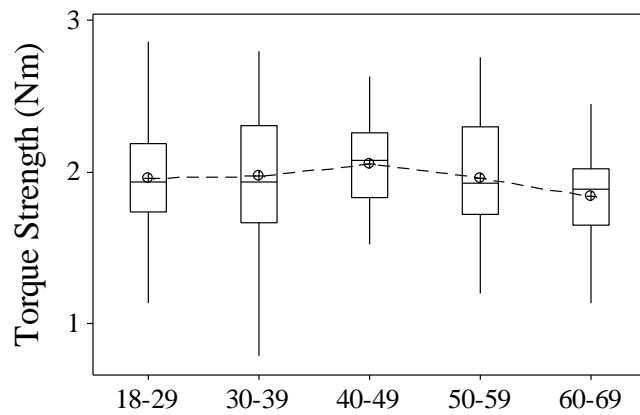


Figure 5.15. Box plot of overall TS with Key in sitting for different age groups.

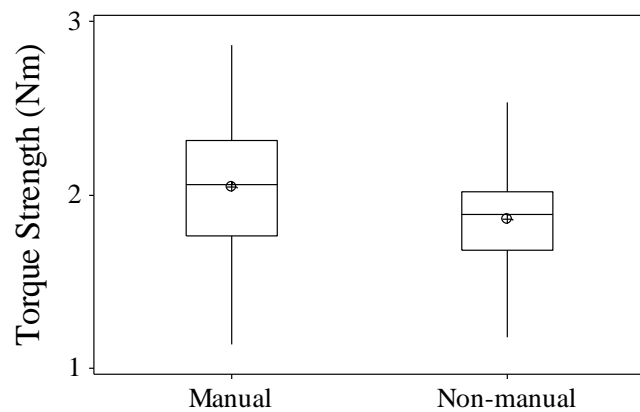


Figure 5.16. Box plot of overall TS with Key in sitting for different job groups.

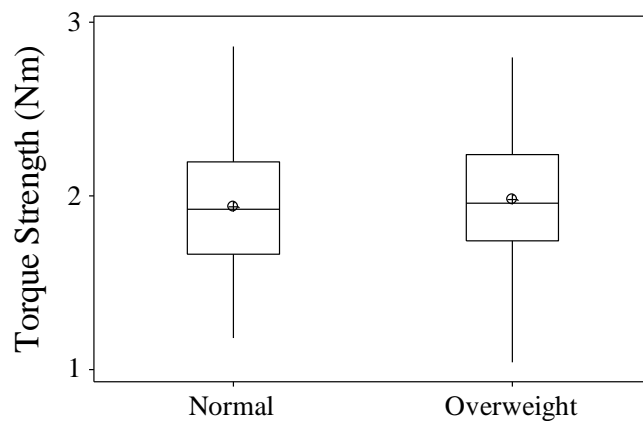


Figure 5.17. Box plot of overall TS with Key in sitting for different BMI groups.

(iv) TS with Cylindrical in Sitting:

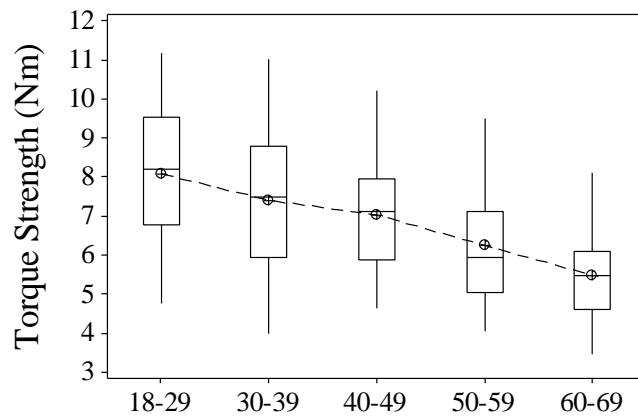


Figure 5.18. Box plot of overall TS with Cylindrical in sitting for different age groups.

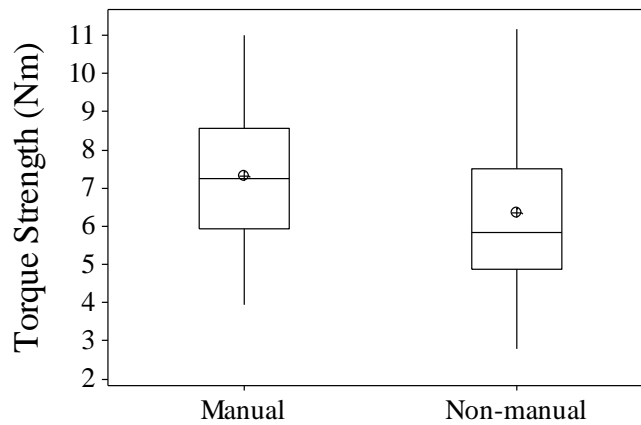


Figure 5.19. Box plot of overall TS with Cylindrical in sitting for different job groups.

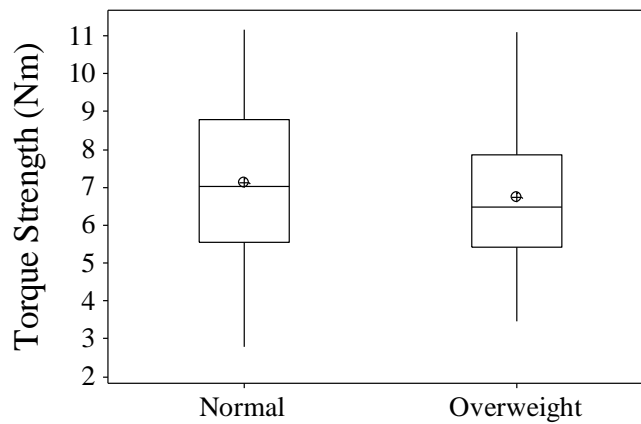


Figure 5.20. Box plot of overall TS with Cylindrical in sitting for different BMI groups.

(v) TS with Ellipsoid in Standing:

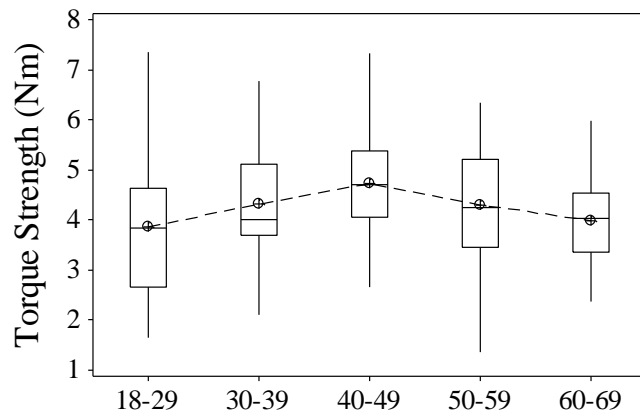


Figure 5.21. Box plot of overall TS with Ellipsoid in standing for different age groups.

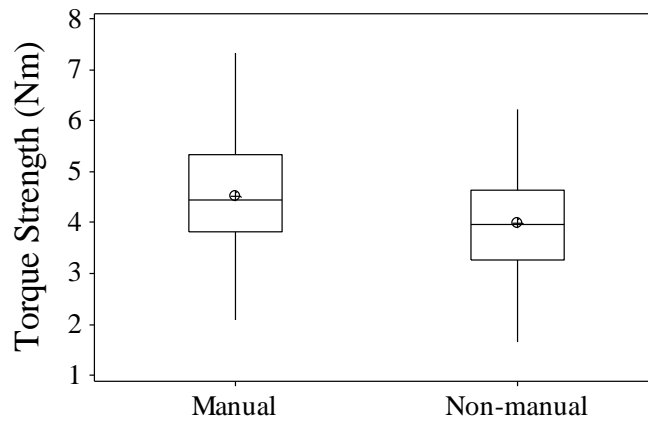


Figure 5.22. Box plot of overall TS with Ellipsoid in standing for different job groups.

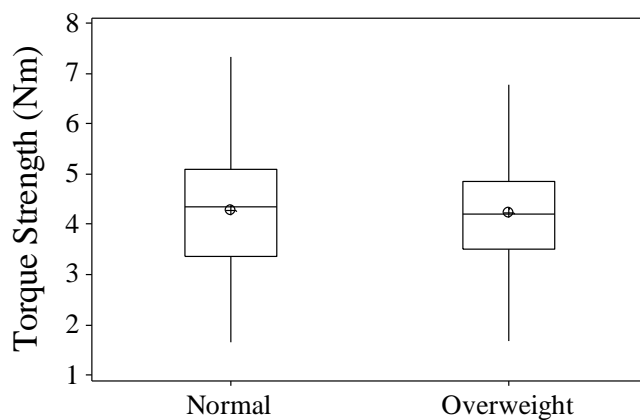


Figure 5.23. Box plot of overall TS with Ellipsoid in standing for different BMI groups.

(vi) TS with Circular in Standing:

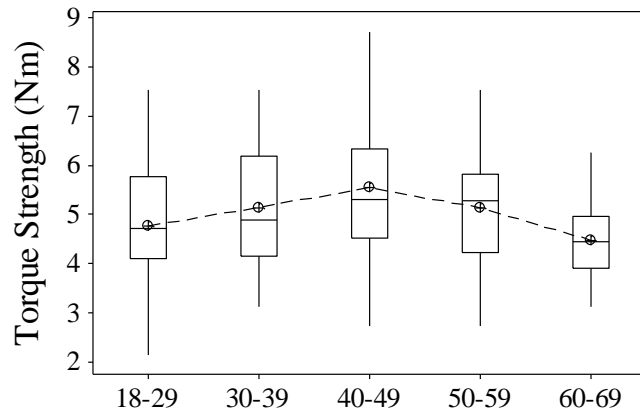


Figure 5.24. Box plot of overall TS with Circular in standing for different age groups.

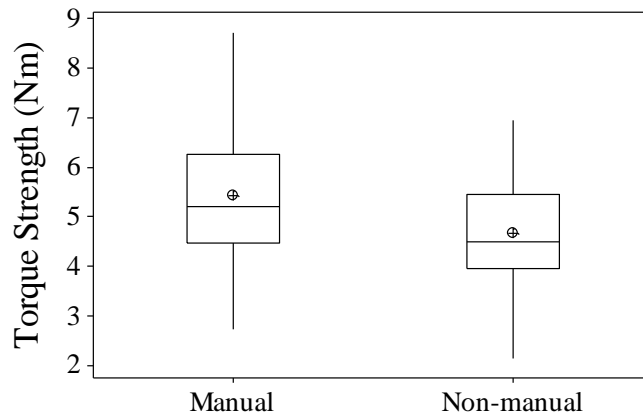


Figure 5.25. Box plot of overall TS with Circular in standing for different job groups.

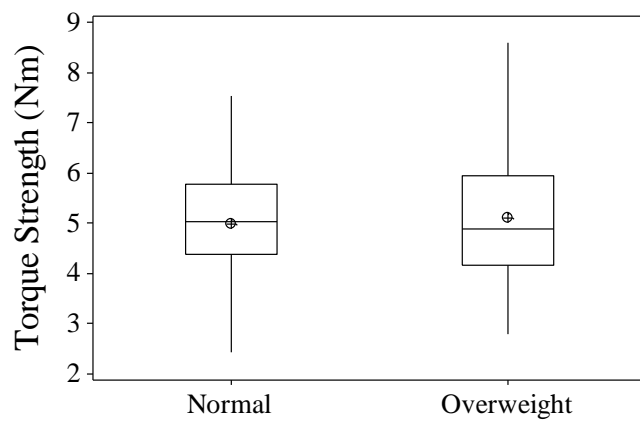


Figure 5.26. Box plot of overall TS with Circular in standing for different BMI groups.

(vii) TS with Key in Standing:

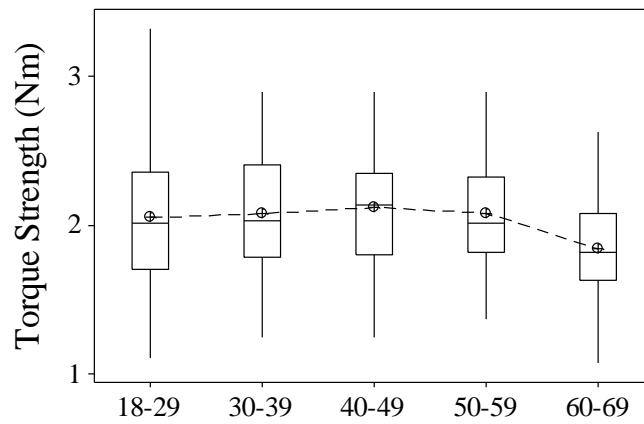


Figure 5.27. Box plot of overall TS with Key in standing for different age groups.

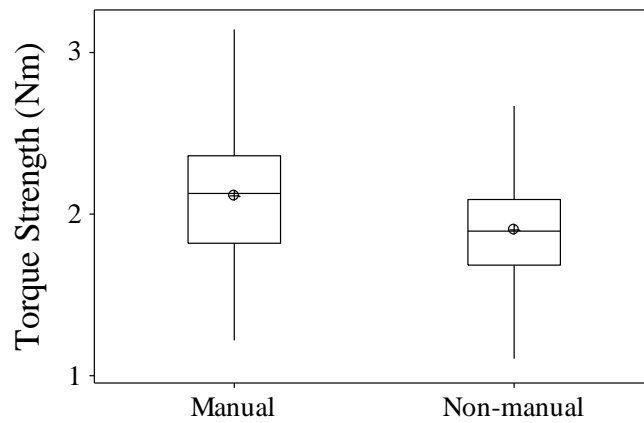


Figure 5.28. Box plot of overall TS with Key in standing for different job groups.

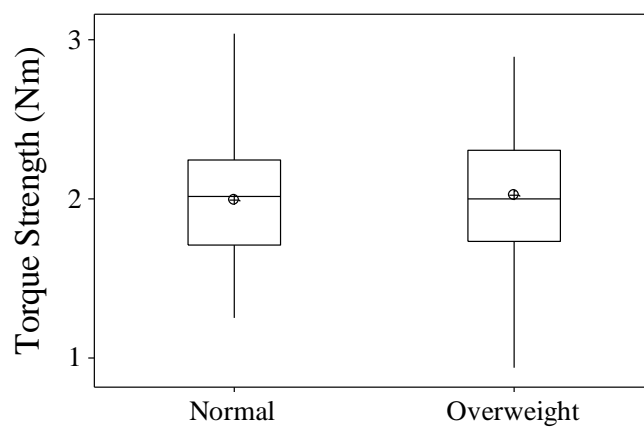


Figure 5.29. Box plot of overall TS with Key in standing for different BMI groups.

(viii) TS with Cylindrical in Standing:

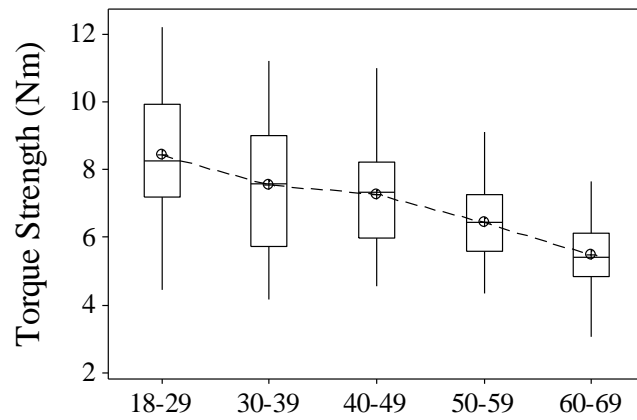


Figure 5.30. Box plot of overall TS with Cylindrical in standing for different age groups.

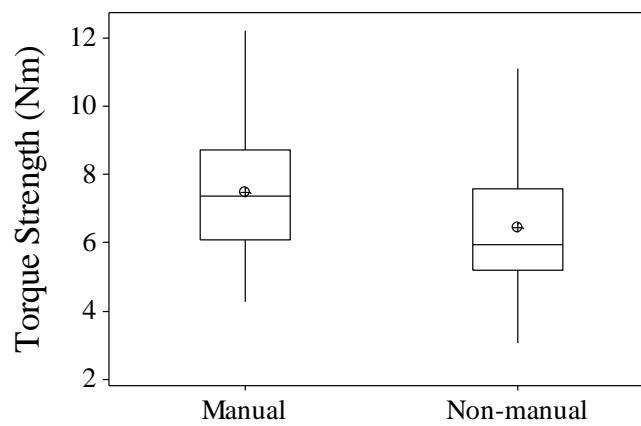


Figure 5.31. Box plot of overall TS with Cylindrical in standing for different job groups.

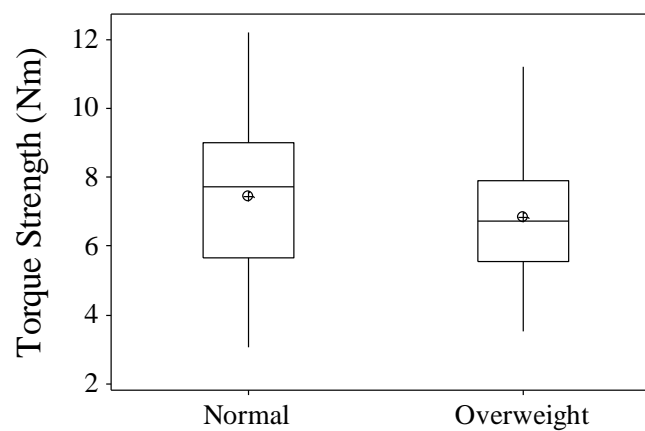


Figure 5.32. Box plot of overall TS with Cylindrical in standing for different BMI groups.

5.2.2. Percentiles

In this part, the percentiles of the measured values were calculated for each testing position (Table 5.5). Moreover, percentiles of eight different hand torque strength values were calculated for each occupation and age groups (Table 5.6 and Table 5.7).

Table 5.5. Hand Torque strength percentile values in each test position (in Nm).

Position	Handle	Percentiles			SD
		5	50	95	
Sitting	Ellipsoid	2.26	4.12	5.98	1.09
	Circular	3.06	4.78	7.06	1.12
	Key	1.32	1.94	2.63	0.38
	Cylindrical	4.21	6.64	10.41	1.82
Standing	Ellipsoid	2.38	4.23	6.18	1.12
	Circular	3.31	4.94	7.53	1.28
	Key	1.35	2.02	2.86	0.45
	Cylindrical	4.53	6.96	10.8	1.87

Table 5.6. Hand torque strength percentile values for job groups (in Nm).

Job Group	Position		Percentiles			SD
		Handle	5	50	95	
Manual	Sitting	Ellipsoid	2.29	4.44	6.28	1.14
		Circular	3.52	5.14	7.2	1.08
		Key	1.38	2.06	2.67	0.39
		Cylindrical	4.82	7.26	10.47	1.65
	Standing	Ellipsoid	2.31	4.45	6.54	1.19
		Circular	3.61	5.26	7.95	1.31
		Key	1.36	2.13	2.87	0.45
		Cylinder	4.89	7.38	10.8	1.74
Non-Manual	Sitting	Ellipsoid	2.19	3.78	5.24	0.93
		Circular	2.81	4.41	6.55	1.07
		Key	1.25	1.9	2.59	0.36
		Cylinder	4	5.89	10.41	1.89
	Standing	Ellipsoid	2.45	3.96	5.76	0.98
		Circular	3.08	4.51	6.76	1.13
		Key	1.32	1.92	2.85	0.45
		Cylindrical	4.21	6.02	10.97	1.91

Table 5.7. Hand torque strength percentile values for age groups (in Nm).

Age group (yrs.)	Handle	Sitting				Standing			
		Percentile				Percentile			
		5	50	95	SD	5	50	95	SD
18-29	Ellipsoid	1.78	3.95	6.1	1.16	1.93	3.85	6.49	1.35
	Circular	2.41	4.63	7.37	1.25	2.62	4.77	7.01	1.28
	Key	1.37	1.94	2.69	0.36	1.23	2.02	3.09	0.5
	Cylindrical	4.81	8.2	11.03	1.81	5.24	8.27	11.93	1.98
30-39	Ellipsoid	2.2	4.15	6.21	1.09	2.5	4.01	6.55	1.11
	Circular	3.27	4.75	6.73	1.02	3.46	4.98	7.53	1.32
	Key	1.18	1.94	2.76	0.46	1.38	2.03	2.75	0.41
	Cylindrical	4.27	7.49	10.65	1.82	4.48	7.58	10.95	1.92
40-49	Ellipsoid	2.43	4.62	6.4	1.17	3.1	4.71	6.34	0.97
	Circular	3.33	5	7.53	1.19	3.82	5.32	8.31	1.35
	Key	1.6	2.08	2.62	0.34	1.55	2.16	3.55	0.54
	Cylindrical	4.74	7.13	9.85	1.52	4.73	7.39	10.67	1.64
50-59	Ellipsoid	2.59	3.94	5.88	0.97	2.5	4.25	6.18	1.08
	Circular	3.23	4.92	6.42	0.99	3.39	5.29	7.11	1.15
	Key	1.25	1.93	2.56	0.38	1.33	2.02	2.81	0.4
	Cylindrical	4.21	6.01	9.59	1.61	4.62	6.5	8.56	1.27
60-69	Ellipsoid	2.34	4.05	5.57	0.94	2.5	4.04	5.69	0.88
	Circular	2.95	4.56	6.8	1.09	3.3	4.48	7.77	1.18
	Key	1.22	1.9	2.57	0.36	1.31	1.82	2.39	0.34
	Cylindrical	3.67	5.43	7.72	1.15	3.84	5.46	8.02	1.16

Table 5.8. Hand torque strength percentile values for age groups and job groups (in Nm).

Job Grp.	Age group (yrs.)	Handle	Sitting				Standing			
			Percentile				Percentile			
			5	50	95	SD	5	50	95	SD
Manual	18-29	Ellipsoid	1.87	4.13	6.18	1.16	2.14	4.24	7.15	1.45
		Circular	2.55	4.85	7.86	1.17	3.08	4.95	8.27	1.21
		Key	1.19	2.05	2.8	0.43	1.22	2.19	3.11	0.54
		Cylindrical	5.69	8.5	10.8	1.37	6.08	8.86	11.81	1.57
	30-39	Ellipsoid	1.74	4.45	6.44	1.19	2.2	4.67	6.72	1.29
		Circular	3.66	5.47	6.76	0.95	3.72	5.45	8.87	1.42
		Key	1.33	2.23	2.72	0.46	1.44	2.18	2.75	0.38
		Cylindrical	5.48	8.5	10.9	1.54	5.2	8.45	10.97	1.54
	40-49	Ellipsoid	2.25	5.08	7.61	1.33	2.98	5.17	7.09	1.01
		Circular	2.91	5.49	7.62	1.27	3.03	5.45	8.54	1.45
		Key	1.57	2.18	3.17	0.39	1.35	2.23	3.71	0.53
		Cylindrical	4.72	7.03	9.4	1.41	4.68	7.44	10.24	1.57
	50-59	Ellipsoid	2.51	4.38	6.19	1.05	2.03	4.51	6.23	1.15
		Circular	3.2	5.11	6.48	0.91	3.61	5.52	7.41	1.09
		Key	1.31	2.09	2.66	0.37	1.23	2.14	2.87	0.42
		Cylindrical	4.27	6.71	10.62	1.72	4.84	6.74	9.67	1.27
	60-69	Ellipsoid	2.91	4.39	6.32	0.85	2.76	4.33	6.24	0.87
		Circular	3.69	5.08	7.2	1.05	3.19	4.86	8.43	1.42
		Key	1.41	2	2.68	0.32	1.37	1.88	2.58	0.32
		Cylindrical	4.16	5.88	8.04	0.98	4.3	5.6	8.21	1.04
Non-Manual	18-29	Ellipsoid	1.65	3.45	6.13	1.14	1.66	3.4	5.97	1.22
		Circular	2.28	4.32	6.95	1.29	2.24	4.47	6.47	1.27
		Key	1.45	1.91	2.59	0.28	1.19	1.96	3.13	0.45
		Cylindrical	4.77	7.74	11.16	2.17	4.6	7.6	12.05	2.23
	30-39	Ellipsoid	2.29	3.78	5.86	0.89	2.78	3.88	5.72	0.83
		Circular	3.04	4.65	6.93	1	3.14	4.48	6.76	1.08
		Key	0.87	1.86	2.79	0.42	1.29	1.88	2.85	0.4
		Cylindrical	4.03	6.5	9.19	1.7	4.23	6.1	10.83	1.92
	40-49	Ellipsoid	2.38	4.34	5.63	0.9	3.05	4.61	6.15	0.85
		Circular	3.52	4.74	7.43	0.98	3.92	5.14	8.39	1.24
		Key	1.59	1.98	2.62	0.29	1.55	2.08	3.64	0.56
		Cylindrical	4.73	7.42	11.25	1.64	4.66	7.34	11.84	1.73
	50-59	Ellipsoid	2.5	3.67	5.44	0.73	2.54	4.02	6.01	0.96
		Circular	2.76	4.37	6.73	1.01	2.94	4.49	6.79	1.08
		Key	1.23	1.88	2.49	0.36	1.14	1.96	2.59	0.36
		Cylindrical	4.09	5.52	8.2	1.05	4.42	5.74	8.19	1.04
	60-69	Ellipsoid	2.01	3.55	4.99	0.79	2.38	3.67	4.99	0.81
		Circular	2.81	3.94	6.52	1	3.32	4.27	5.61	0.62
		Key	1.15	1.8	2.59	0.37	1.14	1.72	2.32	0.34
		Cylindrical	3.01	4.74	6.92	0.97	3.21	5.12	8.28	1.2

5.3. Correlation Analysis

Correlation analyses (Pearson) were performed to understand the degree of linearity between continuous independent variables and response (hand torque strength) variable.

Table 5.9 displays the Pearson correlation matrix between strength values of eight different treatment combinations. With moderate and high correlation coefficients and with p-values < 0.001, it is obvious that there is a positive and significant correlation between them. The highest linear correlation was found between sitting and standing hand torque strength values by using cylindrical handle. The correlation analysis involves the following hypotheses:

$$\begin{aligned}
 H_0: \rho &= 0 \\
 H_1: \rho &\neq 0
 \end{aligned}
 \tag{5.1}$$

Table 5.9. Pearson correlations between hand torque strengths of eight treatment combinations.

Strength	Ellipsoid Sit	Ellipsoid Stand	Circular Sit	Circular Stand	Key Sit	Key Stand	Cylinder Sit
Ellipsoid Stand	0.770* < 0.001**						
Circular Sit	0.648 < 0.001	0.596 < 0.001					
Circular Stand	0.570 < 0.001	0.653 < 0.001	0.730 < 0.001				
Key Sit	0.435 < 0.001	0.363 < 0.001	0.383 < 0.001	0.328 < 0.001			
Key Stand	0.441 < 0.001	0.435 < 0.001	0.449 < 0.001	0.468 < 0.001	0.703 < 0.001		
Cylinder Sit	0.351 < 0.001	0.302 < 0.001	0.396 < 0.001	0.413 < 0.001	0.228 < 0.001	0.403 < 0.001	
Cylinder Stand	0.264 < 0.001	0.313 < 0.001	0.334 < 0.001	0.384 < 0.001	0.221 < 0.001	0.379 < 0.001	0.853 < 0.001

*Pearson correlation coefficient; **p-value

Table 5.10 displays Pearson correlation coefficients between hand torque strengths and particular anthropometric measures of subjects. It can be said that height and dominant hand forearm circumference are significantly and positively correlated with torque strength

at all test combinations. Grip strength also has positive and significant correlation with all eight hand torque strength combinations. Hand breadth and wrist circumference were also correlated with hand torque strengths except cylindrical torque strengths. However, the correlation between BMI and hand torque strengths (except cylindrical strengths) was found generally insignificant.

Table 5.10. Pearson correlations between hand torque strengths and anthropometric data.

Strength	Ellipsoid Sit	Ellipsoid Stand	Circular Sit	Circular Stand	Key Sit	Key Stand	Cylinder Sit	Cylinder Stand
Age	0.040* 0.526**	0.033 0.594	-0.016 0.803	-0.025 0.687	-0.055 0.383	- 0.135 0.030	-0.486 < 0.001	-0.511 < 0.001
Height	0.177 0.005	0.126 0.043	0.120 0.054	0.127 0.042	0.206 0.001	0.240 < 0.001	0.362 < 0.001	0.353 < 0.001
Weight	0.110 0.079	0.062 0.325	0.096 0.126	0.101 0.108	0.190 0.002	0.156 0.012	0.035 0.575	0.018 0.769
BMI	0.036 0.570	0.010 0.877	0.046 0.463	0.051 0.412	0.102 0.102	0.048 0.448	-0.150 0.016	-0.160 0.010
DHL	0.149 0.017	0.068 0.279	0.106 0.089	0.098 0.117	0.192 0.002	0.209 0.001	0.311 < 0.001	0.272 < 0.001
DHB	0.249 < 0.001	0.189 0.002	0.217 < 0.001	0.179 0.004	0.296 < 0.001	0.240 < 0.001	0.003 0.961	-0.041 0.509
DHWC	0.124 0.047	0.111 0.077	0.176 0.005	0.143 0.022	0.181 0.004	0.190 0.002	-0.077 0.220	-0.070 0.262
DHFC	0.203 0.001	0.156 0.012	0.254 < 0.001	0.232 < 0.001	0.258 < 0.001	0.276 < 0.001	0.122 0.050	0.142 0.023
Grip Strength	0.215 0.001	0.226 < 0.001	0.334 < 0.001	0.418 < 0.001	0.221 < 0.001	0.407 < 0.001	0.634 < 0.001	0.646 < 0.001

*Pearson correlation coefficient; **p-value

Table 5.11 represents Pearson correlation coefficients among anthropometric measures and also age and hand grip strength. Age is significantly but negatively correlated with Height although it is significantly and positively correlated with BMI, dominant hand breadth and dominant hand wrist circumference. Almost all of the length measurements (DHL, DHB, DHWC and DHFC) are positively and significantly correlated between each other.

Table 5.11. Pearson correlations between anthropometric data.

Strength	Age	Height	Weight	BMI	DHL	DHB	DHWC	DHFC
Height	-0.337* < 0.001**							
Weight	0.057 0.364	0.434 < 0.001						
BMI	0.237 < 0.001	-0.049 0.431	0.876 < 0.001					
DHL	-0.155 0.013	0.620 < 0.001	0.377 < 0.001	0.090 0.149				
DHB	0.163 0.009	0.309 < 0.001	0.556 < 0.001	0.448 < 0.001	0.447 < 0.001			
DHWC	0.276 < 0.001	0.205 0.001	0.697 < 0.001	0.663 < 0.001	0.377 < 0.001	0.664 < 0.001		
DHFC	-0.023 0.708	0.303 < 0.001	0.785 < 0.001	0.711 < 0.001	0.333 < 0.001	0.602 < 0.001	0.735 < 0.001	
Grip Strength	- 0.583 < 0.001	0.386 < 0.001	0.109 0.082	-0.076 0.224	0.279 < 0.001	-0.008 0.893	-0.053 0.399	0.244 < 0.001

*Pearson correlation coefficient; **p-value

5.4. Factor Effects: ANOVA and Post-hoc Analyses

5.4.1. Overview

There were two types of independent variables in this study: experimental and classification variables. For each type of variables two separate ANOVA models were used. For experimental type independent variables, complete randomized block design (CRBD) model was used with subjects serving as blocks to investigate the effects of posture and handle type on torque strength. For classification type independent variables, complete randomized design (CRD) model was used to investigate the effects of age-group, job-group and BMI group on torque strength. ANOVA results are further investigated by post-hoc analysis using Tukey tests. The details of the analysis results were covered in the following sections.

Before conducting each ANOVA, ANOVA assumptions were checked carefully and the details about the ANOVA assumptions are shown in the Appendix E and Appendix F.

5.4.2. Effects of Experimental variables on Torque Strength

Table 5.12 depicts the summary of ANOVA of CRBD. The results indicate that both experimental variables; handle type and posture, had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant. For ANOVA, log transformation of TS was performed to satisfy the equality of variance assumption, since the original data did not satisfy the equality of variance assumption.

Table 5.12. Analysis of variance table for Blocked Design.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Block (Subjects)	256	12.88781	12.88781	0.05034	7.57	< 0.001
Handle type	3	78.71571	78.71571	26.23857	39.4357	< 0.001
Posture	1	0.12822	0.12822	0.12822	19.27	< 0.001
Error	1795	11.94304	11.94304	0.00665		
Total	2055	103.67478				

(a) Handle type effect on TS:

Following the ANOVA, multiple comparison tests were performed by Tukey tests. The results for handle type are shown in Table 5.13 and 5.14.

Table 5.13. Results of Tukey's test for hand tools.

Handle Type Comp.	Difference of Means	SE of Difference	T- value	Adj. p - value
Group 2 - Group 1	0.0781	0.005088	15.35	< 0.001
Group 3 - Group 1	-0.3121	0.005088	-61.34	< 0.001
Group 4 - Group 1	0.2229	0.005088	43.80	< 0.001
Group 3 - Group 2	-0.3902	0.005088	-76.69	< 0.001
Group 4 - Group 2	0.1448	0.005088	28.45	< 0.001
Group 4 - Group 3	0.5350	0.005088	105.1	< 0.001

Group 1 - Ellipsoid, Group 2 - Circular, Group 3 - Key, Group 4 - Cylindrical

Table 5.14. Grouping information for Hand tools using Tukey Method.

Handle Type	N	Mean	Grouping
Cylindrical	514	0.8	A
Circular	514	0.7	B
Ellipsoid	514	0.6	C
Key	514	0.3	D

According to the multiple comparison results, TS is significantly different for all handle types in the following order: $TS_{Cylindrical} > TS_{Circular} > TS_{Ellipsoid} > TS_{Key}$. That is, TS with cylindrical handle is the highest and with key handle is the lowest.

(b) Posture Effect on TS:

Since posture had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength at both postures, it can be concluded that TS at standing posture is significantly higher than TS at sitting posture.

5.4.3. Effects of Classification Variables on Torque Strength

Since TS at eight treatment combinations are highly correlated with each other, using all of TS data in one ANOVA leads to violation of independence assumption. Hence, the effects of the classification variables (age-group, job-group and BMI group) on TS were investigated separately for each of the eight treatment combinations; that is, for each of eight response variables. Here response variables are: TS with ellipsoid handle in sitting, TS with ellipsoid in standing, and so on.

5.4.3.1. TS with Ellipsoid in Sitting. Table 5.15 depicts the summary of ANOVA of CRD for TS with ellipsoid in sitting. The results indicate that except BMI group; age-group and job-group had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.15. ANOVA of TS with Ellipsoid Handle in Sitting.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	17.811	17.740	4.435	4.27	0.002
Job Group	1	25.934	25.619	25.619	24.64	< 0.001
BMI Group	1	0.019	0.019	0.019	0.02	0.892
Error	250	259.889	259.889	1.040		
Total	256	303.654				

(a) Age-Group Effect on TS with ellipsoid in sitting:

Table 5.16 and 5.17 show the results of Tukey's test for different age groups. Results indicated that 40-49 age group is statistically stronger than 18-29 and 60-69 age groups. Strength increases with age increases and peaks at age between 40-49 years then it decreases.

(b) Job-Group Effect on TS with ellipsoid in sitting:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be

concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

Table 5.16. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	0.3707	0.2085	1.7778	0.3366
Group 3 - Group 1	0.8119	0.2098	3.8697	0.0010
Group 4 - Group 1	0.2552	0.2064	1.2364	0.7300
Group 5 - Group 1	0.2013	0.2085	0.9654	0.8707
Group 3 - Group 2	0.4412	0.2040	2.1627	0.1940
Group 4 - Group 2	- 0.1155	0.1983	- 0.5821	0.9777
Group 5 - Group 2	- 0.1694	0.2039	- 0.8307	0.9212
Group 4 - Group 3	- 0.5566	0.1980	- 2.812	0.0395
Group 5 - Group 3	- 0.6106	0.2040	- 2.993	0.0231
Group 5 - Group 4	- 0.05394	0.1983	- 0.2720	0.9988

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

Table 5.17. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
40-49 yrs.	50	4.6	A
30-39 yrs.	50	4.2	A B
50-59 yrs.	57	4	B
60-69 yrs.	50	4	B
18-29 yrs.	50	3.8	B

5.4.3.2. TS with Circular in Sitting. Table 5.18 depicts the summary of ANOVA of CRD for TS with circular in sitting. The results indicate that except job-group; age-group and BMI group had insignificant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.18. ANOVA of TS with Circular Handle in Sitting.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	10.805	10.773	2.693	2.39	0.052
Job Group	1	27.595	27.541	27.541	24.4	< 0.001
BMI Group	1	0.029	0.029	0.029	0.03	0.874
Error	250	282.222	282.222	1.129		
Total	256	320.650				

(a) Age-Group Effect on TS with Circular in Sitting:

Table 5.19 and 5.20 show the results of Tukey's test for different age groups. Results indicated that age-group is marginally significant. Strength increases with age increases and peaks at age between 40-49 years then it decreases.

Table 5.19. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	0.27698	0.2173	1.27469	0.7068
Group 3 - Group 1	0.54361	0.2186	2.48641	0.0937
Group 4 - Group 1	0.10129	0.2151	0.47082	0.9900
Group 5 - Group 1	- 0.01382	0.2173	- 0.06361	1.0000
Group 3 - Group 2	0.2666	0.2126	1.254	0.7193
Group 4 - Group 2	- 0.1757	0.2067	- 0.850	0.9148
Group 5 - Group 2	- 0.2908	0.2125	- 1.368	0.6480
Group 4 - Group 3	- 0.4423	0.2063	- 2.144	0.2015
Group 5 - Group 3	- 0.5574	0.2126	- 2.622	0.0664
Group 5 - Group 4	- 0.1151	0.2067	- 0.5569	0.9811

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

Table 5.20. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
40-49 yrs.	50	5.2	A
30-39 yrs.	50	4.9	A
50-59 yrs.	57	4.7	A
18-29 yrs.	50	4.6	A
60-69 yrs.	50	4.6	A

(b) Job-Group Effect on TS with Circular in Sitting:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

5.4.3.3. TS with Key in Sitting. Table 5.21 depicts the summary of ANOVA of CRD for TS with key in sitting. The results indicate that except age-group; job-group and BMI group had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.21. ANOVA of TS with Key Handle in Sitting.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	1.0766	1.0884	0.2721	1.98	0.099
Job Group	1	1.9645	2.1007	2.1007	15.26	< 0.001
BMI Group	1	0.3754	0.3754	0.3754	2.73	0.10
Error	250	34.4087	34.4087	0.1376		
Total	256	37.8252				

(a) Age-Group Effect on TS with Key in Sitting:

Table 5.22 and 5.23 shows the results of Tukey's test for different age groups. Results indicated that age-group is marginally significant. Strength peaks at age 40-49 years. Only 40-49 age group and 60-69 age group is significantly different.

(b) Job-Group Effect on TS with Key in Sitting:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

(c) BMI Group Effect on TS with Key in Sitting:

Since BMI group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both BMI groups, it can be concluded that mean TS of overweight subjects is significantly higher than mean TS of normal subjects.

Table 5.22. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	- 0.0124	0.07587	- 0.163	0.9998
Group 3 - Group 1	0.0899	0.07634	1.178	0.7640
Group 4 - Group 1	- 0.0446	0.07512	- 0.594	0.9760
Group 5 - Group 1	- 0.1128	0.07587	- 1.486	0.5714
Group 3 - Group 2	0.1023	0.07423	1.378	0.6416
Group 4 - Group 2	- 0.0323	0.07217	- 0.447	0.9918
Group 5 - Group 2	- 0.1004	0.07420	- 1.353	0.6578
Group 4 - Group 3	- 0.1346	0.07203	- 1.868	0.3347
Group 5 - Group 3	- 0.2027	0.07423	- 2.731	0.0496
Group 5 - Group 4	- 0.06815	0.07217	- 0.9442	0.8796

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

Table 5.23. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
40-49 yrs.	50	2.1	A
18-29 yrs.	50	2	A B
30-39 yrs.	50	2	A B
50-59 yrs.	57	1.9	A B
60-69 yrs.	50	1.9	B

5.4.3.4. TS with Cylindrical in Sitting. Table 5.24 depicts the summary of ANOVA of CRD for TS with cylindrical in sitting. The results indicate that except BMI group; age-group and job-group had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.24. ANOVA of TS with Cylindrical Handle in Sitting.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	206.978	205.421	51.355	21.78	< 0.001
Job Group	1	55.317	55.695	55.695	23.62	< 0.001
BMI Group	1	0.379	0.379	0.379	0.16	0.689
Error	250	589.484	589.484	2.358		
Total	256	852.158				

(a) Age-Group Effect on TS with Cylindrical in Sitting:

Table 5.25 and 5.26 shows the results of Tukey's test for different age groups. Results indicated that the highest torque strength is at 18-29 age groups, and then it decreases.

Table 5.25. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	- 0.708	0.3140	- 2.255	0.1599
Group 3 - Group 1	- 0.989	0.3160	- 3.129	0.0151
Group 4 - Group 1	- 1.777	0.3109	- 5.714	< 0.001
Group 5 - Group 1	- 2.678	0.3140	- 8.527	< 0.001
Group 3 - Group 2	- 0.281	0.3072	- 0.914	0.8918
Group 4 - Group 2	- 1.069	0.2987	- 3.577	0.0032
Group 5 - Group 2	- 1.97	0.3071	- 6.413	< 0.001
Group 4 - Group 3	- 0.0788	0.2982	- 2.643	0.0629
Group 5 - Group 3	- 1.689	0.3072	- 5.497	< 0.001
Group 5 - Group 4	- 0.9010	0.2987	- 3.016	0.0216

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

Table 5.26. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
18-29 yrs.	50	8.1	A
30-39 yrs.	50	7.4	A B
40-49 yrs.	50	7.1	B C
50-59 yrs.	57	6.3	C
60-69 yrs.	50	5.4	D

(b) Job-Group Effect on TS with Cylindrical in Sitting:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

5.4.3.5. TS with Ellipsoid in Standing. Table 5.27 depicts the summary of ANOVA of CRD for TS with ellipsoid in standing. The results indicate that except BMI group; age-group and job-group had significant effect on torque strength. Only the interaction of age-group*BMI group took place in the ANOVA since this interaction effect was found significant.

Table 5.27. ANOVA of TS with Ellipsoid Handle in Standing.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	21.514	19.591	4.898	4.48	0.002
Job Group	1	16.286	14.971	14.971	13.69	< 0.001
BMI Group	1	0.961	0.562	0.562	0.51	0.474
Age Group* BMI Group	4	12.145	12.145	3.036	2.78	0.028
Error	246	269.067	269.067	1.094		
Total	256	319.973				

(a) Age-Group Effect on TS with Ellipsoid in Standing:

Table 5.28 and 5.29 shows the results of Tukey's test for different age groups. Torque strength increases with age increases and peaks at age between 40-49 years then it decreases.

Table 5.28. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	0.5029	0.2169	2.3185	0.1389
Group 3 - Group 1	0.9077	0.2182	4.1590	0.0003
Group 4 - Group 1	0.4707	0.2147	2.1919	0.1827
Group 5 - Group 1	0.2113	0.2169	0.9741	0.8670
Group 3 - Group 2	0.4048	0.2122	1.908	0.3132
Group 4 - Group 2	- 0.0322	0.2063	- 0.156	0.9999
Group 5 - Group 2	- 0.2916	0.2121	- 1.375	0.6440
Group 4 - Group 3	- 0.4370	0.2059	- 2.122	0.2106
Group 5 - Group 3	- 0.6964	0.2122	- 3.282	0.0091
Group 5 - Group 4	- 0.2594	0.2063	- 1.257	0.7174

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

Table 5.29. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
40-49 yrs.	50	4.6	A
30-39 yrs.	50	4.4	A B
50-59 yrs.	57	4.4	A B
60-69 yrs.	50	3.9	B
18-29 yrs.	50	3.8	B

(b) Job-Group Effect on TS with Ellipsoid in Standing:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

5.4.3.6. TS with Circular in Standing. Table 5.30 depicts the summary of ANOVA of CRD for TS with circular in standing. The results indicate that except BMI group; age-group and job-group had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.30. ANOVA of TS with Circular Handle in Standing.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	20.912	19.794	4.948	3.41	0.01
Job Group	1	32.245	32.567	32.567	22.43	< 0.001
BMI Group	1	0.328	0.328	0.328	0.23	0.635
Error	250	363.016	363.016	1.452		
Total	256	416.502				

(a) Age-Group Effect on TS with Circular in Standing:

Table 5.31 and 5.32 show the results of Tukey's test for different age groups. Torque strength increases with age increases and peaks at age between 40-49 years then it decreases.

Table 5.31. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	0.033334	0.02094	1.5921	0.5024
Group 3 - Group 1	0.059723	0.02107	2.8350	0.0370
Group 4 - Group 1	0.022666	0.02073	1.0934	0.8101
Group 5 - Group 1	- 0.008112	0.02094	- 0.3874	0.9952
Group 3 - Group 2	0.02639	0.02048	1.288	0.6985
Group 4 - Group 2	- 0.01067	0.01992	- 0.536	0.9837
Group 5 - Group 2	- 0.04145	0.02048	- 2.024	0.2543
Group 4 - Group 3	- 0.03706	0.01988	- 1.864	0.3368
Group 5 - Group 3	- 0.06784	0.02048	- 3.312	0.0082
Group 5 - Group 4	- 0.03078	0.01992	- 1.545	0.5328

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

Table 5.32. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
40-49 yrs.	50	5.5	A
30-39 yrs.	50	5.2	A B
50-59 yrs.	57	5.1	A B
18-29 yrs.	50	4.9	B
60-69 yrs.	50	4.7	B

(b) Job-Group Effect on TS with Circular in Standing:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

5.4.3.7. TS with Key in Standing. Table 5.33 depicts the summary of ANOVA of CRD for TS with circular in standing. The results indicate that except BMI group; age-group and job-group had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.33. ANOVA of TS with Key Handle in Standing

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	3.6242	3.6291	0.9073	4.78	0.001
Job Group	1	1.5413	1.5986	1.5986	8.42	0.004
BMI Group	1	0.1011	0.1011	0.1011	0.53	0.466
Error	250	47.4517	47.4517	0.1898		
Total	256	52.7183				

(a) Age-Group Effect on TS with Key in Standing:

Table 5.34 and 5.35 show the results of Tukey's test for different age groups. Results indicated that torque strength increases with age increases and peaks at age between 40-49 years then it decreases.

Table 5.34. Results of Tukey's test for different age groups.

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	0.00754	0.01903	0.396	0.9948
Group 3 - Group 1	0.03274	0.01915	1.709	0.4281
Group 4 - Group 1	- 0.00359	0.01885	- 0.190	0.9997
Group 5 - Group 1	- 0.04391	0.01903	- 2.307	0.1425
Group 3 - Group 2	0.02520	0.01862	1.353	0.6577
Group 4 - Group 2	- 0.01112	0.01811	- 0.614	0.9729
Group 5 - Group 2	- 0.05145	0.01861	- 2.764	0.0453
Group 4 - Group 3	- 0.03632	0.01807	- 2.01	0.2611
Group 5 - Group 3	- 0.07665	0.01862	- 4.116	0.0004
Group 5 - Group 4	- 0.04032	0.01811	- 2.227	0.1696

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

Table 5.35. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
40-49 yrs.	50	2.2	A
30-39 yrs.	50	2.1	A B
18-29 yrs.	50	2.1	A B
50-59 yrs.	57	2.0	A B
60-69 yrs.	50	1.8	B

(b) Job-Group Effect on TS with Key in Standing:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

5.4.3.8. TS with Cylindrical in Standing. Table 5.36 depicts the summary of ANOVA of CRD for TS with cylindrical in standing. The results indicate that except BMI group; age-group and job-group had significant effect on torque strength. Here a reduced non interaction model was used, since interaction effects were found insignificant.

Table 5.36. ANOVA of TS with Cylindrical Handle in Standing.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	235.126	226.687	56.672	23.28	< 0.001
Job Group	1	51.689	50.934	50.934	20.92	< 0.001
BMI Group	1	0.088	0.088	0.088	0.04	0.849
Error	250	608.586	608.586	2.434		
Total	256	895.489				

(a) Age-Group Effect on TS with Cylindrical in Standing:

Table 5.37 and 5.38 shows the results of Tukey's test for different age groups. Results indicated that the highest torque strength is at 18-29 age groups, and then it decreases.

(b) Job-Group Effect on TS with Cylindrical in Standing:

Since job-group had only two levels, without performing Tukey test, from the ANOVA results and mean values of torque strength of both job-groups, it can be concluded that mean TS of manual workers is significantly higher than mean TS of non-manual workers.

Table 5.37. Results of Tukey's test for different age groups

Age Group Difference	Difference of Means	SE of Difference	T- value	Adj. P- value
Group 2 - Group 1	- 0.869	0.3191	- 2.723	0.0506
Group 3 - Group 1	- 1.037	0.3211	- 3.231	0.0108
Group 4 - Group 1	- 1.956	0.3159	- 6.191	< 0.001
Group 5 - Group 1	- 2.822	0.3191	- 8.844	< 0.001
Group 3 - Group 2	- 0.169	0.3122	- 0.540	0.9832
Group 4 - Group 2	- 1.087	0.3035	- 3.581	0.0032
Group 5 - Group 2	- 1.953	0.3120	- 6.259	< 0.001
Group 4 - Group 3	- 0.918	0.3029	- 3.031	0.0206
Group 5 - Group 3	- 1.784	0.3122	- 5.716	< 0.001
Group 5 - Group 4	- 0.8661	0.3035	- 2.854	0.0351

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

Table 5.38. Grouping information for Age groups using Tukey Method.

Age Group	N	Mean	Grouping
18-29 yrs.	50	8.4	A
30-39 yrs.	50	7.6	A B
40-49 yrs.	50	7.4	B
50-59 yrs.	57	6.5	C
60-69 yrs.	50	5.6	D

5.4.4. Effects of smoking and exercise on TS

The effects of smoking and exercise on TS were also investigated in this study. Results indicated that smoking has no significant effect on TS, whereas exercise has significant effect on TS with key in sitting, TS with cylindrical in sitting and TS with cylindrical in standing. ANOVA results were displayed in Appendix D.

5.5. Regression Analysis of Hand Torque Strength Values

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

For developing the best regression equation, Stepwise Regression Analysis technique was used. Moreover, Best Subsets Regression analysis method was used to verify the results. Interaction effects were neglected and only the main effects were taken into consideration.

5.5.1. Regression Equation of Hand Torque Strength for Males

The general form of the male hand torque strength regression model is as follows:

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_ix_i + \gamma_1D_1 + \gamma_2D_2 + \gamma_3D_3 + \gamma_4D_4 + \gamma_5D_5 + \varepsilon \quad (5.2)$$

where, β_0 is constant, β_1 is the regression coefficient of age, β_2 is the regression coefficient of BMI, β_i is the regression coefficient of i^{th} anthropometric variable, $\gamma_1, \gamma_2, \gamma_3$ are the regression coefficients of handle type, γ_4 is the regression coefficient of posture, γ_5 is the regression coefficient of occupation, ε is the error term, x_1 is the regressor variable of age, x_2 is the regressor variable of BMI, x_i is the regressor variable of i^{th} anthropometric variable, D_1, D_2, D_3 are the dummy variables for handle type, D_4 is the dummy variable for posture and D_5 is the dummy variable for occupation.

Tool	D_1	D_2	D_3	Posture	D_4	Job-group	D_5
Ellipsoid	1	0	0	Sitting	1	Manual	1
Circular	0	1	0	Standing	0	Non-manual	0
Key	0	0	1				
Cylinder	0	0	0				

In addition to these predictors, anthropometric variables were also added to regression model to predict strength. In order to determine that which anthropometric variables will be added, the Pearson correlation coefficients are used.

Table 5.39. Correlation between anthropometric variables and strength.

Item	Age	Height	Weight	BMI	DHL	DHB	DHCW	DHCF	GS
Pearson C. (r)	-0.109	0.123	0.038	- 0.020	0.099	0.064	0.030	0.097	0.231
p - value	< 0.001	< 0.001	0.083	0.369	< 0.001	0.004	0.174	<0.001	<0.001

According to correlation table, weight, BMI and DHCW are found uncorrelated with strength. In table 5.40 there are 11 different model alternatives represented.

Table 5.40. Different regression model alternatives.

Regression Models	S	R ² (%)	R ² adj. (%)	Cp
Model 1	1.11627	73.81	73.63	15
Model 2	1.11821	73.70	73.54	13
Model 3	1.11712	73.75	73.59	13
Model 4	1.11102	74.03	73.88	13
Model 5	1.11154	73.97	73.86	10
Model 6	1.11474	73.81	73.71	9
Model 7	1.12564	73.28	73.19	8
Model 8	1.21621	68.78	68.70	6
Model 9	1.25197	66.88	66.83	4
Model 10	1.13331	72.90	72.82	7
Model 11	1.13086	73.03	72.94	8

- Model 1: Age, height, weight, BMI, DHL, DHB, DHCW, DHCF, grip strength, handle type, posture and job group
- Model 2: Age, height, weight, DHL, DHB, DHCW, grip strength, handle type, posture and job group
- Model 3: Age, BMI, DHL, DHB, DHCW, DHCF, grip strength, handle type, posture and job group
- Model 4: Age, age², height, DHL, DHB, DHCF, grip strength, handle type, posture and job group (only significant variables added to model)

- Model 5: Age, age², height, grip strength, handle type, posture and job group (Best model according to Stepwise regression and Best subsets regression)
- Model 6: Age, age², grip strength, handle type, posture and job group
- Model 7: Age, grip strength, handle type, posture and job group
- Model 8: Handle type, posture and job group
- Model 9: Handle type
- Model 10: Age, age², grip strength, handle type
- Model 11: Age, age², height, grip strength, handle type

When all of the models are checked, Model 4 seems as the most appropriate model due to its highest R^2 adjusted value and the smallest S value. Hence, Model 4 can be used to predict hand torque strength value.

$$\begin{aligned}
 H_0 &= \beta_i = 0 \\
 H_1 &= \text{Not all } \beta_i \text{ are zero}
 \end{aligned}
 \tag{5.3}$$

Table 5.41 presents analysis of variance table of regression model. Since p value < 0.01 it is clear that at least one of the regressor variables contributes significantly to the model.

Table 5.41. Analysis of variance table of regression model.

Source	DoF	SS	MS	F	P
Regression	12	7190.06	599.17	485.41	< 0.001
Residual Error	2043	2521.79	1.23		
Total	2055	9711.85			

After that, in order to find a simple regression equation some trials were done with Stepwise Regression Analysis, the equation that has the higher adjusted R^2 value 73.9% and smaller Mallows' statistic $C_p = 10$ was accepted as regression equation. The regression equation for males can be seen in Table 5.42.

Table 5.42. Regression analysis results of hand torque strength for males.

Predictor	Coef.	SE Coef.	T	P	VIF
Constant	0.8696	0.7619	1.14	0.254	
Age	0.07442	0.01154	6.45	< 0.001	45.568
Age ²	- 0.0008113	0.0001321	- 6.14	< 0.001	45.796
Height	0.015177	0.004247	3.57	< 0.001	1.212
Hand grip	0.0048771	0.0003422	14.25	< 0.001	1.706
Handle type 1	- 2.78759	0.06934	-40.20	< 0.001	1.500
Handle type 2	- 2.00422	0.06934	-28.91	< 0.001	1.500
Handle type 3	-4.96444	0.06934	-72.60	< 0.001	1.500
Posture 1	- 0.16863	0.04903	-3.44	< 0.001	1.000
Job group 1	0.39707	0.05044	7.87	0.001	1.058

Therefore, the regression equation for male hand torque strength is:

$$TS = 0.87 + 0.0744 \times \text{Age} - 0.000811 \times \text{Age}^2 + 0.0152 \times \text{Height} + 0.00488 \times \text{Grip Strength} - 2.79 \times \text{Handle type 1} - 2 \times \text{Handle type 2} - 4.96 \times \text{Handle type 3} - 0.169 \times \text{Posture} + 0.397 \times \text{Job-group}$$

$$(S = 1.11154, R\text{-sq} = 74.\%, R\text{-sq (adj.)} = 73.9\%, \text{Mallow Cp} = 10)$$

Where,

Age (in years), BMI (in kg/m²), hand grip (in N); and

$$\text{Handle type 1} : \begin{cases} 1, & \text{if handle is ellipsoid} \\ 0, & \text{otherwise} \end{cases}$$

$$\text{Handle type 2} : \begin{cases} 1, & \text{if handle is circular} \\ 0, & \text{otherwise} \end{cases}$$

$$\text{Handle type 3} : \begin{cases} 1, & \text{if handle is key} \\ 0, & \text{otherwise} \end{cases}$$

$$\text{Posture} : \begin{cases} 1, & \text{if posture is sitting} \\ 0, & \text{otherwise} \end{cases}$$

$$\text{Occupation} : \begin{cases} 1, & \text{if occupation is manual} \\ 0, & \text{otherwise} \end{cases}$$

(This modeling format was also used for the following regression models)

5.5.2. Regression Equation of Hand Torque Strength for Males for four different Handles

For each handle type, best regression models were determined by using stepwise regression. The table 5.43 shows a summary for four different regression models.

Table 5.43. Summary of four different regression models for four different handle types.

Regression Models	S	R ² (%)	R ² adj. (%)	Cp
Model 1	0.999521	18.73	18.09	5
Model 2	1.01591	29.92	29.09	7
Model 3	0.378047	20.64	19.70	7
Model 4	1.34600	47.59	46.97	7

Model 1 for Ellipsoid Handle:

$$TS_{Ellipsoid} \text{ (Nm)} = - 0.410723 + 0.141113 \times \text{Age} - 0.00144865 \times \text{Age}^2 + 0.00342048 \times \text{Grip strength} + 0.424033 \times \text{Job-group}$$

Model 2 for Circular Handle:

$$TS_{Circular} \text{ (Nm)} = - 2.12973 + 0.125495 \times \text{Age} - 0.00121654 \times \text{Age}^2 + 0.201462 \times \text{DHB} + 0.00610264 \times \text{Grip Strength} - 0.271556 \times \text{Posture} + 0.425237 \times \text{Job-group}$$

Model 3 for Key Handle:

$$TS_{Key} \text{ (Nm)} = - 0.637908 + 0.0233359 \times \text{Age} - 0.000249408 \times \text{Age}^2 + 0.175366 \times \text{DHB} + 0.00148857 \times \text{Grip Strength} - 0.0768093 \times \text{Posture} + 0.0885561 \times \text{Job-group}$$

Model 4 for Cylindrical Handle:

$$TS_{Cylindrical} \text{ (Nm)} = 0.610252 - 0.0250889 \times \text{Age} - 0.0372693 \times \text{BMI} + 0.266327 \times \text{DHL} + 0.00909089 \times \text{Grip strength} - 0.199689 \times \text{Posture} + 0.529032 \times \text{Job-group}$$

5.5.3. Regression Equations of Hand Torque Strength for specific purposes

Sixteen different regression models were developed for specific purposes. These models are different combinations of handle type (4), posture (2) and job-group (2). Table 5.44 represents a summary table of these sixteen regression models.

Regression equations of these sixteen models are given in Appendix C.2 in detail. It can be seen that R^2 (adj.) values are lower than the regression model that is determined above. This obvious difference can be explained by considerably high correlation between handle type and strength.

Table 5.44. Summary table of sixteen regression models.

Models	Occupation	Posture	Handle type	Predictors
Model 1	Manual	Sitting	Ellipsoid	Age, BMI, DHB, Grip strength
Model 2	Manual	Standing	Ellipsoid	Age, Age ² , Height, Weight, DHL, DHB, Grip strength
Model 3	Manual	Sitting	Circular	Age, Age ² , DHB, Grip strength
Model 4	Manual	Standing	Circular	Age, Age ² , DHL, DHB, Grip strength
Model 5	Manual	Sitting	Key	DHB, Grip strength
Model 6	Manual	Standing	Key	Age, Age ² , DHB, Grip strength
Model 7	Manual	Sitting	Cylindrical	Age, DHL, DHCW, Grip strength
Model 8	Manual	Standing	Cylindrical	Age, BMI, DHL, Grip strength
Model 9	Non-manual	Sitting	Ellipsoid	Age, Age ² , Grip strength
Model 10	Non-manual	Standing	Ellipsoid	Age, Age ² , DHL, Grip strength
Model 11	Non-manual	Sitting	Circular	Age, Weight, DHCF, Grip strength
Model 12	Non-manual	Standing	Circular	Age, Age ² , DHL, Grip strength
Model 13	Non-manual	Sitting	Key	Height, DHB, Grip strength
Model 14	Non-manual	Standing	Key	Age, Age ² , DHB, Grip strength
Model 15	Non-manual	Sitting	Cylindrical	Grip strength
Model 16	Non-manual	Standing	Cylindrical	Height, Grip strength

Table 5.45. Summary results table of sixteen regression models.

Models	S	R² (%)	R² adj. (%)	Cp
Model 1	1.08	14	11.30	5
Model 2	1.06	25.50	21.29	8
Model 3	0.989	18.63	16.07	5
Model 4	1.13	28.84	26.02	6
Model 5	0.378	8.95	7.54	3
Model 6	0.404	21.58	19.11	5
Model 7	1.31	38.20	36.25	5
Model 8	1.26	48.83	47.22	5
Model 9	0.862992	15.5	13.4	4
Model 10	0.884007	20.6	17.95	5
Model 11	0.942994	24.18	21.65	5
Model 12	0.219068	30.09	27.75	5
Model 13	0.328261	16.67	14.61	4
Model 14	0.855890	23.28	20.72	5
Model 15	0.0335027	52.03	51.24	3
Model 16	0.0312268	50.14	49.32	3

6. DISCUSSION

6.1. Discussion of the Current Study Results

In this section, results of the study were evaluated. The effects of the factors on TS were discussed and the reasons of the results were questioned. Moreover, results of the current study were compared with the results of the other studies in the literature.

Handle type Factor:

Results indicated that handle type is the most significant factor affecting hand torque strength. The result is similar with the findings of study by Mital and Sanghavi (1986) where the effects of different hand tools were investigated and the major changes on hand torque strength were observed. Gripping and grasping strengths of the whole hand depend on the coupling between the hand and the handle (Kroemer, 2006). Grasp surface is larger with cylindrical handle and also torque direction was different than the other three handles. That's why; more torque was exerted with cylindrical handle as compared with other hand tools. In general, the lowest hand torque strength values were exerted with key handle. Because not all fingers but only thumb, index and middle fingers generated the torque strength. Also, this can be explained by the type of grip, handle characteristics (dimensions, shape, surface finish etc.) and force direction.

Posture Factor:

Most of the variation in TS may be explained by posture that used while torque exertion (Daams, 1990). Measured strength is highly posture dependent. Even small changes in the body angles of persons being tested or changes in the direction of force application can result in large changes in measured strength (Gallagher *et al.*, 1998). Results indicate that higher hand torque strength is generally exerted in standing posture compared with the sitting posture. However, the difference may not be considered

important in practical applications. This finding is also consistent with the findings of the study of Mital and Sanghavi (1986).

Age Factor:

Age is another influential factor on hand torque strength. The results of Peebles and Norris (2003) showed that maximum strength increases throughout childhood, peaks in adulthood, and then decreases with age from around 50 years. The results of the current study also confirmed the results of Peebles and Norris (2003). There is a curvilinear relationship between age and hand torque strength for ellipsoid, circular and key handle. On the other hand, TS for cylindrical handle decreasing with age. Hand torque strength peaking somewhere between 40 and 49 years of age and decreasing thereafter. Results of the study is similar with Slob (2000) which 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.

Job Group Factor:

Job group is another influential factor on hand torque strength. Effect of occupation was investigated in a few studies. A study by Xiao *et al.* (2005) indicated that industrial workers and students had higher mean strengths than administrators for males, and industrial workers had higher mean strengths than students. According to the results of the current study, manual subjects have significantly higher strength values than non-manual subjects. This might be a result of their heavy physical activities with their hands, which are used forcefully more often, therefore their muscles get bigger and stronger. And it is well known, that muscle strength is a function of size of related muscles (Ekşioğlu and Silahlı, 2012).

BMI Factor:

The effect of BMI on hand torque strength was also investigated. Positive correlations have been found between muscle force capacities and body build, body

weight, or stature (Damon *et al.*, 1966; Laubach and McConville, 1966; Roberts *et al.*, 1959; Tornvall, 1963). The results of the study indicated that the mean hand torque strength value of Normal weight group is higher than the mean hand torque strength value of the Overweight group; however, the difference is not statistically significant. The study did not include underweight group, thus, this need to be investigated further.

The correlations between anthropometric measures and hand torque strength were investigated to determine the significantly correlated anthropometric variables in order to use while predicting the hand torque strength. According to correlation analysis, weight and BMI are found uncorrelated with strength. However, other anthropometric variables are significantly but slightly correlated with hand torque strength.

Moreover, the results of the current study indicated that hand grip strength is significantly and positively correlated with hand torque strength. It was an expected result of the study, so hand grip was used as the main predictor of the regression models.

6.2. Comparison with Other Studies

In order to determine the place of the torque strength data of male population of Turkey in the literature, the results of the study is required to compare with the similar studies has done. There is no such a study done before in Turkey for male population. So, this study will be a base for further research. The studies in the literature vary in sample size, sample type, measure used, experimental procedure, experimental posture, age range, methods and handles used. The direct comparisons of the current study with the related studies in the literature are not feasible since there could not be found study in the literature, which has similar experimental conditions.

In order to make some comparisons, it was tried to find the most similar experimental conditions with the most similar handle characteristics. Therefore for each handle, the following studies are considered for comparisons.

For circular handle, the most similar studies for comparison:

- Kim, Kim (2000)

- Peebles, Norris (2002)
- Miller, Nair, Baratz (2005)

For cylindrical handle, the most similar studies for comparison:

- Imrhan, Jenkins (1999)
- Kim, Kim (2000)
- Seo, Armstrong, Chaffin, Ashton-Miller (2008)

For key handle, the most similar studies for comparison:

- Peebles, Norris (2002)

However, no study in the published literature was found to compare with the result of the current study for ellipsoid handle.

Even though, all of the studies mentioned above were explained in detail in the literature review part, some specific information about them are given once more.

(a) Current study vs. Seo *et al.* (2008) for cylindrical handle:

Seo *et al.* (2008) conducted a study in USA to investigate the relationship among friction, applied torque, and axial push force on cylindrical handles. Twelve subjects (6 F and 6 M) with age ranging from 21 to 35 years grasped a cylindrical object with diameters of 57.8 and 51.2 mm in a power grip, and performed maximum torque exertions about the long axis of the handle in two directions: the direction the thumb points and the direction the fingertips point. Subjects were seated with an elbow flexed about 90° and forearm horizontal, and grasped a vertical cylindrical handle with the right hand in a power grip. Results indicated that axial push force was 12% greater for the rubber handle than for the aluminum handle. Even though, diameters and gripping methods differ, the results of t-tests indicated that there is no statistical difference between rubber cylindrical handle and handle of the current study, and there is not a statistical difference for aluminum cylindrical handle.

Table 6.1. Comparison of results for cylindrical handle of current study with rubber cylindrical handle of Seo *et al.*'s study (age range: 21-35).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Seo <i>et al.</i> (2008)	6	8.7	2.5	1	1.16	1.11	0.318	5
Current Study	66	7.54	1.9	0.23				

Table 6.2. Comparison of results for cylindrical handle of current study with aluminum cylindrical handle of Seo *et al.*'s study (age range: 21-35).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Seo <i>et al.</i> (2008)	6	6.9	1.3	0.53	-0.64	-1.1	0.306	7
Current Study	66	7.54	1.9	0.23				

(b) Current study vs. Miller, Nair and Baratz (2005) for circular handle:

Miller, Nair and Baratz (2005) used a simple device to quantify twisting strength of 64 normal subjects from USA (no history of upper extremity pathology) with age average 40.5 ± 12 and age range 19–74. 46 of them were females with average age 41 ± 12 and 18 of the normal subjects were males with average age 39 ± 13 . In addition, 13 (9 Male, 4 Female) subjects (with arthritis of the thumb carpometacarpal joint) with average age 58 ± 8 were measured as well. During the experiments, subjects applied a twisting torque to each of the five disks (ranging in diameters from 2.5 to 12.5), with each hand, in both the clockwise and counterclockwise directions for three trials.

The test posture is not clear enough to compare with the current study but at least for male subjects with dominant hand, and in sitting position twisting strength was found as follows 2.16 Nm for 5 cm diameter disk and 3.37 Nm for 7.5 cm diameter disk. These two diameters were chosen, because they are the closest to the 5.99 cm diameter of circular handle that was used in the current study. For the current study, the hand torque strength in sitting posture for circular handle was 4.83 Nm for males. Two independent t-tests were done for these two diameters to compare results. As can be seen in Table 6.1 and Table 6.2, there are statistical differences between the current study and Miller *et al.* (2005) study. This difference might be explained by the difference in diameters, materials of the handles and even gripping method, and population.

Table 6.3. Comparison of results for circular handle of current study with 5 cm diameter disk of Miller *et al.*'s study (age range: 19-74).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	P- value	DoF
Miller, Nair, Baratz (2005)	18	2.16	0.63	0.15	-2.67	-16.27	< 0.001	25
Current Study	257	4.83	1.12	0.07				

Table 6.4. Comparison of results for circular handle of current study with 7.5 cm diameter disk of Miller *et al.*'s study (age range: 19-74).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	P- value	DoF
Miller, Nair, Baratz (2005)	18	3.37	0.86	0.2	-1.46	-6.81	< 0.001	21
Current Study	257	4.83	1.12	0.07				

(c) Current study vs. Peebles and Norris (2003):

(i) For circular handle:

In the study of Peebles and Norris (2003), however around 150 subjects, from UK population, aged from 2 to 86 years were measured for six different strength exertion respectively, finger push strength, pinch-pull strength, handgrip strength, wrist twisting strength, opening strength, and push and pull strength. For wrist twisting strength, subjects exerted their maximum static torques of dominant hand for 5 seconds on a clockwise direction to various handles like door lever (diameter 15 mm; length 170 mm); door knob (diameter 65 mm; depth 45 mm); (iii) circular knob (diameter 40 mm; depth 20 mm); ridged knob (length 40 mm; depth 15 mm); butterfly nut (length 40 mm; depth 10 mm); and tap (diameter 50 mm; depth 40 mm). All handles were positioned at elbow height and orientated vertically. Subjects were in standing posture while applying twisting force. For the purpose of comparison only the age groups which are between 20 and 70 years were taken into consideration because current study includes only the groups with ages ranging from 18 to 69 years. Diameter of the circular knob used in Peebles and Norris (2003) is smaller than that was used in the current study. Strength values which were measured in free standing posture were compared with appropriate strength values of current study. P values of independent t-test show that there are no statistical differences between circular handle of current study for each age ranges (Tables 6.5, 6.6, 6.7 and 6.8).

Table 6.5. Comparison of results for circular handle of current study with 4 cm diameter disk of Peebles, Norris's study (age range: 21-30).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	P- value	DoF
Peebles, Norris (2002)	7	4.1	1.8	0.68	-0.82	-1.15	0.29	7
Current Study	43	4.92	1.36	0.21				

Table 6.6. Comparison of results for circular handle of current study with 4 cm diameter disk of Peebles, Norris's study (age range: 31-50).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	P- value	DoF
Peebles, Norris (2002)	5	4.5	1.7	0.76	-0.94	-1.22	0.29	4
Current Study	98	5.44	1.31	0.13				

Table 6.7. Comparison of results for circular handle of current study with 4 cm diameter disk of Peebles, Norris's study (age range: 51-60).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	P- value	DoF
Peebles, Norris (2002)	4	4.2	1.1	0.55	-0.89	-1.56	0.216	3
Current Study	65	5.09	1.17	0.15				

Table 6.8. Comparison of results for circular handle of current study with 4 cm diameter disk of Peebles, Norris's study (age range: 61-70).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	P- value	DoF
Peebles, Norris (2002)	4	3.2	1.4	0.7	-1.42	-1.96	0.145	3
Current Study	38	4.62	1.14	0.18				

(ii) For key handle:

The butterfly nut is used in torque exertion experiment in the study of Peebles and Norris (2003). The gripping method used in torque measurement of butterfly nut resembles the gripping method of the key handle of the current study. The dimensions of the butterfly nut are different from the dimensions of key handle used in the current study. However, they were compared, at least to see the differences. The following tables show the results of independent t-tests for each age ranges. It can be concluded that there are statistical differences between these two studies results. But as it was explained above,

butterfly nut is not a key handle, it just resembles it in some ways, and difference also can be a result of different dimensions and different material.

Table 6.9. Comparison of results for key handle of current study with butterfly nut of Peebles, Norris's study (age range: 21-30).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Peebles, Norris (2002)	7	3.9	1	0.38	1.82	4.74	0.003	6
Current Study	43	2.08	0.43	0.066				

Table 6.10. Comparison of results for key handle of current study with butterfly nut of Peebles, Norris's study (age range: 31-50).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Peebles, Norris (2002)	5	4.3	1.6	0.72	2.14	2.98	0.041	4
Current Study	98	2.16	0.48	0.048				

Table 6.11. Comparison of results for key handle of current study with butterfly nut of Peebles, Norris's study (age range: 51-60).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Peebles, Norris (2002)	4	3.6	0.8	0.4	1.59	3.95	0.029	3
Current Study	65	2.01	0.39	0.048				

Table 6.12. Comparison of results for key handle of current study with butterfly nut of Peebles, Norris's study (age range: 61-70).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Peebles, Norris (2002)	4	3.2	0.5	0.25	1.39	5.43	0.012	3
Current Study	38	1.81	0.34	0.055				

(d) Current study vs. Kim and Kim (2000) for cylindrical handle:

Kim and Kim (2000) was conducted an experimental study to investigate the effects of body posture and of different types of common non-powered hand tools on maximum volitional torque exertion capabilities of Korean people. Fifteen healthy male and 15 female university students were participated in the experiment. Each participant exerted

their maximum volitional torque in 15 different body postures while using five different common non-powered hand tools.

Two of the 15 postures are similar to the sitting and standing postures in the current study, handle at the elbow height with the horizontal tool axis. In addition, among five hand tools only one of them (cylindrical handle), is similar to the handles used in the current study. Kim and Kim (2000) conducted the study where male subjects were university students, therefore, in order to make logical comparison with the current study, only the non-manual subjects with age ranging from 18 to 29 are considered. Even though, the diameter of cylindrical handle is 34 mm, which is smaller than 50.7 mm diameter of current study, the independent t-test results indicate that there is a statistically significant difference between the current study and Kim and Kim (2000).

Table 6.13. Comparison of sitting results for cylindrical handle of current study with cylindrical handle of Kim, Kim's study (age range: 18-29).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Kim, Kim (2000)	15	11.4	1.52	0.39	3.52	6.02	< 0.001	36
Current Study	25	7.88	2.17	0.43				

Table 6.14. Comparison of standing results for cylindrical handle of current study with cylindrical handle of Kim, Kim's study (age range: 18-29).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Kim, Kim (2000)	15	12.66	1.73	0.45	4.77	7.56	<0.001	35
Current Study	25	7.89	2.23	0.45				

(e) Current study vs. Imrhan and Jenkins (1999) for cylindrical handle:

Imrhan and Jenkins (1999) tried to determine the effects of four variables with various levels on the torquing capabilities of American male and female adults in simulated maintenance tasks. Ten male (28 - 43 years) and ten female (25 - 40 years) subjects were tested. During the experiments subjects were exerted static MVC torques on a 2.25 in (57.2 mm) diameter cylindrical handle with each hand over 24 different test conditions defined by combinations of levels among 4 variables which were surface finish,

wrist action, arm position, and hand laterality. Subjects were required to grip handles bare-handed with power grip in comfortable standing posture.

In order to compare the current study with Imrhan and Jenkins's study, the most similar experimental conditions were taken, therefore torque strength values for smooth cylindrical handles, with flexion torque in 90 degrees arm position was considered. It was seen from independent t-test results, that there is a statistical difference between these two studies, but it is important to keep in mind, that, slightly different arm position, larger diameter and some other different experimental conditions can lead to this statistical differences.

Table 6.15. Comparison of results for cylindrical handle of current study with aluminum cylindrical handle of Imrhan, Jenkins's study (age range: 28-43).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Imrhan, Jenkins (1997)	10	9.11	0.72	0.23	1.57	5	<0.001	29
Current Study	73	7.54	1.85	0.22				

Table 6.16. Summary results of previous studies.

Population of Turkey vs.	Country	Sample Size (Male)	Handle Type	Age Range	Posture	TS (Nm)
Seo <i>et al.</i> (2008)	USA	6	Cylindrical handle (dia:57.8 mm rubber)	21-35	Sitting	8.7±2.5
Seo <i>et al.</i> (2008)	USA	6	Cylindrical handle (dia: 57.8 mm aluminum)	21-35	Sitting	6.9±1.3
Miller, Nair & Baratz (2005)	USA	18	Disk (dia:5 cm)	19-74	Sitting	2.16±0.63
Miller, Nair & Baratz (2005)	USA	18	Disk (dia:7.5 cm)	19-74	Sitting	3.37±0.86
Peebles, Norris (2003)	UK	7	Disk (dia:4 cm)	21-30	Standing	4.1±1.8
Peebles, Norris (2003)	UK	5	Disk (dia:4 cm)	31-50	Standing	4.5±1.7
Peebles, Norris (2003)	UK	4	Disk (dia:4 cm)	51-60	Standing	4.2±1.1
Peebles, Norris (2003)	UK	4	Disk (dia:4 cm)	61-70	Standing	3.2±1.4
Peebles, Norris (2003)	UK	7	Butterfly nut	21-30	Standing	3.9±1
Peebles, Norris (2003)	UK	5	Butterfly nut	31-50	Standing	4.3±1.6
Peebles, Norris (2003)	UK	4	Butterfly nut	51-60	Standing	3.6±0.8
Peebles, Norris (2003)	UK	4	Butterfly nut	61-70	Standing	3.2±0.5
Kim, Kim (2000)	Korea	15	Cylindrical handle (dia:34 mm)	18-29	Sitting	11.4±1.52
Kim, Kim (2000)	Korea	15	Cylindrical handle (dia:34 mm)	18-29	Standing	12.66±1.73
Imrhan, Jenkins (1999)	USA	10	Cylindrical handle (dia: 57.2 mm aluminum)	28-43	Standing	9.11±0.72

Table 6.17. Summary of comparisons.

Population of Turkey vs.	Country	Sample Size	% Diff.	t-value (p-value)	Handle Type	Age Range	Posture
Seo <i>et al.</i> (2008)	USA	6	-15.38	1.11 (0.318)	Cylindrical handle (dia:57.8 mm rubber)	21-35	Sitting
Seo <i>et al.</i> (2008)	USA	6	8.49	-1.1 (0.306)	Cylindrical handle (dia: 57.8 mm aluminum)	21-35	Sitting
Miller, Nair & Baratz (2005)	USA	18	55.28	-16.27 (<0.001)	Disk (dia:5 cm)	19-74	Sitting
Miller, Nair & Baratz (2005)	USA	18	30.23	-6.81 (<0.001)	Disk (dia:7.5 cm)	19-74	Sitting
Peebles, Norris (2003)	UK	7	16.67	-1.15 (0.29)	Disk (dia:4 cm)	21-30	Standing
Peebles, Norris (2003)	UK	5	17.28	-1.22 (0.29)	Disk (dia:4 cm)	31-50	Standing
Peebles, Norris (2003)	UK	4	17.49	-1.56 (0.216)	Disk (dia:4 cm)	51-60	Standing
Peebles, Norris (2003)	UK	4	30.74	-1.96 (0.145)	Disk (dia:4 cm)	61-70	Standing
Peebles, Norris (2003)	UK	7	-87.5	4.74 (0.003)	Butterfly nut	21-30	Standing
Peebles, Norris (2003)	UK	5	-99.07	2.98 (<0.041)	Butterfly nut	31-50	Standing
Peebles, Norris (2003)	UK	4	-79.1	3.95 (0.029)	Butterfly nut	51-60	Standing
Peebles, Norris (2003)	UK	4	-76.8	5.43 (0.012)	Butterfly nut	61-70	Standing
Kim, Kim (2000)	Korea	15	-44.67	6.02 (<0.001)	Cylindrical handle (dia:34 mm)	18-29	Sitting
Kim, Kim (2000)	Korea	15	-60.46	7.56 (<0.001)	Cylindrical handle (dia:34 mm)	18-29	Standing
Imrhan, Jenkins (1999)	USA	10	-20.82	5 (<0.001)	Cylindrical handle (dia: 57.2 mm aluminum)	28-43	Standing

% Difference = $100 \times (\text{mean for Pop. of Turkey} - \text{mean for comparison nationality}) / \text{mean of Pop. of Turkey}$

The sample sizes of the studies compared are considerably small so the results of these studies may not be reliable enough to make a realistic comparison with the current study. Moreover, there are so many conditions that lead to difference between the current study and study compared with. One of them is handle type, difference in the dimensions

and structure of the hand tool can lead to difference between two studies. Another one can be posture.

(f) A comparison with the female torque strength of population of Turkey:

The results of the current study was also compared with the study of Recep (2013) which was a unique hand torque strength study conducted on female population of Turkey. The results of the comparison indicated that mean hand torque strength of males are significantly greater than mean hand torque strength of female population of Turkey in all handle types and postures. The results of the comparison are shown in the Table 6.18.

Table 6.18. Summary of comparisons with the study of (Recep, 2013).

Sample Size	% Diff.	t-value (p-value)	Handle Type	Age Range	Posture
257	33.5	- 17.01 (<0.001)	Ellipsoid Handle	18-69	Sitting
257	31.6	-17.37 (<0.001)	Circular Handle	18-69	Sitting
257	19.3	-11.19 (<0.001)	Key Handle	18-69	Sitting
257	27.2	-13.4 (<0.001)	Cylindrical Handle	18-69	Sitting
257	30.3	-15.15 (<0.001)	Ellipsoid Handle	18-69	Standing
257	31.2	-16.41 (<0.001)	Circular Handle	18-69	Standing
257	19.5	-10.42 (<0.001)	Key Handle	18-69	Standing
257	25	-12.21 (<0.001)	Cylindrical Handle	18-69	Standing

7. CONCLUSIONS

The aim of the study was estimating the maximum voluntary hand torque strength capacity of adult male population of Turkey. The data were collected in both sitting and standing postures with four different handle types. Statistical analyses were performed to investigate the effects of handle type, posture, age, job, BMI and some anthropometric variables on torque strength. The correlation analysis was conducted to investigate the linear relationship between hand torque strengths and some anthropometric variables. Regression analysis was performed prediction models for hand torque strength. Lastly, comparisons were made with some studies on other nationalities in the literature. Based on the analysis results, the following conclusions can be drawn:

- (i) Static hand torque strength norms of male population of Turkey were established.
- (ii) The hand torque strength peaks between 40-49 years for both non-manual and manual workers in all handles following a slightly curvilinear trend, except for cylindrical handle. For cylindrical handle, TS peaks at 18-29 age group and gradually decreases. However, the differences from 18 to 49 years are insignificant.
- (iii) Means of hand torque strength values for normal and overweight body mass index groups are not statistically different.
- (iv) Manual workers have significantly higher hand torque strength values than non-manual workers. The difference of mean is 12%.
- (v) On average, torque strength in standing is higher than in sitting. However, the difference may be insignificant in practical application.
- (vi) The most important factor affecting hand torque strength is handle type. The mean values of hand torque values for four different handle types are significantly different from each other. The lowest strength values are measured by using key handle and the highest strength values are measured by using cylindrical handle. In addition, the

mean strength values of circular handle are significantly higher than the mean strength values of ellipsoid handle.

- (vii) With some exceptions, height, hand length, hand breadth, forearm circumference and grip strength are significantly correlated with hand torque strength.

This study is a comprehensive study on hand torque strength investigating a great number of factors in a single study. The effect of job-group which was not investigated before in any male hand torque studies was investigated in this study. Also studying a sample of handles taken from the real world with well-defined properties, especially like key handle, which was not studied before, enable the study to investigate handle-hand torque strength interaction. Beside handle type, this study has also focused on relationship between body posture and hand torque strength.

7.1. Recommendations for Future Research and Practicionary

In the current study, hand torque strength of Turkish male population aged between 18 to 69 years was investigated in two different postures with four different handles. However, there are still many gaps related hand torque strength to be filled. This study became an initial but meanwhile profound and comprehensive step in estimating the hand torque strength of male population of Turkey.

Data on hand torque strength of children and older adults over 70 years old remain fruitful areas for future hand torque strength research in Turkey. Therefore, future hand torque studies should be much more focused on these age ranges.

This study has used four handles which are commonly used in many daily and work tasks. However hand torque strengths involving various handle design in terms of material, size, knurling, diameter and shape should be considered for the future research. Especially, future studies should examine a wider range of diameters of current handles, to evaluate the effect of handle diameter.

Handles examined in this study were always on elbow height, so the influence of different arm configurations has not been quantified, therefore it will be also useful to examine the effects of different handle locations on hand torque strength.

In the current study, hand torque strength was exerted by dominant hands so strength capabilities of other hand remain unknown. Some work are required the strength of both hands together. Therefore, it might be useful to examine the hand torque strength capabilities of non dominant hand.

Moreover, environmental conditions were predetermined in the current study. When working conditions were considered, the environmental conditions like temperature and humidity change in considerable ranges. In order to make an efficient design the effect of environmental conditions on hand torque strength could be examined.

It is hoped that further studies will be undertaken in order to clarify the problems which remain unsolved in the current study. It is also essential to be conscious about the practicatory of the torque strength data available.

Torque strength data is useful to design safe and efficient work stations and daily life equipments. So, in the near future, torque strength capabilities of people will be more valuable for designers. With utilizing torque strength data, designers can design equipments that can be used by the majority of a population.

APPENDIX A: FORMS

Appendix A includes the necessary forms that were used during the experiments. These forms are brief medical history form, personal consent form and data collection form respectively. Since, the experiment was conducted in Turkey; Brief Medical History form and Personal Consent form are also prepared in Turkish.

(i) Brief Medical History Form: The health conditions of the candidates were questioned by this form because the subjects must be healthy enough for the experiments. All candidates are asked some health questions and only ones who are free from any musculoskeletal disorders and related health problems are accepted to participate in the study.

(ii) Personal Consent Form: The participants then must sign the “Personal Consent Form”, which includes a detailed description of the objectives and procedures of the study. In order to ensure the voluntary participation of the subjects to the study, this form was being signed. In this form, it was reported that all information obtained during the study would be held in strict confidence.

(iii) Personal Data Form: The participants also give the information related age, occupation, family origin, and mother and father’s birthplace, dominant hand, preferred handgrip span, smoking and physical condition, these information are recorded on form, which called “Personal Data Form”. Some anthropometric measurements like height, weight, dominant hand length, dominant hand breadth, dominant hand wrist circumference and dominant hand forearm circumference are also measured during the study and are recorded on “Personal Data Form”.

(iv) Instructions: In order to prevent the confusion of the participant, the experimenter will direct the subjects according to these instructions.

A.1. Brief Medical History Form

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

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

Check space if you now have or recently had.

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

Check space for medications you are now taking.

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

Please list any other prescribed medications you are now taking.

A.2. Sağlık Anketi

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

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

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

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

Aşağıdaki sorunlarla ilgili ilaç alıyorsanız, çarpı işaretiyle işaretleyiniz.

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

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

A.3. Personal Consent Form

In this thesis study, the aim is to determine the maximum wrist twisting force statistics of Turkish male population ranging between 18 and 69 years old in sitting and standing postures while applying force to four different handles. You do not have any serious health problem which affects your participation to the experiments adversely.

The strength statistics that is determined via this study can be used to design hand tools which are appropriate to the usage of Turkish males in the daily life and industrial life. Thanks to designs which are made by using this data, the worker satisfaction and also productivity will increase in the daily and industrial life.

If you decided to participate, please take into consideration the issues below.

1. Before the experiments, your birthday, birth place, your family origin, occupation, dominant hand, sport and smoking abilities will be asked, after that, your height, weight, dominant hand length and breadth, and wrist and forearm circumference will be measured.
2. Experiments will be performed in a predetermined random order and utilizing Caldwell protocol. The experiments will be performed in two different body postures; sitting and standing. The appropriate grasping style and posture for each measurement will be shown you by the experimenter. Four different handle will be used in the experiments. After checking that you are in the correct position and 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 four different handle with dominant hand in the sitting and standing postures by repeating the tests at least two times, so at least 16 tests will be done. The tests will be performed in a predetermined order and there will be 2 minutes break 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.

3. Before the tests, participants should not be full. Hungry, or sleepless, and should not consume harmful substances. 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 Ersin Baştürk or Dr. Mahmut Ekşioğlu from Department of Industrial Engineering of Boğaziçi University.

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

Signature of Participant:

Date:

A.4. Kişisel Kabul Formu

Bu tez çalışmasında, 18 ile 69 yaş arasındaki Türk erkeklerinin oturarak ve ayakta iken baskın elleriyle, dört farklı kulpa uygulayacakları maksimum çevirme kuvvetinin istatistiklerini belirlemek hedeflenmektedir. Bu çalışmaya engel teşkil edecek herhangi bir sağlık probleminizin olmamasından dolayı, deneylere katılmak için uygun durumda bulunmaktasınız.

Bu çalışmadan elde edilecek kuvvet istatistikleri, el aletleri başta olmak üzere endüstride ve günlük hayatta kullanılan birçok aletin, Türk erkeklerinin kullanımına uygun bir şekilde tasarlanması için kullanılabilir. Bu veriler kullanılarak yapılacak tasarımlar sayesinde hem günlük hayatta hem de iş yaşamında çalışan memnuniyeti ve dolayısıyla verimlilik artacaktır.

Eğer katılmaya karar verdiyseniz, lütfen aşağıdaki hususlara dikkat ediniz.

1. Deneye başlamadan önce doğum tarihiniz, doğum yeriniz, ailenizin doğum yeri, mesleğiniz, baskın eliniz, spor ve sigara gibi alışkanlıklarınız sorulacak ve akabinde boyunuz, kilonuz, baskın el uzunluğunuz, baskın el genişliğiniz, bilek ve önkol çevreniz ölçülecektir.
2. Deneyler rassal sıraya göre ve Caldwell protokolüne uygun olarak gerçekleştirilecektir. Deneyler oturarak ve ayakta olmak üzere iki farklı vücut pozisyonunda gerçekleştirilecektir. Tutuş ve duruş biçimleri deney yürütücüsü tarafından sizlere gösterilecektir. Deneyde dört farklı kulp kullanılmaktadır. Kulba uygun şekilde tutmanız sağlandıktan sonra hazır olduğunuzda, deney yürütücüsünün başla komutuyla deney başlayacak ve yaklaşık 1-2 saniyede maksimum çevirme kuvvetine ulaşmanız ve 3-4 saniye boyunca o maksimum değerde tutmanız istenecektir. Bu deney dört farklı kulp için oturarak ve ayakta, sadece baskın elle ve asgari ikişer defa tekrarlanacak olup en az 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.

3. Deneylerden önce katılımcılar çok aç, fazla tok veya uykusuz olmamalı, zararlı maddeler tüketmemelidirler. 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 Ersin Baştürk veya Doç. 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.5. Personal Data Form

1. General Information about the Subject

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

2. Anthropometric Measurements of the Subject

Stature (cm)	
Weight (kg)	
Dominant Hand length (cm)	
Dominant Hand breadth (cm)	
Dominant Hand Circumference of wrist (cm)	
Dominant Hand Circumference of forearm (cm)	

3. Grip Strength Data of the Subject (Dominant Hand)

Measure	Trial 1	Trial 2	Trial 3
Grip strength while sitting			
Grip strength while standing			

4. Hand Torque Strength Data of the Subject (Dominant Hand)

Measure	Trial 1	Trial 2	Trial 3
Ellipsoid Handle Torque Strength while sitting			
Circular Handle Torque Strength while sitting			
Key Handle Torque Strength while sitting			
Cylindrical Handle Torque Strength while sitting			
Ellipsoid Handle Torque Strength while standing			
Circular Handle Torque Strength while standing			
Key Handle Torque Strength while standing			
Cylindrical Handle Torque Strength while standing			

A.6. Instructions

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

A.7. Talimatlar

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

APPENDIX B: Experimental Conditions Forms

Subject no		Posture															
		Sitting								Standing							
		Ellipsoid		Circular		Key		Cylinder		Ellipsoid		Circular		Key		Cylinder	
		Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails	Trails
		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	Order	2	2	6	6	3	3	5	5	7	7	8	8	1	1	4	4
	MVC	5.85	5.35	4.03	4.86	1.75	1.42	9.79	10.63	4.25	3.30	4.08	4.53	1.72	1.58	7.69	7.67
2	Order	3	3	7	7	6	6	4	4	2	2	8	8	5	5	1	1
	MVC	3.66	3.66	3.92	3.42	2.71	2.48	3.47	3.09	4.32	4.18	3.56	3.45	1.65	1.77	8.54	8.47
3	Order	3	3	8	8	6	6	7	7	4	4	1	1	2	2	5	5
	MVC	2.31	2.19	3.55	3.44	1.20	0.99	7.79	7.86	1.30	1.37	4.32	4.39	0.97	0.97	6.51	6.39
4	Order	1	1	4	4	3	3	8	8	6	6	5	5	7	7	2	2
	MVC	4.16	3.99	4.89	5.10	1.25	1.30	7.36	7.50	4.67	4.32	4.36	4.39	1.87	2.08	8	7.8
5	Order	5	5	6	6	4	4	8	8	3	3	7	7	2	2	1	1
	MVC	4.01	3.99	4.58	4.20	1.42	1.39	5.78	5.46	4.53	4.08	4.93	4.62	1.32	1.16	4.84	4.94
,	Order																
,	,																
,	MVC																
257	Order	6	6	3	3	8	8	4	4	7	7	1	1	5	5	2	2
	MVC	3.38	3.17	4.04	4.23	1.74	1.83	5.17	4.89	4.04	3.86	4.69	4.48	2.08	1.97	4.93	4.88

APPENDIX C: REGRESSION EQUATION

C.1. Regression Models for Full Data

Hand torque strength	- Nm
Age	- Years
Height	- cm
Weight	- kg
BMI	- kg/m ²
DHL	- cm
DHB	- cm
DHCW	- cm
DHCF	- cm

Model 1. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & - 5.97 + 0.00448 \times \text{Age} + 0.0529 \times \text{Height} - 0.0466 \times \text{Weight} + \\ & 0.105 \times \text{BMI} - 0.0258 \times \text{DHL} + 0.195 \times \text{DHB} - 0.0268 \times \text{DHCW} + 0.0642 \times \text{DHCF} + \\ & 0.00475 \times \text{Grip Strength} - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} \\ & - 0.169 \times \text{Sitting Posture} + 0.362 \times \text{Manual} \end{aligned}$$

Model 2. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & - 0.243 + 0.00446 \times \text{Age} + 0.0198 \times \text{Height} - 0.0119 \times \text{Weight} - \\ & 0.0245 \times \text{DHL} + 0.189 \times \text{DHB} - 0.0256 \times \text{DHCW} + 0.0652 \times \text{DHCF} + 0.00478 \times \text{Grip Strength} \\ & - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} - 0.169 \times \text{Sitting Posture} \\ & + 0.365 \times \text{Manual} \end{aligned}$$

Model 3. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & 2.48 + 0.00383 \times \text{Age} - 0.0385 \times \text{BMI} + 0.0067 \times \text{DHL} + 0.198 \times \text{DHB} - \\ & 0.0255 \times \text{DHCW} + 0.0698 \times \text{DHCF} + 0.00486 \times \text{Grip Strength} - 2.79 \times \text{Ellipsoid Handle} - \\ & 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} - 0.169 \times \text{Sitting Posture} + 0.355 \times \text{Manual} \end{aligned}$$

Model 4. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & - 0.061 + 0.0562 \times \text{Age} - 0.000578 \times \text{Age}^2 + 0.0147 \times \text{Height} - \\ & 0.0516 \times \text{DHL} + 0.132 \times \text{DHB} - 0.0206 \times \text{DHCF} + 0.0132 \times \text{Grip Strength} - 0.000010 \times \text{Hand} \\ & \text{Grip}^2 - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} - 0.169 \times \text{Sitting} \\ & \text{Posture} + 0.369 \times \text{Manual} \end{aligned}$$

Model 5. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & 0.087 + 0.0744 \times \text{Age} - 0.000811 \times \text{Age}^2 + 0.0152 \times \text{Height} + \\ & 0.00488 \times \text{Grip Strength} - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} \\ & - 0.169 \times \text{Sitting Posture} + 0.397 \times \text{Manual} \end{aligned}$$

Model 6. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & 3.39 + 0.0765 \times \text{Age} - 0.000848 \times \text{Age}^2 + 0.00518 \times \text{Grip Strength} - \\ & 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} - 0.169 \times \text{Sitting Posture} + \\ & 0.368 \times \text{Manual} \end{aligned}$$

Model 7. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & 4.73 + 0.00351 \times \text{Age} + 0.00531 \times \text{Grip Strength} - 2.79 \times \text{Ellipsoid Handle} \\ & - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} - 0.169 \times \text{Sitting Posture} + 0.399 \times \text{Manual} \end{aligned}$$

Model 8. The regression equation is

$$\begin{aligned} \text{Torque Strength} = & 6.76 - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle} \\ & - 0.169 \times \text{Sitting Posture} + 0.574 \times \text{Manual} \end{aligned}$$

Model 9. The regression equation is

$$\text{Torque Strength} = 6.97 - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle}$$

Model 10. The regression equation is

$$\text{Torque Strength} = 3.13 + 0.0818 \times \text{Age} - 0.000882 \times \text{Age}^2 + 0.00575 \times \text{Grip Strength} - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle}$$

Model 11. The regression equation is

$$\text{Torque Strength} = 0.873 + 0.0801 \times \text{Age} - 0.000850 \times \text{Age}^2 + 0.0136 \times \text{Height} + 0.00549 \times \text{Grip Strength} - 2.79 \times \text{Ellipsoid Handle} - 2 \times \text{Circular Handle} - 4.96 \times \text{Key Handle}$$

C.2. Regression Models for Partial Data

Hand torque strength	- Nm
Age	- Years
Height	- cm
Weight	- kg
BMI	- kg/m ²
DHL	- cm
DHB	- cm
DHCW	- cm
DHCF	- cm

Model 1. The regression equation is

$$TS_{Ellipsoid (Sitting)} = - 3.37 + 0.0150 \times \text{Age} - 0.0475 \times \text{BMI} + 0.811 \times \text{DHB} + 0.00252 \times \text{Grip Strength}$$

Model 2. The regression equation is

$$TS_{Ellipsoid (Standing)} = - 10.5 + 0.194 \times \text{Age} - 0.00207 \times \text{Age}^2 + 0.0503 \times \text{Stature} - 0.0300 \times \text{Weight} - 0.211 \times \text{DHL} + 0.806 \times \text{DHB} + 0.00273 \times \text{Grip Strength}$$

Model 3. The regression equation is

$$TS_{Circular (Sitting)} = - 2.62 + 0.131 \times \text{Age} - 0.00140 \times \text{Age}^2 + 0.4 \times \text{DHB} + 0.00346 \times \text{Grip Strength}$$

Model 4. The regression equation is

$$TS_{Circular (Standing)} = - 1.68 + 0.154 \times \text{Age} - 0.00151 \times \text{Age}^2 - 0.233 \times \text{DHL} + 0.545 \times \text{DHB} + 0.00755 \times \text{Grip Strength}$$

Model 5. The regression equation is

$$TS_{Key (Sitting)} = - 0.028 + 0.197 \times \text{DHB} + 0.000714 \times \text{Grip Strength}$$

Model 6. The regression equation is

$$TS_{Key (Standing)} = - 0.803 + 0.0397 \times \text{Age} - 0.000443 \times \text{Age}^2 + 0.152 \times \text{DHB} + 0.00189 \times \text{Grip Strength}$$

Model 7. The regression equation is

$$TS_{Cylindrical (Sitting)} = 0.54 - 0.0295 \times \text{Age} + 0.64 \times \text{DHL} - 0.307 \times \text{DHCW} + 0.00448 \times \text{Grip Strength}$$

Model 8. The regression equation is

$$TS_{Cylindrical (Standing)} = -1.14 - 0.0322 \times \text{Age} - 0.0591 \times \text{BMI} + 0.519 \times \text{DHL} + 0.00462 \times \text{Grip Strength}$$

Model 9. The regression equation is

$$TS_{Ellipsoid (Sitting)} = 0.00915329 + 0.109173 \times \text{Age} - 0.00110226 \times \text{Age}^2 + 0.00383072 \times \text{Grip Strength}$$

Model 10. The regression equation is

$$TS_{Ellipsoid (Standing)} = 2.56596 + 0.133382 \times \text{Age} - 0.00133068 \times \text{Age}^2 - 0.180677 \times \text{DHL} + 0.00496056 \times \text{Grip Strength}$$

Model 11. The regression equation is

$$TS_{Circular (Sitting)} = -1.05586 + 0.0202866 \times \text{Age} - 0.0207875 \times \text{Weight} + 0.145802 \times \text{DHCF} + 0.00627523 \times \text{Grip Strength}$$

Model 12. The regression equation is

$$TS_{Circular (Standing)} = 1.25 + 0.141 \times \text{Age} - 0.00136 \times \text{Age}^2 - 0.138 \times \text{DHL} + 0.00781 \times \text{Grip Strength}$$

Model 13. The regression equation is

$$TS_{Key (Sitting)} = -1.33246 + 0.00761324 \times \text{Stature} + 0.182261 \times \text{DHB} + 0.000686576 \times \text{Grip Strength}$$

Model 14. The regression equation is

$$TS_{Key (Standing)} = -1.12 + 0.0321 \times \text{Age} - 0.000320 \times \text{Age}^2 + 0.165 \times \text{DHB} + 0.00246 \times \text{Grip Strength}$$

Model 15. The regression equation is

$$TS_{Cylindrical (Sitting)} = 0.797 + 0.0159 \times \text{Grip Strength}$$

Model 16. The regression equation is

$$TS_{Cylindrical (Standing)} = -5.14 + 0.0391 \times \text{Height} + 0.0140 \times \text{Grip Strength}$$

APPENDIX D: ANOVA TABLES FOR EXERCISE AND SMOKING

Table D-1. ANOVA table for ellipsoid hand torque strength with sitting posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	17.811	14.390	3.597	3.48	0.009
Job Group	1	25.934	25.731	25.731	24.88	< 0.001
BMI Group	1	0.019	0.007	0.007	0.01	0.936
Exercise	1	2.493	2.641	2.641	2.55	0.111
Smoking	1	0.898	0.898	0.898	0.87	0.352
Error	248	256.498	256.498	1.034		
Total	256	303.654				

Table D-2. ANOVA table for circular hand torque strength with sitting posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	10.805	10.455	2.614	2.30	0.059
Job Group	1	27.595	26.974	26.974	23.75	< 0.001
BMI Group	1	0.029	0.041	0.041	0.04	0.850
Exercise	1	0.489	0.462	0.462	0.41	0.524
Smoking	1	0.128	0.128	0.128	0.11	0.738
Error	248	281.606	281.606	1.136		
Total	256	320.650				

Table D-3. ANOVA table for key hand torque strength with sitting posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	1.0766	1.4204	0.3551	2.6	0.037
Job Group	1	1.9645	2.1718	2.1718	15.93	< 0.001
BMI Group	1	0.3754	0.4167	0.4167	3.06	0.082
Exercise	1	0.5843	0.5895	0.5895	4.32	0.039
Smoking	1	0.0073	0.0073	0.0073	0.05	0.817
Error	248	33.8171	33.8171	0.1364		
Total	256	37.8252				

Table D-4. ANOVA table for cylindrical hand torque strength with sitting posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	206.978	107.851	26.963	12.28	< 0.001
Job Group	1	55.317	52.065	52.065	23.70	< 0.001
BMI Group	1	0.379	0.055	0.055	0.03	0.874
Exercise	1	44.17	44.58	44.58	20.30	< 0.001
Smoking	1	0.6	0.6	0.6	0.27	0.602
Error	248	544.714	544.714	2.196		
Total	256	852.158				

Table D-5. ANOVA table for ellipsoid hand torque strength with standing posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	21.514	20.111	5.028	4.47	0.002
Job Group	1	16.286	14.787	14.787	13.13	< 0.001
BMI Group	1	0.961	0.593	0.593	0.53	0.469
Exercise	1	0.359	0.285	0.285	0.25	0.616
Smoking	1	1.643	1.643	1.643	1.46	0.228
Error	248	279.21	279.21	1.126		
Total	256	319.973				

Table D-6. ANOVA table for circular hand torque strength with standing posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	0.15592	0.17154	0.04288	4.15	0.003
Job Group	1	0.23307	0.23629	0.23629	22.85	< 0.001
BMI Group	1	0.00356	0.00060	0.00060	0.06	0.81
Exercise	1	0.02776	0.03059	0.03059	2.96	0.087
Smoking	1	0.0278	0.0278	0.0278	2.69	0.102
Error	248	2.5647	2.5647	0.01034		
Total	256	3.0128				

Table D-7. ANOVA table for key hand torque strength with standing posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	3.6242	3.4256	0.8564	4.48	0.002
Job Group	1	1.5413	1.5601	1.5601	8.17	0.005
BMI Group	1	0.1011	0.1325	0.1325	0.69	0.406
Exercise	1	0.0002	0.0009	0.0009	0.00	0.945
Smoking	1	0.0881	0.0881	0.0881	0.46	0.498
Error	248	47.3634	47.3634	0.1910		
Total	256	52.7183				

Table D-8. ANOVA table for cylindrical hand torque strength with standing posture by adding exercise and smoking as extra independent variables.

Source	DoF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	235.126	110.94	27.735	12.59	< 0.001
Job Group	1	51.689	46.28	46.28	21.01	< 0.001
BMI Group	1	0.088	0.326	0.326	0.15	0.701
Exercise	1	62.174	61.985	61.985	28.13	< 0.001
Smoking	1	0.001	0.001	0.001	0.00	0.981
Error	248	546.411	546.411	2.203		
Total	256	895.489				

APPENDIX E: CHECKING ANOVA ASSUMPTIONS

1) Checking ANOVA Assumptions

a) Normality Test

Although the raw data of maximum hand torque strength is approximately normal, some transformations such as square root ($\sqrt{strength}$), square ($strength^2$), inverse ($1/strength$) and logarithm ($\log(strength)$) were applied to make the raw strength data normally distributed. None of those transformations satisfied the normality assumption. Then, log transformation was applied because it improves the equality of variance assumption. Actually, when the sample sizes are not small and unbalanced, the F test will not be seriously affected by light-tailedness or heavy-tailedness. In particular, small and unbalanced sample sizes can increase vulnerability to assumption violations.

To use ANOVA, residuals of hand torque strength values must fit to normal distribution. Therefore, normality of the residuals of the hand torque strength data were tested by using Anderson-Darling normality test ($\alpha= 0.05$) in Minitab 16.0. According to Anderson- Darling normality test, the p-values of residuals of hand torque strength data is < 0.05 .

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

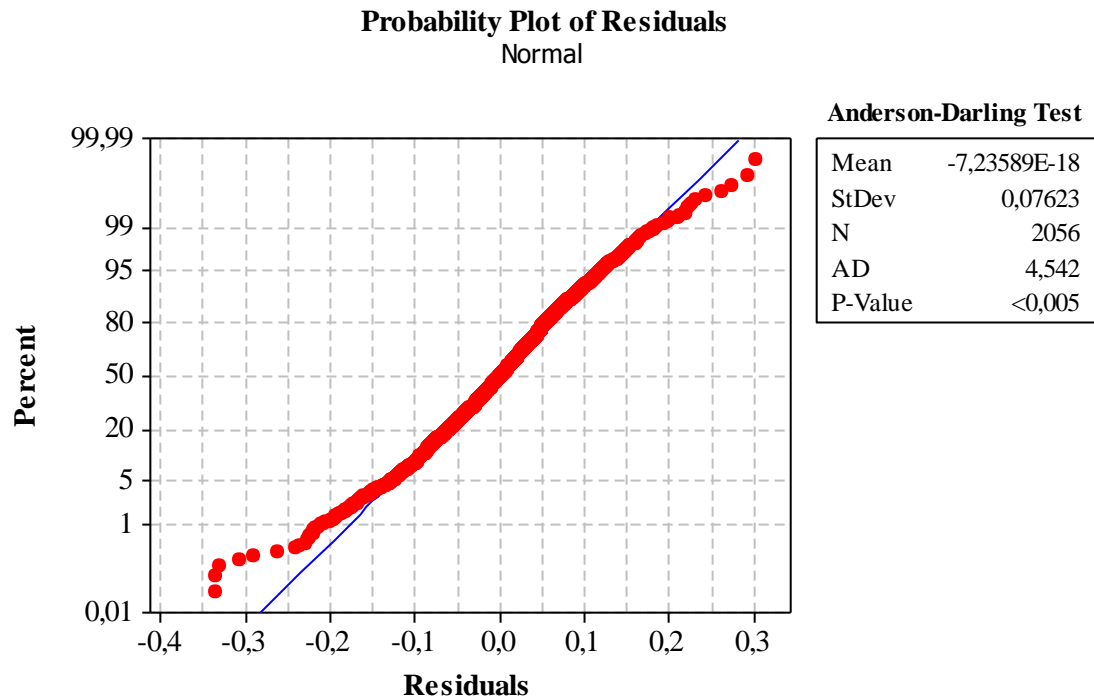


Figure E-1. Normal probability plots of residuals of hand torque strength data for Blocked Design ANOVA.

b) 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).

The plot of the residuals versus observation order for males is shown in Figure. There is no reason to suspect any violation of the independence assumption.

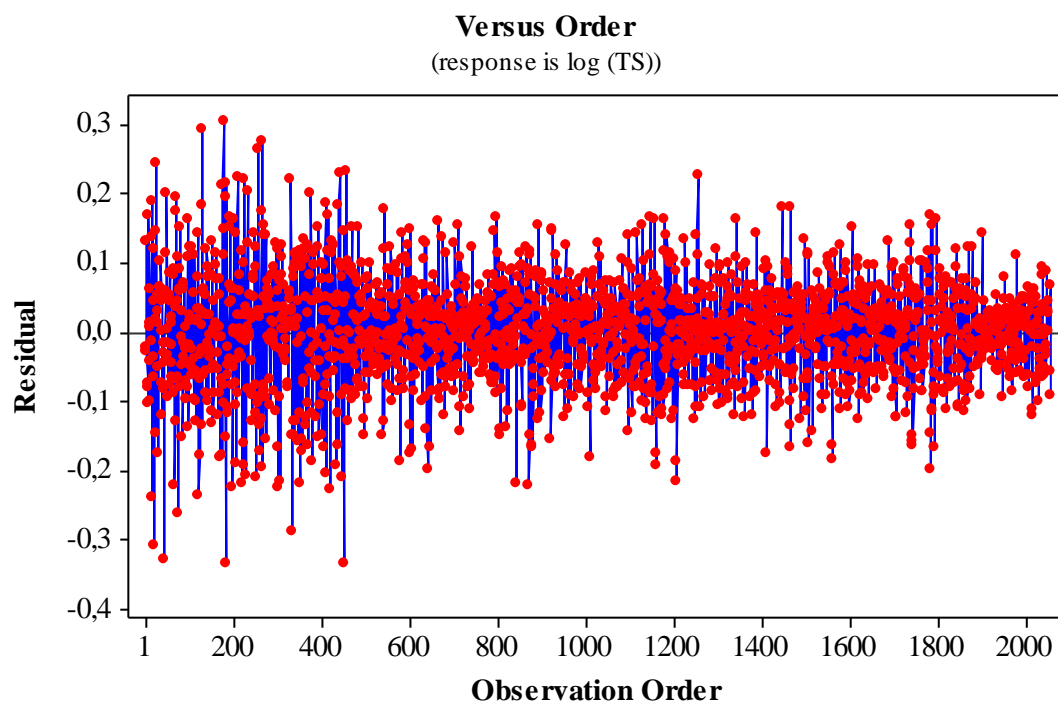


Figure E-2. Plot of residuals versus observation order for blocked ANOVA.

c) 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 below, plot of residuals versus fitted values for males can be seen. In this figure, an unusual structure is apparent. Therefore, equality variance assumption was unsatisfied.

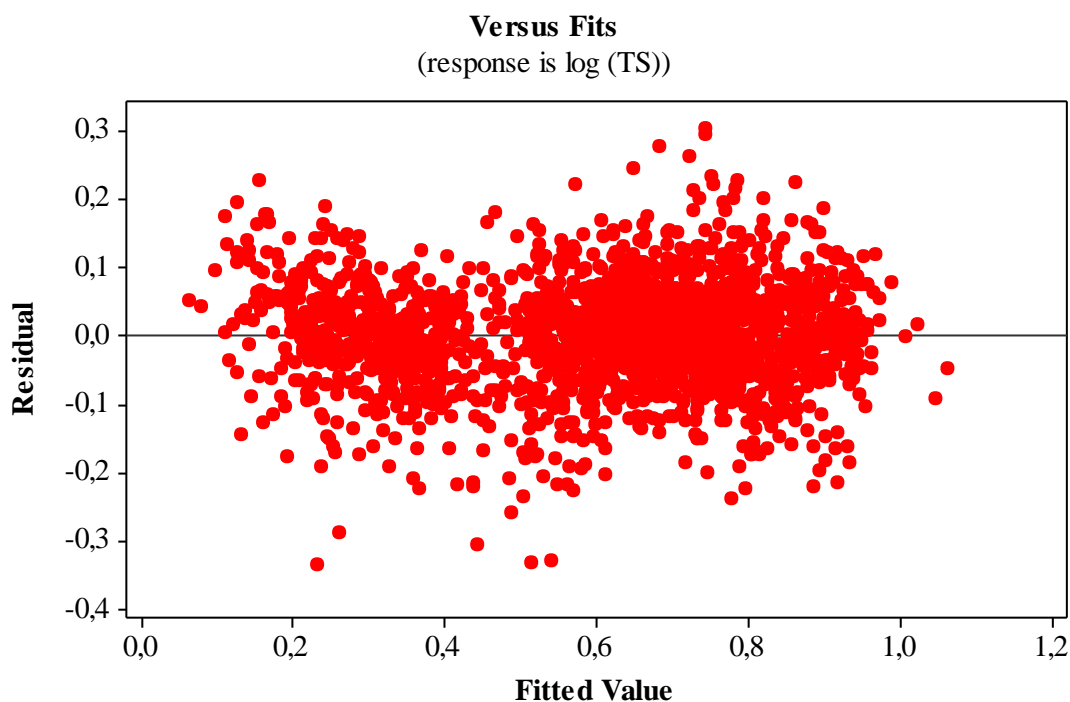


Figure E-3. Plot of residuals versus fitted values of blocked Design ANOVA for males.

2) Interpretation of ANOVA Assumptions

Three main assumptions which are normality of residuals, independence of cases and equality of variances were examined to make a reliable test and get reliable results.

Results of the tests indicated that residuals were approximately normally distributed, independence of cases was satisfied but equality of variances was not satisfied. The main source of this violation was considerable differences between the variances of each handle type.

A potentially more damaging assumption violation occurs when the population variances are unequal, especially if the sample sizes are not approximately equal (unbalanced). However, in the current study sample sizes are approximately equal for almost all independent variables.

Since all of the sample sizes were approximately equal except BMI group, there is not great violation about using ANOVA. To this end, ANOVA procedure can be used for analyzing the data.

APPENDIX F: CHECKING ANOVA ASSUMPTIONS (EIGHT TREATMENT COMBINATIONS)

1) Checking ANOVA Assumptions for Ellipsoid Handle with Sitting

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Ellipsoid Hand Torque Strength with Sitting (Nm)

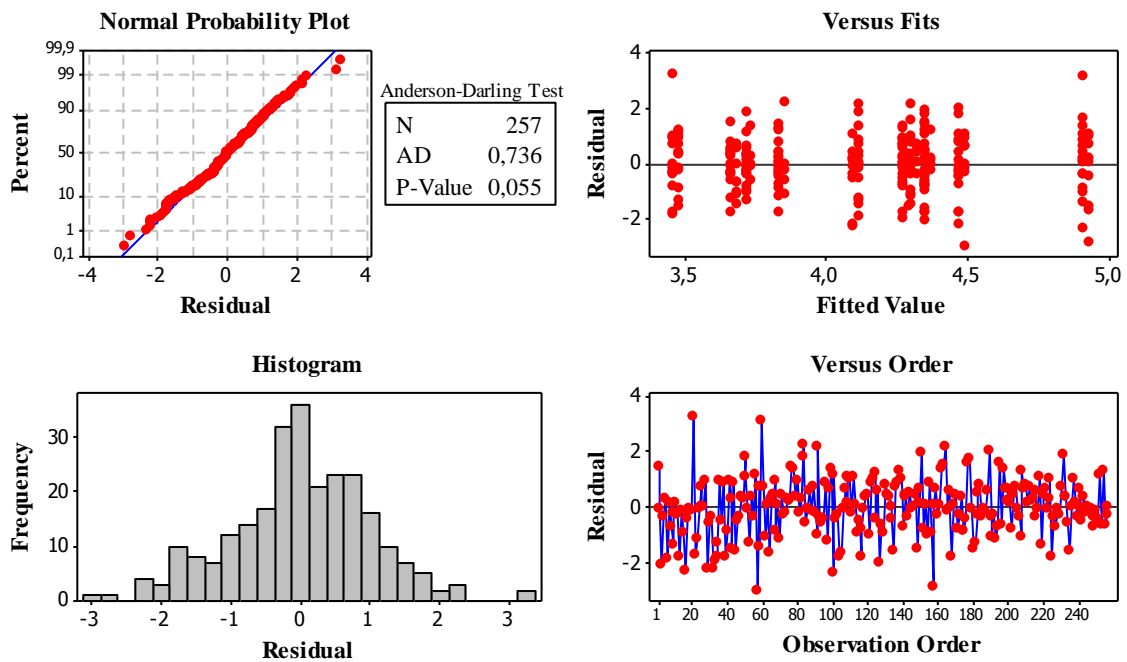


Figure F-1. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve's test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-1. The Result of Levene's test for Ellipsoid Hand Torque Strength with Sitting.

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	0.94	0.536

2) Checking ANOVA Assumptions for Circular Handle with Sitting

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Circular Hand Torque Strength with Sitting (Nm)

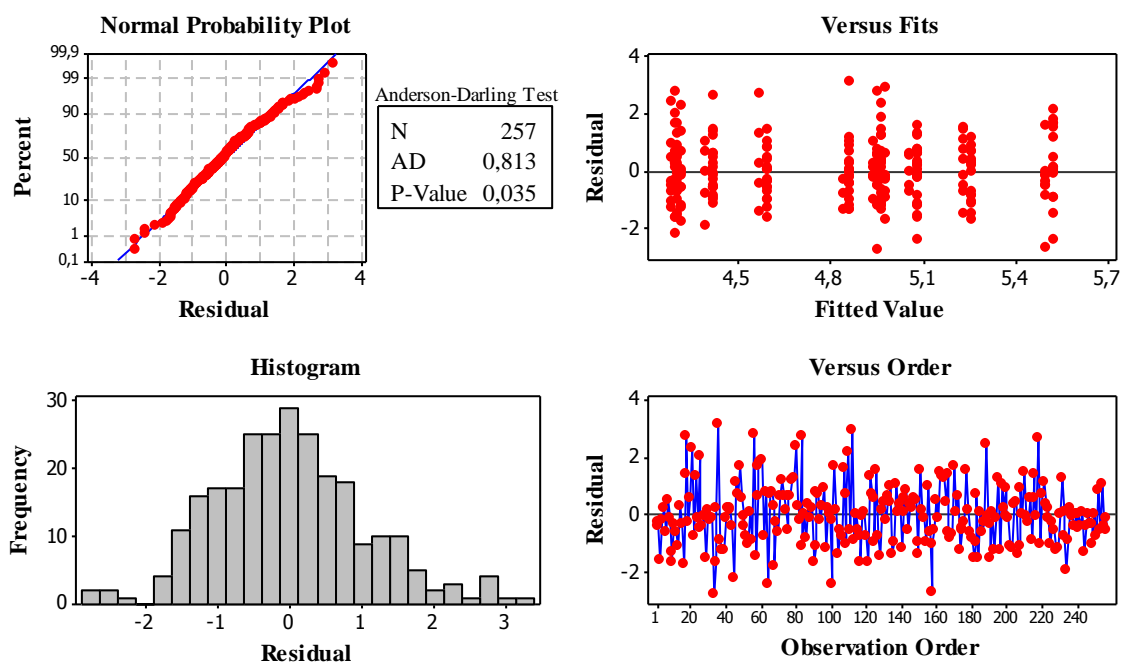


Figure F-2. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve's test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-2. The Result of Levene's test for Ellipsoid Hand Torque Strength with Sitting.

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	0.69	0.83

3) Checking ANOVA Assumptions for Key Handle with Sitting

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Key Hand Torque Strength with Sitting (Nm)

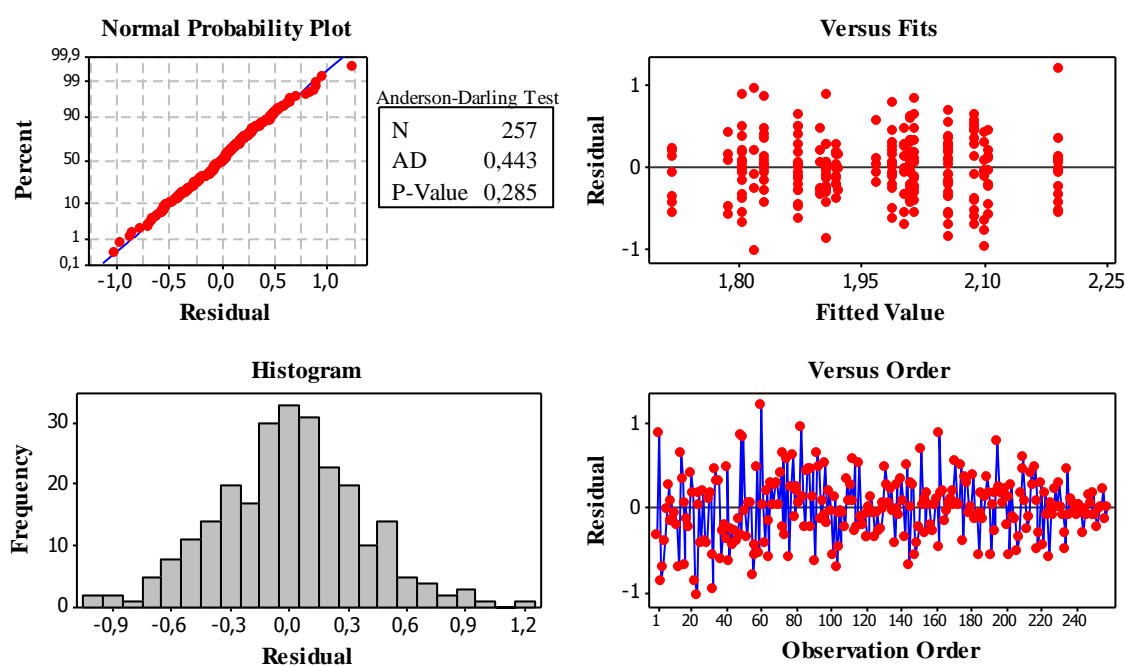


Figure F-3. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve’s test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-3. The Result of Levene’s test for Key Hand Torque Strength with Sitting.

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	0.91	0.576

4) Checking ANOVA Assumptions for Cylindrical Handle with Sitting

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Cylindrical Hand Torque Strength with Sitting (Nm)

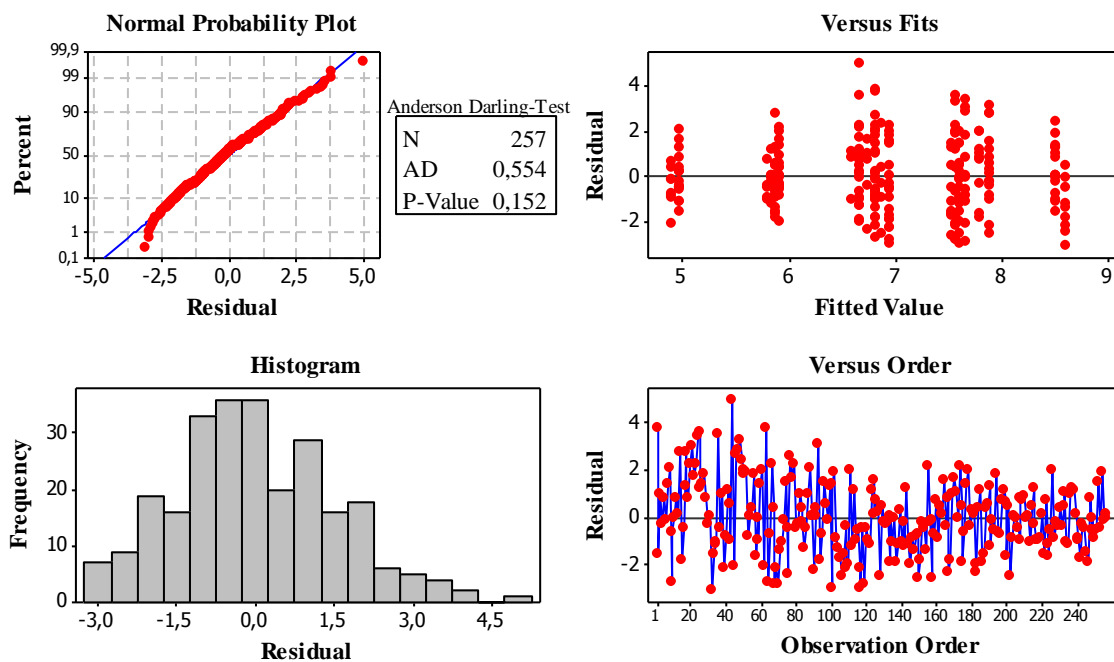


Figure F-4. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve's test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-4. The Result of Levene's test for Cylindrical Hand Torque Strength with Sitting.

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	1.57	0.063

5) Checking ANOVA Assumptions for Ellipsoid Handle with Standing

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Ellipsoid Hand Torque Strength with Standing (Nm)

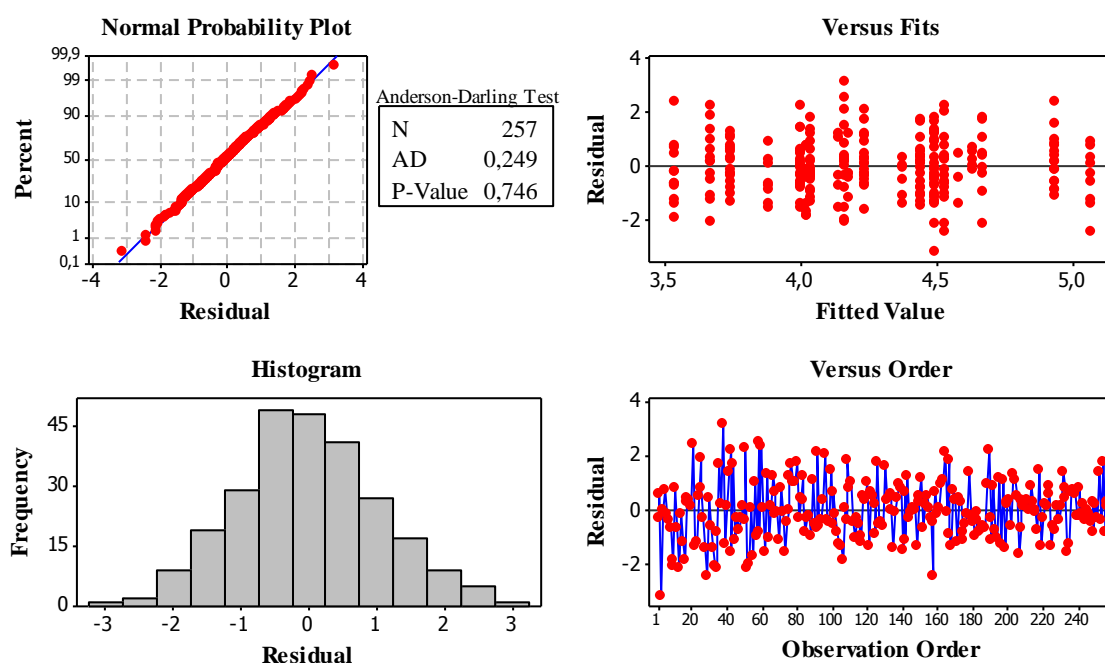


Figure F-5. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve's test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-5. The Result of Levene's test for Ellipsoid Hand Torque Strength with Standing.

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	1.00	0.457

6) Checking ANOVA Assumptions for Circular Handle with Standing

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Circular Hand Torque Strength with Standing (Nm)

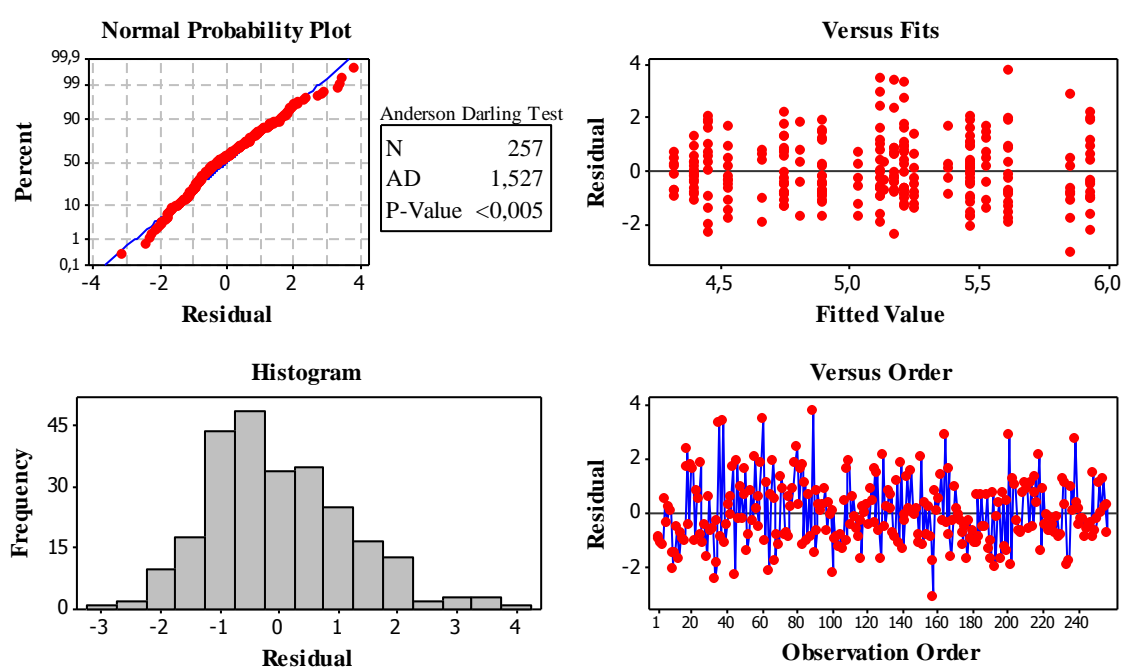


Figure F-6. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve's test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-6. The Result of Levene's test for Circular Hand Torque Strength with Standing

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	1.04	0.421

7) Checking ANOVA Assumptions for Key Handle with Standing

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Key Hand Torque Strength with Standing (Nm)

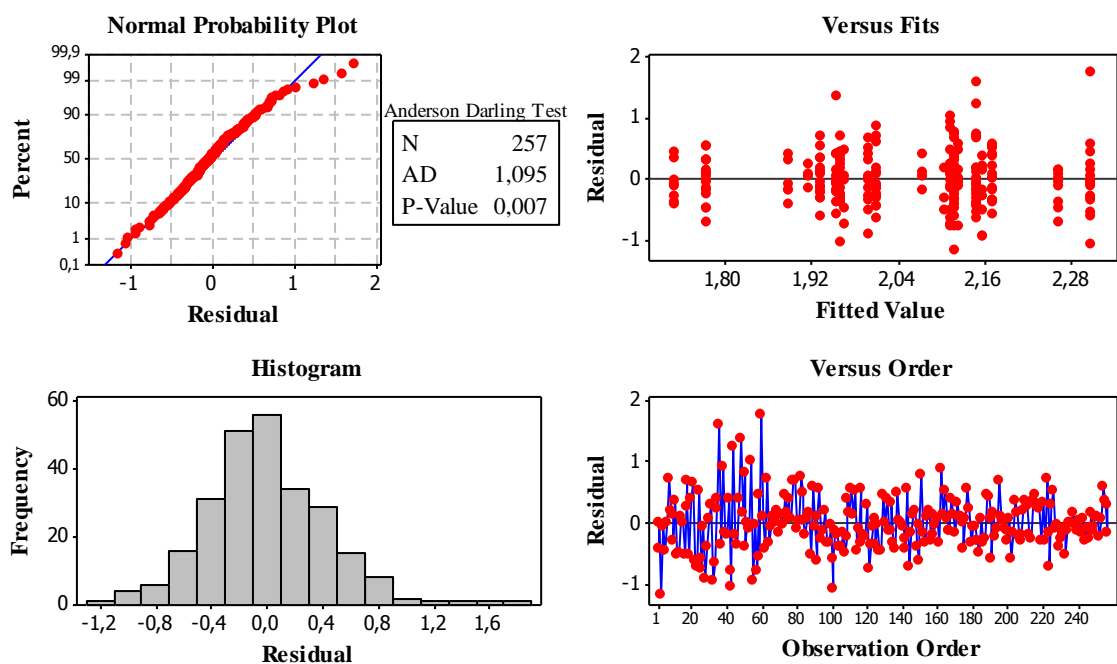


Figure F-7. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve’s test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-7. The Result of Levene’s test for Key Hand Torque Strength with Standing

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	0.85	0.645

8) Checking ANOVA Assumptions for Cylindrical Handle with Sitting

ANOVA assumptions were checked so as to test the adequacy of ANOVA results. Three ANOVA assumptions were tested for Completely Randomized Design ANOVA.

Normal probability plot of residuals follows a straight line so there is no suspect that normality assumption is violated.

Residual Plots for Cylindrical Hand Torque Strength with Standing (Nm)

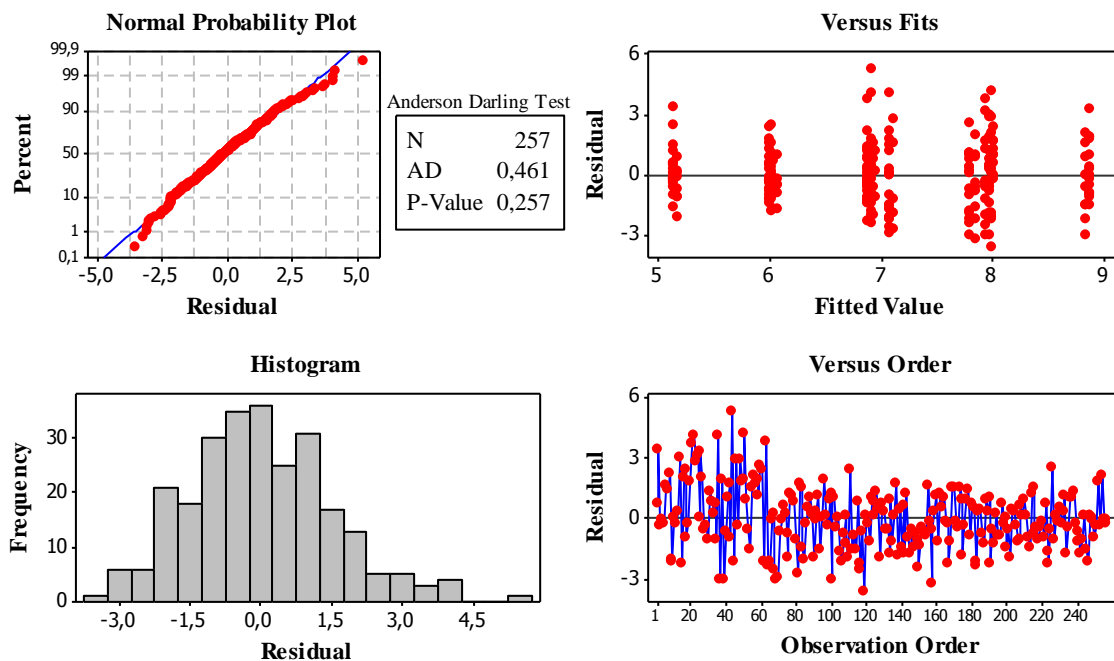


Figure F-8. ANOVA Assumptions for Completely Randomized Design ANOVA.

Residuals versus fitted value displayed above and Results of Leneve's test displayed in the Table below indicated that there is no suspect of any violation of equality of variance assumption.

Table F-8. The Result of Levene's test for Cylindrical Hand Torque Strength with Standing.

Test	Test Statistic	P-Value
Levene's test for CRD ANOVA	1.92	0.013

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