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

by

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ABSTRACT

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

A number of industrial work and daily life situations require hand torque strength exertions. Besides gender, age and handle type, it is also known that hand torque strength is affected by cross-national variations. Hence, hand torque strength norms should be established for various populations of the world for safe and efficient design of work, equipment and product that require use of hand torque strength. Therefore, this study aimed 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 with roots from all seven regions of Turkey participated in the study. Maximum voluntary torque strengths of dominant hand were measured both in sitting and standing with four types of handles (cylindirical, circular, ellipsoid and key). Through statistical analysis descriptive values of torque strength and factor effects were determined.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. Grip strength and some of the anthropometric variables, such as forearm circumference and hand breadth were significantly correlated with torque strength. Through this study, a first is achieved, and the static hand torque strength norms of adult female population of Turkey are established between the ages of 18 and 69 years. These norms can serve as a ‘reference’ in the design for torque strength for female population of Turkey. At the same time, one more ´gap´ is being filled in the ergonomics knowledgebase in the world.

ÖZET

TÜRKİYE YETİŞKİN KADIN NÜFUSUNUN STATİK EL TORK KUVVET KAPASİTESİNİN TAHMİNLEMESİ

Endüstriyel iş ve günlük aktivitelerin çoğunda el tork kuvvetini kullanıyoruz. El tork kuvvetinin cinsiyet, yaş ve kulp türünün yanı sıra, aynı zamanda ulusal farklılıklardan da etkilendiği bilinmektedir. Güvenli ve etkili tasarımlar için dünyanın çeşitli nüfusları için el tork kuvveti standartları belirlenmelidir. Bu nedenle, bu çalışmanın ana amacı, sağlıklı yetişkin Türkiye kadın nüfusunun maksimum statik el tork kuvvetini yaş, meslek ve birkaç antropometrik özelliklere göre istatistiksel olarak hesaplamaktı. Aile kökenleri Türkiye'nin yedi farklı bölgesinden olan, 257 sağlıklı kadın katılımcı çalışmaya katıldı. Oturarak ve ayakta, dört kulp türüyle (silindirik, dairesel, elipsoid ve anahtar) baskın elin maksimum el döndürme kuvveti ölçüldü. Istatistiksel analizler yapılarak tork kuvvetinin tanımlayıcı değerleri ve faktörlerin tork kuvveti üzerindeki etkileri tespit edildi. Sonuçlar, el tork kuvvetinin büyük derecede kulp türünden, yaş ve meslek grubundan etkilendiği ortaya koydu. En yüksek kuvvet değerleri silindirik kulp, daha sonra dairesel ve elipsoid ile elde edilirken, en az kuvvet anahtar kulbu ile elde edilmiştir. El tork kuvveti, hafif işlerde çalışanlarda 30 ile 39 yaşlar arası maksimuma ulaşırken, daha ağır işlerde çalışanlarda ise 40 ile 49 yaşlar arası maksimuma ulaşmıştır. Ağır işlerde çalışanların, hafif işlerde çalışanlara göre daha güçlü oldukları tespit edildi. Ayakta iken ölçülen ortalama kuvvet değerleri, otururken ölçülenlerden ve vücutça ağır olanların ortalama el tork kuvvet değerleri normal ağırlıkta olanlardan, az da olsa, daha yüksek çıktı. Statik el kavrama kuvveti, önkol çevre uzunluğu ve el genişliği gibi bazı antropometric değerlerin el tork kuvveti ile korelasyonda olduğu gözlemlendi. Bu çalışma ile bir ilk başarılarak, 18-69 yaş arası Türkiye yetişkin kadın nüfusunun maksimum statik el tork kuvvet standartları belirlenmiştir. Bu standartlar Türkiye kadınları için yapılacak tasarımlarda referans olarak kullanılabilecektir. Aynı zamanda, dünyada ergonomi alanında bir eksik daha giderilmiş oldu.

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LIST OF SYMBOLS

H_0	Null hypothesis
H_1	Alternative hypothesis
R^2	Coefficient of determination
R^2_{adj}	Adjusted coefficient of determination
$\bar{x}$	Sample mean
y_{ij}	The observation in the jth block receiving the ith treatment
α	The percentage of relative accuracy desired
β_j	The effect of the jth block
δ_k	Effect of kth 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 mth level for age group factor
μ	Overall mean
τ_i	The effect of the ith treatment
φ_l	Effect of lth level for occupation group factor

LIST OF ACRONYMS/ABBREBIATIONS

ANOVA	Analysis of Variance
ASHT	The American Society of Hand Therapists
BMI	Body mass index
CWR	Circumference of wrist
CFO	Circumference of forearm
Cm	Centimeter
DF	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
Std. Dev.	Standard deviation
SE	Standard error
SS	Sum of squares
VIF	Variance inflation factor
yrs	Years

1. INTRODUCTION

Anthropometric and strength data are fundamental and essential for the design of safe and usable products (Norris and Wilson, 1997), as well as safe and efficient workplaces, tools, and equipment used in occupational settings (Ekşioğlu and Kızılaslan, 2008). The benefits of applying these data in the early stages of the design process are widely recognized (Peebles and Norris, 2003). The objective of strength tests used for ergonomic purposes is often to generate data that enable predicting the strength capacity of a desired population percentile.

Human strength assessment is required to form population norms for the better design of machines and tools (Chaffin, 1975). On the other hand, population standards are set in order to figure out the physical limits of human beings. These norms are vital in industry so as to achieve productivity and safety of workforce and consumers (Ekşioğlu and Silahlı, 2009). Moreover, data on voluntary strength are utilized by the design engineers to determine maximum and optimum control resistances, forces required in manual tasks, and the arrangement of the weight for safe, efficient lifting and carrying.

In the case that a worker's strength is not enough to satisfy the demands of the job, then it is more likely for the worker to undergo exertion related injuries. 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). With the use of assessing the percentage of maximum strength required by a repetitive task, a possible fatigue is avoided (Xiao *et al*., 2005). It is of great importance to determine required strength for a specific task since workers can be prevented from exerting too high force causing musculoskeletal disorders. To sum up, it is a main prerequisite to set the strength limits in order to design safely and to prevent injuries.

Strength data have been collected on a number of different populations so far, however, these studies have been inadequate for the wider population. Kroemer (1970) emphasizes that there is a gap in the 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 population in general. Namely, it cannot be mentioned about strength norms including majority of a 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).

Hand torque strength is important over a broad range of manual tasks because in many industrial work situations and also in daily life, person frequently encounters handle and knob turning tasks such as rotating a door knob to enter a room, spinning the knob of any machine, tightening-loosening connectors or even turning a key. It can be said that, every day we use our hands and fingers to exert torque and rotational forces in many activities. Kroemer (1999) says “Information on strength that can be applied to objects such as hand tools or handling loads is of great importance for ergonomic design”. Therefore a large number of studies have been conducted to model, measure, and predict hand torque strength under specified conditions.

The hand torque strength data available for different populations usually vary greatly. Using this strength data of one population for another population may give rise to problems. And it is known that there has not been any study conducted to investigate torque capabilities of population of Turkey. Therefore, to fill this gap, this study attempts to establish hand torque strength norms of people of Turkey, which has not been done before. Moreover, it is known that the strength data collected via this study may be used for industrial design of the new products and hand tools.

To do this, a considerable number of healthy female volunteers were recruited to conduct the hand torque strength tests with four handle types in two body postures; sitting and standing by using their dominant hands. 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.

In general, the primary consideration of manufacturers is customer satisfaction. In order to ensure satisfaction they have to produce according to their user portfolio. That is, they have to consider target customer's age distribution, occupation distribution and so on. By taking into consideration this requirement, age group, BMI group and occupation group of the subjects are also taken as independent variables.

There are many factors that influence hand torque strength, but only a few factors can be studied in a single laboratory investigation. That's why only the main factors that are considered as highly correlated with the strength values are taken as independent variables. According to Mital (1986), maximum volitional torque is strongly influenced by the type of tool used and posture assumed.

Though it is not practical and easy to investigate many handle types in a single study, the investigation of a few variables on some handle types simultaneously in multi-factorial studies, such as the present study, can yield important information.

The thesis is organized as follows: Chapter 2 includes a brief summary of literature about hand torque strength studies performed on various populations all around the world. In Chapter 3, the rationale behind the study and also the main objectives of the current study are presented. In Chapter 4 the methodology of the experiments that includes description of subjects, equipment 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 given in detail. Moreover, the statistical analysis results of the study are presented in this chapter. In Chapter 6, discussions about the results of the current study presented and also comparison with the results of the previous studies is presented in this chapter. In the last chapter, conclusions of the current study are presented.

2. LITERATURE REVIEW

Even though there is a considerably great improvement in the automation, most occupational activities and a great amount of daily activities are still performed through human intervention. In such cases, a person's capacity to perform mechanical work is determined by his/her ability to exert muscular strength (Mital and Kumar, 1998). Therefore, one common reason of strength tests is build an anthropometric database of population strength data that can be used to create design data for products, tasks, equipment, and so forth.

Application of strength data to human engineering problems is often hampered by ambiguities of terminology (Kroemer, 1970). Therefore, before analyzing studies which have been done on hand torque strength measurement, the term "strength" must be defined and the concept of strength measurement must be explained.

2.1. Strength

Strength is precisely defined as the capacity to produce force or torque with voluntary muscle contraction. Dimensions of strength are force or torque×time, i.e., impulse over a given time, or force or torque alone if the effort is exerted instantaneously (Kroemer, 1970). *Maximum strength* is defined as the capacity to produce force or torque with a maximum voluntary muscle contraction (Gallagher *et al.*, 1998). But it must be known that when a person's physical strength is measured, only the effort the person willingly puts forth at the time is measured. Thus, when we test a person's "maximum strength," we are not measuring his or her actual maximum, but some lesser value representing what he or she is comfortable expressing at the time with the existing equipment and environmental conditions (Gallagher *et al.*, 1998).

2.1.1. Strength types

Many different types of strength classifications are reported in the literature but muscle strength can be divided into two groups according to the type of force being applied and the movement of the body parts which the force is applied. These groups are isometric strengths, which are also known as static strengths; and dynamic strengths.

2.1.1.1. Isometric (static) Strength. Isometric (static) strength is defined as the capacity to produce force or torque with a voluntary isometric contraction (Gallagher *et al.*, 1998). There is no perceptible change in muscle length during an isometric effort. No body movement occurs during the measurement period. The tested person's body angles and posture remain the same throughout the test. The basic procedures for testing isometric strength are well-established (Gallagher *et al.*, 1998). Therefore, measuring isometric (static) strength is rather easy and controllable (Mital and Kumar, 1998).

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

2.1.2. Strength measurement

Measurements of isometric (static) muscle strength have for many decades, been popular among physiologists, anthropologists, physical educationists and human factors engineers. Most of the information currently available on "human strength" describes the outcomes of isometric (static) strength testing (Kroemer, 1999). On the other hand some strength researchers feel that isometric (static) strength data may be difficult to apply to some "real life" situations, because in most real circumstances people are moving, they are not static. Even though most work and daily activities consist mainly of dynamic forces and at present there is little evidence that static force data accurately predict dynamic performance, isometric muscle tests are conducted more often, because these tests are relatively easy to administer and are rather simple (Kroemer, 1999). At the same time, the basic procedures for testing isometric (static) strength are well-established (Gallagher *et al.*, 1998).

Ergonomic protocols, such as famous Caldwell Regimen (Caldwell *et al*., 1974), have been suggested and accepted in order to reduce the variation of the measurement techniques. Protocols by Kroemer (1970) and Chaffin (1975) give essentially the same information with Caldwell Regimen. All of them underline the importance of the correct instruction given to subject, the duration of the measurement period and the amount of rest allowed between trials. They emphasize the importance of an extensive description of experimental method, which at that time was lacking in many articles (Daams, 1994).

The main instruction set within the Caldwell Regimen is a slow build-up to maximal force in about 1 s and to maintenance of that force for another 4 s. Strength variations during this period should be within $\pm$10% of the mean. According to this protocol, the subject should be informed about the objectives of the study and the procedures, at the beginning of a 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. There should be at least a two minute break between the trials (Caldwell *et al*., 1974). Caldwell Regimen also indicates that 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).

2.2. Hand Torque Strength

Many activities of daily living require turning handles, knobs, lids and objects of many sizes. At the same time, in many industrial work situations, hand torque exertion and rotational forces are required in maintenance, repair activities and many other industrial activities (Kong *et al*., 2007). Therefore sufficient hand torque strength must be applied with the hands to perform many activities of work, daily living and recreation.

All of the factors that affect grip strength also affect hand torque strength (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 (Adams, 2006).

Only a few factors can be studied in a single laboratory investigation and these factors are chosen according to the aim and conditions of the study.

A variety of isometric hand torque strength recording devices are available. They change due to factors and conditions of experiments.

2.3. Hand Torque Studies

In the literature there are a considerable number of studies conducted to measure, model and predict hand torque strength under various specified conditions. Studies generally vary in the subject specifications, procedures used, strength type measured, instruments used, handle type used and so on. Some of the significant studies summarized below are examined in detail before conducting the current study, even though they do not have exactly the same conditions as the current study has.

Nagashima and Konz (1986) examined the effect of diameter, gripping material and knurling on torque strength of ten female subjects. In the experiment, each of ten female subjects twisted six jar lids, which were a smooth and a knurled lid at each of three diameters (48, 67 and 86 mm) with a bare hand, rubber gripper and a cotton cloth. The torque strengths of three different lid diameters were significantly different from each other. The torque strengths of different gripping materials were also significantly different. But the torque for smooth lid was not significantly lower than for knurled lid. A second experiment was conducted to repeat the first one with a larger, more varied group of subjects to see if knurling was worthwhile. In this experiment 29 subjects (17 male and 12 females) were measured and it was found that only for two diameters (for 86 mm and 67 mm), there were statistically significant differences between smooth and knurled lids.

Voorbij and Steenbekkers (2002) measured the twisting force of 750 aged consumers (123 of them were aged between 20 and 30 years and 627 were over 50 years of age) with a force transducer shaped like a jam jar. They have used jar-shaped measuring unit to make the force measurements as realistic as possible. Before torque measurements, subjects were asked two questions about how they opened jars at home. The subject was asked to adopt the posture normally used for opening jars. To minimize fatigue effect, a two-minute rest separated each trial. 79 variables were measured on subjects. These variables can be classified into four major groups; physical variables, psychomotor variables, sensory variables and cognitive variables. After measurements of these 79 variables, Voorbij and Steenbekkers (2002) reached to the conclusion that if opening torque was reduced to 2 Nm 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.

Mital and Sanghavi (1986) examined the effects of many operator and task related factors on peak volitional torque exertion capabilities of males and females with common nonpowered hand tools. Maximum volitional torque was measured on 55 adult subjects (30 male, 25 female) in 540 treatment combinations (5 Tools × 2 Postures × 3 Heights × 3 Reach Distances × 6 Angles). They found that the effect of operator gender was found to be highly significant (peak torque exertion capabilities of females average 66% of the male torques). They have also found out, that many factors like height of torque application and the angle of the arm holding the tool, that had been thought to be significant, were not found practically significant. The effects of posture and reach distance were found relatively more significant. And the type of hand tool was found the most significant factor.

Mital (1986) conducted a study to study the effects of body postures and of different types of hand tools on maximum volitional torque exertion capabilities of thirty-six males and fourteen females. Using nine different hand tools, each subject exerted maximum volitional torque in 21 postures that makes in total 189 different torque measurements. It was found, that there was a strong correlation between the tool type and peak torque. And that there was no correlation between posture and peak torque. Many other researches on similar topic have also reported the similar findings. The study suggests that selection of the proper hand tool is critical for the safety and efficiency (Mital, 1986).

Kong *et al.* (2007) evaluated the effects of screwdriver handle shape, surface material and work piece orientation on torque performance, finger force distribution and muscle activity in a maximum screwdriving torque task. Twelve right handed male subjects performed maximum screw-tightening exertions using screwdriver handles with three longitudinal shapes and four lateral shapes and two surfaces, six of them tested torque from vertical orientation, the other six from horizontal orientation. At the end of the study, the effect of handle surface, longitudinal and lateral shapes were found to be statistically significant on torque output. Torque was greater when rubber-coated handles were used. Hexagonal and circular handles were resulted in higher torque outputs than triangular handles.

Kong and Lowe (2005) conducted an experimental study which objective was to evaluate the effects of gender, handle diameter and handle orientation (horizontal and vertical) on torque, total finger force, efficiency of flexor and extensor electromyographic (EMG) activity and also subjective comfort rating in a maximum voluntary torque task. For this purpose, twelve males and twelve females participated in the study. Six cylindrical handle diameters with vertical and horizontal orientations were tested. At the end of the study, it was seen that the effects of handle diameter, orientation and the interaction between them were statistically significant on maximum voluntary torque, however gender and hand size were not statistically significant. And it was concluded that the maximum voluntary torque increased as handle diameter increased in both handle orientations, with largest torque for 50 mm diameter handles.

Peebles and Norris (2003) conducted a two-stage research project, which consists of identification of data needs and data collection. They collected data of around 150 subjects aged from 2 to 86 years on a series of six strength measurements, which are: (i) finger push strength, (ii) pinch-pull strength, (iii) handgrip strength, (iv) wrist twisting strength, (v) opening strength, and (vi) push and pull strength. For wrist twisting strength testing, each subject stood in front of measuring machine adopting free posture, and exerted wrist twisting strength with a variety of knobs and handles. Results showed that no significant differences in maximum wrist twisting strength were found between male and female children (2-15 years). However, in adults aged 16 years and over, males were generally found to be significantly stronger than females.

Imrhan and Jenkins (1999) investigated the effects of four variables, which were – surface finish, wrist action, arm position and hand laterality, on torquing capabilities of males and female adults in simulated maintenance tasks. Ten male (from 28 to 43 years old) and ten females (from 25 to 40 years old) generated torques on a 2.25 in diameter cylindrical handle over 24 different test conditions. Subjects were required to grip handles bare-handed with power grip in comfortable standing posture. The results showed that extension torques were 1.18 as strong as flexion ones; knurled handle torques, 1.15 as strong as smooth handle ones; right-hand torques, 1.10 as strong as left hand ones; and male torques, 2.04 as strong as female ones. Interaction effects showed that the male-female difference was greater for extension torquing compared to flexion torquing, and from using the knurled handle compared with the smooth one.

Adams and Ma (1988) conducted a study, where they tried to define and quantify the relationship between maximum static hand grip torque and the level of interference for six defined levels of interference and four conditions of interference with and without work gloves. For this purpose, a representative population of 18 male and 16 females who would qualify physically as Air Force maintenance technicians participated the study. This study is the results of an extension of the research performed by Adams and Peterson (1986). It was found that torque strength and required separation was a function of level of interference, condition of interference, connector size and glove usage. It was also found 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.

Replogle (1983) analyzed the relationship between the diameter of a smooth phenolic cylindrical handle and hand torque strength. An analytical model has been derived and to test this model, torques were measured on eleven smooth phenolic fiber cylindrical handles with diameters between 0.95 to 8.89 cm. Ten males and ten females participated in the test, turning each cylindrical handle clockwise and counterclockwise with the preferred hand. Overall results of their study indicated that torque increases as the square of the handle diameter up to 2.5 centimeters (grip-span diameter), for larger diameters the torque continues to increase at a decreasing rate and reaches to maximum when the diameter is approximately 5 centimeters. And also it was found that female torque capability is about forty percent of that of males, and grip-span and maximum-torque diameters did not vary greatly between males and females, suggesting that the same size handles can be used for both genders for tools, such as screwdrivers.

Wieszczyk *et al.* (2009) conducted a study to determine how height of a hand wheel affects maximum torque production and risk of injury to the shoulders and back of workers. Twenty four healthy subjects, which were power plant mechanics or operators participated in the study. Maximum torque exertions in the both directions at three heights were measured. The study has some results which indicated that counterclockwise direction was greater than the other. 10% greater torque was exerted at the overhead level than at chest level. And that there was no difference in maximum torque between knee and overhead levels and between knee and chest levels.

There has been interest in the openability of packaging by a number of researchers, Rowson and Yoxall (2010) also conducted a study on this subject. They examined effects of different grips on maximum torque. For this purpose, they have tested 19 females and 15 males. Like many other torque strength studies found, it was also found that females generally produce lower torques than males. And also the results indicated that female consumers were most likely to use a spherical grip on containers of this type, and that this type of grip actually produced maximum torque for females. Whilst for men, all of these grip styles produced maximum torques above the torque required for opening jars.

Gugari and Okamura (2007) conducted a study 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. 6 male and 4 female healthy subjects participated in this study. Results showed that a more distal arm motion is used for a parallel angle of attack, decreased knob size and increased gain.

A laboratory study was conducted by Kim and Kim (2000) to examine the effects of the body posture and of different types of hand tools on maximum volitional torque exertion capabilities of Korean. There were fifteen different body postures and five different common non-powered hand tools. Each subject performed total of 75 torque measurements sessions. Fifteen males and fifteen female participated in the experiment. Results of the study showed that the torque exertion is significantly affected by the type of tool and posture. Also this study showed that females exerted about 51.5 % of torque when compared to that of males, which is quite different with western population.

There is always a trade-off in designing equipment for hand operations. It is often desirable to use a high turning torque to protect against changes in settings by inadvertent actions, but on the other hand it should be also available for hand operation without additional tool. Swain *et al.* (1970) conducted a study to determine the maximum torque that the men in the standing position can apply to different sized diamond knurled knobs with and without gloves in specific applications. 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 from a standing position, using preferred hand to twist the knob, while steadying the apparatus with the other hand. From the results of the study it was apparent that the maximum torque was influenced by the size of the knobs, gloved versus bare hands, knob orientation. And it was concluded that torque increased with the knob size, decreased with usage of gloves and side knobs allowed more torque than front knobs. Torque strength also 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.

Adams and Peterson (1986) conducted a study in which static hand torque exerted on a circular electrical connector was studied as a function of connector size, grip type, connector orientation, use of gloves, connector height, and direction of torque. For this purpose twenty male and eleven female subjects performed maximum hand grip torque for three second exertion. The results showed that connector height and direction of rotation had little effect on torque strength. Adams and Peterson (1986) also proposed that higher torque could be exerted when the connectors were on the subject's right side. Grip torque strength increased with connector size. The use of chemical defense gloves and work gloves resulted in slightly higher torque strength than the use of the bare hand. And it was also seen that torque strength for males was significantly higher than for females.

Openability of consumer packaging is becoming a major issue as the demographics changes, and that is why many studies have done in this area. One of them is a study conducted by Yoxall *et al.* (2006) and their main aim was to develop a torque measuring device, which can represent jar as real as possible. To ensure that, the jar lid and the outer surface of the glass jar were kept unchanged. The appearance and weight was as similar as possible to the original product. Thereby they tried to ensure that a subject's behavior would be as similar as possible to real situation. 235 subjects were tested (97 females and 138 males) and each of them chose the posture as they normally would have while opening a jar. This study had many results but to sum up, it can be said that in order to design inclusively, it is important to fully understand the ability of the target users and the forces required opening packaging.

Several studies have investigated hand torquing strength at different hand-handle interfaces, Pheasant and O'Neill (1975) had the similar study with cylinders simulating handles. Their study explained the biomechanics of some simple hand/handle interactions. There were two experiments in this study, first with 24 subjects and second with 10 subjects. Each subject performed maximal steady voluntary torques on a set of cylindrical handles. Results of the study showed that for forceful activity, the precise shape of the handle is unimportant, the effectiveness of the activity is limited by the size of the handle and the quality of the hand/handle interface.

Crawford *et al.* (2002) conducted a study which aimed to examine the effect of shape, diameter and height of lid on wrist torque opening strength of a group of younger and older adults. 20 young subjects (10 males and 10 females) and 20 older subjects (10 males and 10 females) participated in the experiment. Nine circular and three square totally twelve nylon test pieces, were used in the study. From the study, it was concluded that increased torque can be exerted on square lids compared to those that are circular of the same diameter. And it can be also concluded that as lid diameter and height increase, torque increases for the test pieces between 20 mm and 50 mm diameters.

Voorbij and Steenbekkers (2002), in a study of 750 adults, the majority of whom were over 50 years old, aimed to identify the maximum wrist-twisting force that the elderly could apply when opening a jar. They used the circular turning lid, which is the most commonly used in glass packaging. The data in this study were collected as realistically as possible using a 66 mm diameter lid attached to a strain indicator and the subject was asked to adopt the posture normally used for opening jars. Recommendations from this study were that the required torque for opening a jar should be limited to 2 Nm, which would ensure that only 2.4% of over 50-year-olds would have difficulties (Voorbij and Steenbekkers, 2002).

Rohles *et al*. (1983) measured 100 males and 100 females between the ages of 62 and 92 years to determine their wrist-twisting capabilities on circular jar lids. In this study the diameter of the lids ranged from 27 mm to 123 mm and data indicated again that torque strength increased with the diameter of the lid. Also the study showed that direction of twist did not produce significantly different torque magnitude and that certain hand measurements like grasp and lateral prehension, were significant indicators of wrist twisting force.

Imrhan and Loo (1986) examined the effects of container lid variables on counterclockwise torque on circular lids in the elderly population between the ages of 60-97. Two types of lid surface each with four diameters were investigated. Forty two subjects stood in front of the tester and held the container lid with the preferred hand. The study showed that in the elderly, for both smooth and rough textured knobs of diameters 31, 55, and 74mm, applied torque linearly increases with knob diameter. So it can be said from this study that torque increased diameter rapidly at first, then more slowly with larger diameters. The study also had results which indicated that females were about 0.75 as strong as males, and strength decreased with age.

Miller *et al.* (2005) conducted a study to measure twisting strength of 64 normal subjects (no history of upper extremity pathology) with 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 to them 13 subjects (with arthritis of the thumb carpometacarpal joint) with average age 58±8 were measured as well. 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. Differences of gender, hand dominance, disk size, and pathology were investigated via this study. 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.

In the experimental study of Seo *et al*. (2007), maximum torque, grip force, total normal force, and fingertip/ thumb force were measured. Twelve subjects (6 F and 6 M) with age ranging from 21 to 35 years 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. Subjects were seated with an elbow flexed about 90º and forearm horizontal, and grasped a vertical cylindrical handle with the right hand in a power grip. 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.

A summary of hand torque strength studies is given in Table 2.1.

2.3.1. Summary and Critics of Findings

To summarize all studies and to be able to see their lacks, classifications according to handle type, posture and age groups were done (Table 2.2, Table 2.3 and Table 2.4).

Table 2.3 shows hand tool/handle types used in the studies. Several studies have investigated hand torque strength at different hand-handle interfaces; such as on hand tools like screwdrivers and wrenches, cylinders simulating handles, jar lids, electrical connectors and small knobs. While several studies in literature have investigated hand tools and handles, none involved handle types such as keys and ellipsoid handle, which are actually widely used in daily and work life. The only effort in determining hand torque strength with handle type similar to ellipsoid handle was a study of Peebles and Norris, 2002. But still, the door knob which was used in that study, does not exactly resemble ellipsoid handle.

While some torque strength studies in literature had procedures with no restriction on posture allowing subject to choose sitting or standing posture, some studies were concerned with posture more, and had a specific choice for posture. As it can be seen from Table 2.2 relatively few studies have focused on the standing/sitting postures as a factor. The influence of these two widely used body postures has not been quantified sufficiently and therefore fruitful areas remain for future hand torque strength research.

There have been several previous studies designed to measure the hand torque strength of mainly adult population. But really few of these studies were normative studies on hand torque strength, which are really important to develop a database of hand torque strength for a particular population (Table 2.4). Therefore, it can be said that the studies performed on hand torque strength so far do not provide much information regarding the hand torque strength databases.

Studies previously undertaken by the researchers mainly have the following results:

- Males are stronger than females.
- Dominant hand is stronger than non-dominant hand.
- Strength increases with age throughout childhood, peaks in adulthood, and then decreases with age from around 50 years,
- The magnitude of hand torque strength is strongly influenced by the type of handle or hand tool. The effects of handle dimensions, shape, surface finish and type of material on hand torque strength are worth to investigate. The general agreement

among studies to date is that torque output is proportional to the cylindrical handle diameter, and as it was shown in few studies that voluntary hand torque strength increases as the cylindrical handle increases and reaches maximum when the diameter is 5 centimeters, afterwards it slowly decreases.

- The magnitude of hand torque strength is also influenced by posture. 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.

Table 2.1. Summary of studies in literature.

Source	Location	Factor	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time
Nagashima, Konz (1986)	USA	• Diameter effect • Gripping material • Knurling effect	Exp.1 - 10 F Students	One trial	Torque Meter	NM	Torque strength while opening jar lids	• Grip Strength • Hand Length • Hand Breath • Hand Spread	About 1 min	NM*
		• Diameter effect • Gripping material • Knurling effect	Exp.2 - 17 M and 12 F	One trial		NM	Torque strength while opening jar lids	• Age • Gender • Preferred Hand Grip Strength	15 sec	NM
Miller, Nair, Baratz (2005)	USA	• Age • Disease	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 for disks with different diameters (ulnar and radial deviation)	• Age • Gender	NM	NM
Mital (1986)	USA	• Body Posture • Hand Tool	36 M and 14 F (21-25 for M, 21-29 for F)	Peak	VISHAY-20 digital strainmeter	21 different body postures	Maximum volitional torque using hand tools	18 Anthropometric and strength measurements	5 min	5 sec

*NM- Not mentioned

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Chang, Wang (2001)	China	• Activation mode • Torque • Horizontal operating distance	13 M	Mean of three trials	Pneumatic Screwdrivers with adjustable torque and a fast shut-off mechanism, OctoForce Sensor System	Sitting on an adjustable chair in a comfortable posture	Hand torque strength using powered hand tools	• Age • Hand Length • Stature	20-30 min	5 sec
Peebles, Norris (2003)	UK	• Age • Gender	Around 150 subjects (2-90)	Max of two trials	6 different devices for 6 different strength measurements	Free posture (standing)	• Finger push str. • Pinch-pull str. • Hand grip str. • Wrist-twisting str. • Opening str. • Push and pull str.	• Age • Gender	2 min	5 sec

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

Source	Location	Factor	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time
Imrhan, Jenkins (1999)	USA	• Handle surface • Wrist action • Arm position • Hand laterality	10 M (28-43 yrs) and 10 F (25-40 yrs)	Max of the two measure-Ments	Snapon-Tools model torque meter	Free posture (standing)	Torquing capabilities in maintenance tasks	• Handgrip • Pinch strength • Age • Gender • Stature • Weight • Outer Hand Breadth • Handgrip Circumf. • Forearm Circumf. • Biceps Circumf.	1,5 min	5 sec
Adams, Ma (1988)	USA	• Levels of interference • Condition of interference • Connector size • Glove usage	18 M and 16 F	Mean value of two measurement	• Torque measuring load cell • Bridge amplifier • Analog to digital convertor • Digital computer • Signal tone generator	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

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Replogle (1983)	USA	Handle Diameter	10 M and 10 F	One measurement (peak value)	Torque Meter	NM	Hand Torque Strength	• Grip Span Diameter • Hand Length	NM	NM
Voorbij, Steenbekkers (2001)	Netherlands	• Age • Laterality • Position	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
Kong, Lowe, Lee, Krieg (2007)	Korea, USA	•Screwdriver handle shape • Surface material • Workpiece orientation	12 M	Mean of two measurements	• Handles • Torque measurement system.	Standing	•Screwdriving Torque strength • Finger force • Muscle electromyographic (EMG) activity	• Age • Height • Weight • Hand length • Hand thickness • Hand breadth • Palm length	2 min	4-5 sec

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

Source	Location	Factor	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time
Mital, Sanghavi (1986)	U.S.	• Gender • Isometric strengths • Posture • Anthropometric Variables • Tool type • Height of torque application • Reach distance • Tool orientation	30 M (22.7±1.2) and 25 F (21.6±2.5)	One measurement (peak value)	Special Torque Meter, VISHAY-20 digital strainmeter	Standing and sitting	Maximum Volitional Torque using Common Hand Tools	• 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

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Kong, Lowe (2005)	USA	• Gender • Handle diameter • Handle orientation	12 M and 12 F	Peak	• Force glove system •Electromyographic measurement system • LIDO WorkSET II	The elbow angle about 90° in the vertical orientation.	•Maximum Volitional Torque • Total Finger Force • Muscle activity	• Age • Height • Weight • Hand length	2 min	5 sec
Wieszczyk, Marklin, Sánchez (2009)	USA	• Height of a hand wheel	23 M and 1 F (32-61)	Mean of two measurements	• Torque limiter • Hand wheel • Load cell	• 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 wheel	Maximum torque strength for industrial hand wheel valve	• Age • Height • Weight • Hand length • Work Experience	2 min	5 sec

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Rowson, Yoxall (2011)	UK	Grip Choice	15 M and 19 F	One measurement (peak value)	Torque meter Jar resemble	• Lateral grip posture • Spherical grip, • Pulp grip • Tip grip • Cylindrical grip • Pronated cylindrical • Box grip	Opening torque strength for jars and containers	• Age • Gender • Occupation • Hand Size • Preferred Grip Choice	Suitable rest periods	5 sec
Gugari, Okamura (2007)	USA	• Turning strategy • Arm motions • Numbers of grasps • Time used to complete	6 M and 4 F (from 20-30)	Mean of two measurements	• Knob turning device • Visual display • Video camera	• Standing on a footstool • Sitting in a chair	Knob Turning Torque	• Age • Hand Size • Self-reported experience	NM	No limit
Su, Chiu, Chang, Lin, Hong, Kuo (2009)	China	Grip Patterns	4 M and 6 F (27.2+-5.5)	Mean of three trials	• Jar simulator with one torque sensor • Six axis force transducer	Comfortable sitting position	• Twisting torque strength for opening jars • Thumb forces	• Age • Height • Weight • Hand length • Hand breadth	3 min	NM

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Kim, Kim (2000)	Korea	• Body posture • Type of hand tool	15 M and 15 F (mean M = 24.67, mean-F = 20.87)	Max of two measurements	A work simulator and 5 attached tools	15 postures	Maximum volitional torque strength with common hand tools	• 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
Adams, Peterson (1986)	USA	• Diameter • Type of grip • Orientation of the connector • The usage of gloves • The height of the connectors • Direction of rotation	20 M (18-32) and 11 F (19-40)	Mean of three trials	• Load cell (torque measuring) bridge • Amplifier; analog-to-digital converter • Digital computer-printer signal tone	Standing	Maximum hand grip torque for circular electrical connectors	• Age • Height • Weight • Reach height • Maximum grip range	2 min	3 sec

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Wong, Moskovitz (2010)	USA	Device	18 subjects (Age average 26.8)	Mean of three trials	Portable forearm strength hydraulic dynamometer	Sitting, grasping the doorknob with both shoulder and elbow positioned in visually approximated 45 flexion	Forearm strength for doorknob handle	• Age • Height • Weight • BHD pronation • BHD supination • Cybex pronation • Cybex supination	30 sec between three trials, 3 min between different assessors	NM
Yoxall, Janson, Bradbury, Langley, Wearn, Hayes (2006)	UK	• Age • Gender	138 M (8-95) and 97 F (8-93)	One measurement (peak value)	Torque sensor was embedded into a modified glass jar	Free posture, opening the jar as subjects normally open	Maximum torque strength for opening jar lid	• Age • Gender	NM	NM
Steenbekkers (1993)	Netherlands	• Laterality • Preferred Hand	390 boys and 392 girls (4-13 yrs)	Mean value of two trials	MeteK torque measurement device	Sitting	Maximum static torque strength for knobs	• Age • Gender • Preferred Hand	Minimum 2 min	4 sec

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

Source	**Location**	**Factor**	**Sample type (Size, gender, age)**	**Measure used**	**Instrument**	**Posture**	**Measured Strength**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**
Rohles, Moldrup, Laviana (1983)	USA	• Age • Gender • Grasp type • Lid diameter • CW, CCW	100 M and 100 F (62-92) 100 boys and 100 girls (44-58 months)	Mean value of two measurements	• Torque meter • Hand dynamometer	Free posture	Opening wrist twisting strength for jar lids	• Age • Height • Weight • Grasp • Lateral prehension • Hand length • Hand breadth • Hand spread	NM	NM
Mital, Channaveeraiah (1988)	USA	• Grip shape • Wrist orientation • Duration of repeated exertions	15 M (23.6±3.6) and 15 F (22.6±3.3)	One measurement	VISHAY-20 digital strainmeter	Standing posture for wrenches Sitting posture for screwdrivers	Maximum volitional torque for wrenches and screwdrivers	Some anthropometric measures	Up to 5 min	4 sec
Pheasant, O'neill (1975)	UK	•Screwdriver size • Screwdriver shape • Screwdriver shape quality	1. Exp - 24 subjects 2.Exp - 10 subjects	Mean value	Simple Lever and load cell device	Free posture	Maximum steady voluntary torques for cylindrical handles	NM	NM	NM

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

Source	Location	Factor	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time
Seo, Armstrong, Chaffin, Miller (2008)	USA	• Handle material • Push method	6 M and 6 F (21-35 years)	Mean of two measurements	• Pressure Measurement System • EMG	Free posture	• Axial push force • Torque • Grip force • Finger flexor muscle activities	• Age • Gender • Hand length • Grip strength	2 min	5 sec
Nayak (2004)	UK	• Age • Hand area • Mid arm circumference	65 M and 85 F (age range from 55 to 85 years)	One measurement	• Strain-gauge hand-held dynamometer • torque meter	Sitting	• Wrist twisting strength with jar lid • Pinch and power grip strengths	• Age • Gender • Weight • Height • BMI • Hand measurements	1 min	5 sec
Crawford, Wanibe, Nayak (2002)	UK	• Lid shape • Lid diameter • Height of lid	10 M (69-81) and 10 F (60-72) 10 boys and 10 girls (20-39)	Mean value	• Torque meter •Dynamometer • Pinch gauge	Standing	Wrist torque opening strength with jar lid	• Stature • Weight • Hand breadth • Hand length • Chuck grip force • Grip force • Lateral grip force • Pinch grip force	NM	NM

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

Source	Location	Factor	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time
Yang, Tan, Buttolo, Johnston, Pizlo (2003)	UK	Noise	6 M and 3 F	Average of last 12 reversal amplitudes	• Rotary motor • Optical Encoder • Transformer	Sitting, resting the left elbow on the table in a comfortable position	Sinusoidal torque with rotary switch	NM	NM	NM
Imrhan, Loo (1986)	USA	• Age • Gender • Lid diameter • Lid surface	42 subjects (60-97)	Mean value of trials	Wrist twisting torque	Subjects standing in front of the tester and held the container lid with the preferred hand.	Maximum voluntary wrist twisting in opening screw top containers	• 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
Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009)	UK	Tools	18 young subjects (21-25) 64 older subjects (66-94)	Mean value	Instrumented jar with an embedded torque sensor	Free posture	Opening torque with jar opener	• Age • Gender	2 min	5 sec

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

Source	Location	Factor	Sample type (Size, gender, age)	Measure used	Instrument	Posture	Measured Strength	Anthropometric measures taken	Rest time	Squeeze time
Swain, Shelton, Rigby (1970)	USA	• Knob Size • Knob Orientation • Glove Condition	96 civilian M 24 military M (21-40)	Max of two measurements	• Dial indicating • Screw-driver type torque wrench • Indicator.	• 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

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

Standing	**Sitting**	**Standing and Sitting**	**Standing or sitting (Free to choose)**	**Standing, sitting and some other postures**	**Studies where the posture is not mentioned**
• Voorbij, Steenbekkers (2001) • Kong, Lowe (2005) • Peebles, Norris (2003) • Imrhan, Jenkins (1997) • Adams, Ma (1988) • Adams, Peterson (1986) • Adams, Peterson (1988) • Swain, Shelton, Rigby (1970) • Seo, Armstrong, Chaffin, Miller (2008) • Crawford, Wanibe, Nayak (2002) • Imrhan, Loo (1986)	• Miller, Nair, Baratz (2005) • Su, Chiu, Chang, Lin, Hong, Kuo (2008) • Wong, Moskovitz (2010) • Nayak (2004) • Yang, Tan, Buttolo, Johnston, Pizlo (2003) • Seo, Armstrong, Miller, Chaffin (2007)	• Mital, Sanghavi (1986) • Gugari, Okamura (2007)	• Yoxall, Janson, Bradbury, Langley, Wearn, Hayes (2006) • Rohles, Moldrup, Laviana (1983) • Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009)	• Mital (1986) • Kim, Kim (2000) • Mital, Channaveeraiah (1988)	• Rowson, Yoxall (2010) • Replogle (1983) • Pheasant, O'Neill (1975)

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

Cylindrical Handles	**Circular knob**	**Jar lids**	**Screwdrivers**	**Circular electrical connectors**	**Wrenches**
• 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)	• Peebles, Norris (2002) • Gugari, Okamura • Swain, Shelton, Rigby (1970) • Miller, Nair, Baratz (2005) (Disks) Designed device • Kim, Kim (2000) • Nair, Baratz (2005)	• Nagashima, Konz (1986) • Voorbij, Steenbekkers (2001) • Peebles, Norris (2002) • Rowson, Yoxall • Su, Chiu, Chang, Lin, Hong, Kuo (2008) • Yoxall, Janson, Bradburry, Langley, Wearn, Hayes (2006) • Rohles, Moldrup, Laviana (1983) • Laxman, Nayak (2004) • Crawford, Wanibe, Nayak (2002) • Imrhan, Loo (1986) • Yoxall, Langley, Luxmoore, Janson, Taylor, Rowson (2009)	• Mital, Sanghavi (1986) • Mital (1986) • Kim, Kim (2000) • Mital, Channaveeraiah (1988)	• Adams, Ma (1988) • Adams, Peterson (1986) • Adams, Peterson (1988)	• Mital, Sanghavi (1986) • Mital (1986) • Kim, Kim (2000) • Mital, Channaveeraiah (1988)

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

Children Population	Students	Adults	Elderly population	Normative Study	Not mentioned
• Rohles, Moldrup, Laviana (1983) • Steenbekkers (1993)	• Bradley (1969) • Nagashima, Konz (1986) • Adams, Ma (1988) • Kong, Lowe (2005) • Kong, Lowe, Lee, Krieg (2007)	• Swain, Shelton, Rigby (1970) • Mital, Sanghavi (1986) • Mital (1986) • Cochran, Riley (1986) • Adams, Peterson (1986) • Adams, Peterson (1988) • Mital, Channaveeraiah (1988) • 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, Moskovitz (2010)	• 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)	• Steenbekkers (1993) • Voorbij, Steenbekkers (2001) • Peebles, Norris (2003) • Yoxall, Janson, Bradbury, Langley, Wearn, Hayes (2006)	• Pheasant, O'neill (1975) • Replogle (1983) • Yang, Tan, Buttolo, Johnston, Pizlo (2003)

3. RATIONALE AND OBJECTIVES OF THE STUDY

3.1. Rationale of the Study

Determining the strength norms of a population is very important for various purposes, especially for product and work designs. Even though, there is a great technological improvement in the industry, many activities are still performed through human intervention. The knowledge of strength data is necessary to design within the strength capabilities of people, which is essential to improve the work performance and also reduce the injury possibilities. One of critical success factors in the work life is the perfect match between the job requirements and individual capabilities.

There are many ‘gaps’ in the ergonomics data available to designers. One of these is hand torque strength data (Peebles and Norris, 2002). Due to importance of it, there have been a number of studies on hand torque strength in different countries throughout the world. However, there have not been any studies conducted to investigate hand torque strength capability of population of Turkey. But since, geographical and hereditary differences among different nationalities lead to variation in the strength data, hand torque strength norms should be developed for the populations of different regions and nationalities. Therefore, this study would be useful to develop a database of hand torque strength with different handle types using data collected from a sample of population of Turkey

Furthermore, while many studies have investigated hand torque strength capabilities for various factors, none involved occupation factor as manual and non-manual classification. Relatively few studies have focused on relationship between body posture and hand torque strength. In addition, hand torque strength is affected by the handle type, thus hand torque strength need to be studied with various handles.

This study combines the mentioned factors to study hand torque strength in addition to establish hand torque strength norms of adult female population of Turkey.

3.2. Objectives of the Study

Based on the rationale above, this study aims the following:

(i) Estimating the maximum voluntary static (isometric) hand torque strength distribution of healthy adult female population of Turkey;

(ii) Investigating the effects of handle type, posture, age, occupation and various anthropometric variables on hand torque strength;

(iii) Comparing the hand torque strength data of the female population of Turkey with the hand torque strength data of other populations.

4. METHODOLOGY

4.1. Subjects

The sample of the study included 257 female volunteers from population of Turkey. Nearly all subjects were recruited from İstanbul, a metropolitan city of Turkey. İstanbul is a city whose population is composed of people from all regions of Turkey. That is, it is assumed that the population of İstanbul approximately represents the general population of Turkey.

The subjects were asked about their birthplace, family origin city, father and mother's birthplace in order to ensure approximately balanced distribution among different regions of Turkey. The distribution of family origins of the subjects is shown in Figure 4.1.

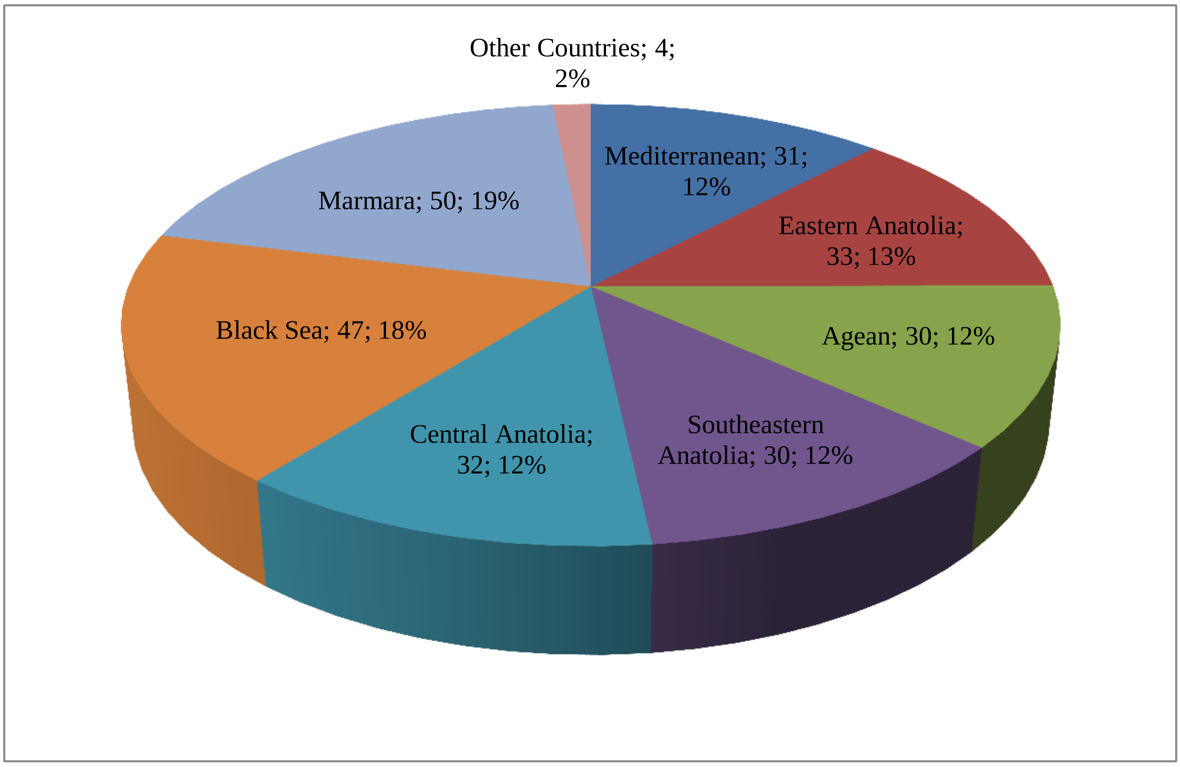


Figure 4.1. The distributions of family origins of the subjects. (*First number in figure, shows subject quantity per region, second number shows percentage of the whole sample).

To examine the occupation effect on hand torque strength; subjects were divided into two groups; manual workers and non-manual workers, according to power demand levels of work they perform (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.

All subjects had to be free from hypertension, heart disease, diabetes, rheumatoid arthritis, arm pain and musculoskeletal disorders; therefore a medical history form hemen (Medical History Form – Appendix A) 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. Among all subjects only 12 female subjects were left handed.

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

In summary, stratified random sampling method was used dividing the population in strata (age group, occupation group and seven geographical region of Turkey based on family roots and birth place. Table 4.1 shows the number of subjects categorized by age, occupation groups and BMI. A permission was obtained from the local human subjects review committee to test the participants. Table 4.2 shows detailed occupation distribution of subjects.

Table 4.1. Subjects categorized by age, occupation groups and BMI groups.

Occupation Group	**BMI Category**	**Age Group**					**All**
		18 – 29	**30 -39**	**40 -49**	**50 - 59**	**60 - 69**	
Manual	**Underweight**	2	0	0	0	0	**2**
	Normal	12	10	8	4	1	**35**
	Overweight	14	17	17	21	24	**93**
	All	**28**	**27**	**25**	**25**	**25**	**130**
Non-manual	**Underweight**	1	2	1	1	0	**5**
	Normal	22	20	9	8	8	**67**
	Overweight	2	5	15	16	17	**55**
	All	**25**	**27**	**25**	**25**	**25**	**127**
Total		**53**	**54**	**50**	**50**	**50**	**257**

Table 4.2. Occupation Distribution.

Manual workers (130)	**Non-manual workers (127)**
Canteen worker (carrying load) (6)	Accountant (2)
Cleaner- charwoman (27)	Administrative assistant (1)
Cleaner and tea seller (5)	Agricultural engineer (1)
Coiffeur (4)	Architects (2)
Cook (5)	Assistant (sales) (1)
Electric assembly worker (1)	Biologist (1)
Housewife (farmer) (13)	Business analyst (1)
Housewife (gardening) (29)	Clerk (23)
Housekeeper (1)	Clerk (retired) (23)
Housewife (weaving) (16)	Clerk (transportation) (2)
Masseur (1)	Consultant (5)
Nursery nurse (1)	Entrepreneur (1)
Nursery personal (1)	Film maker (1)
Part time waiter (1)	Genetics engineer (1)
Retired printer (1)	Gym instructor (1)
Self- employed (painter)(1)	Housewife (light) (1)
Special security (2)	Instructor (2)
Sportswoman (lifting) (1)	Kindergarten teacher (2)
Store (warehouse) (1)	Music teacher (1)
Tailor (2)	Officer (2)
Technician (1)	Pharmacist (1)
Textile worker (retired) (1)	Physical education teacher (1)
Textile worker (2)	Printmaker (1)
Tourism worker (2)	Publisher (retired) (1)
Violin maker (1)	Purchasing manager (1)
Waiter (1)	Secretary (1)
Washerwoman (1)	Secretary tourism (2)
Worker (assembly) (2)	Street trader (5)
	Student (16)
	Teacher (14)
	Teacher (retired) (4)
	Trade (import & export) (3)
	Tourism personal (office) (3)

4.2. Equipment

The information about the tools used for hand torque strength, hand grip strength and some anthropometric dimensions (height, weight, hand length, wrist circumference, etc.) measurements provided in the following;

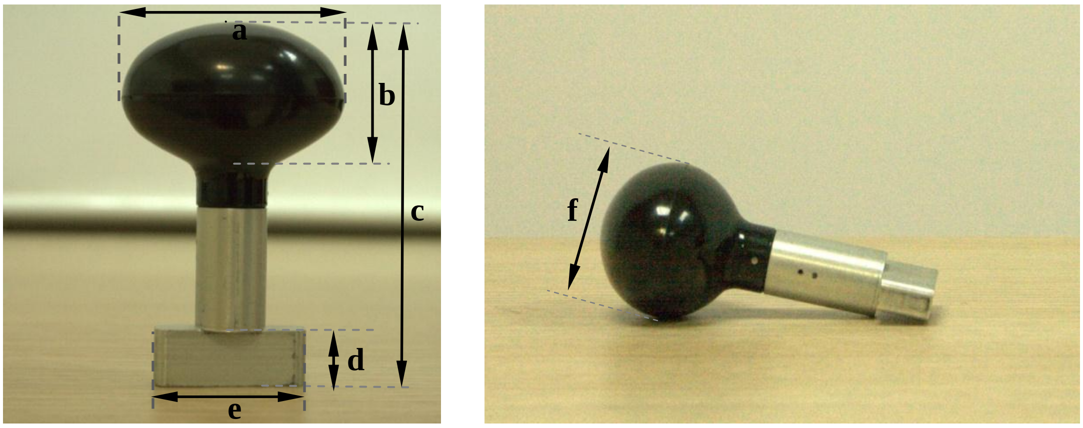
4.2.1. Torque Tester

Hand torque strength was measured with the CAP-TT01-250 Digital Torque Tester (Figure 4.7) which is a special high-capacity version calibrated for a range up to 250 lb-in / 2875 kg-mm / 2875 N-cm (Electromatic Equipment Co., Inc., USA). This torque tester was specially modified for the current study by the manufacturing company. For this modification, it was supplied with custom female rectangular block that perfectly match the "tongue" ends of the handles considered for the current study. In addition, the orientation of the tool for measurement was changed. Therefore it can be said that it is a custom ordered torque meter. The experimental apparatus that was used is shown in Figure 4.2. Four handles that were used are:

- Ellipsoid handle – major axis(a): 55.58 mm; minor axis(f): 41.95 mm; intermediate axis (b): 35.41 mm; total height(c): 90.08 mm; tongue depth(d): 14 mm; tongue width(e): 37.5 mm (Figure 4.3)
- 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 4.4)
- 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 4.6)
- 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 4.5)

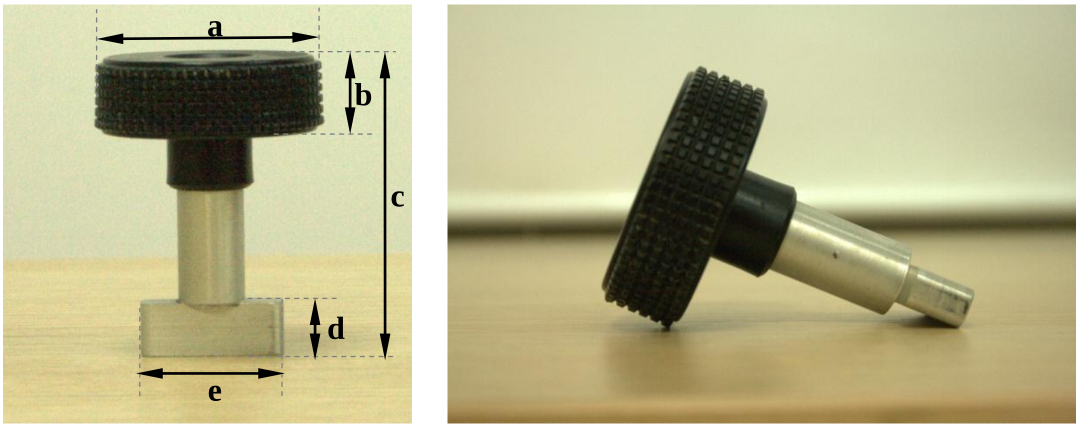
The materials of handles are as following: Ellipsoid and circular handles are made of plastic; key handle is made of natural anodized coated aluminum; cylindrical handle is made of black anodized coated aluminum.

Figure 4.2. The CAP-TT01-250 Digital Torque Tester (Electromatic Equipment Co., Inc., USA).



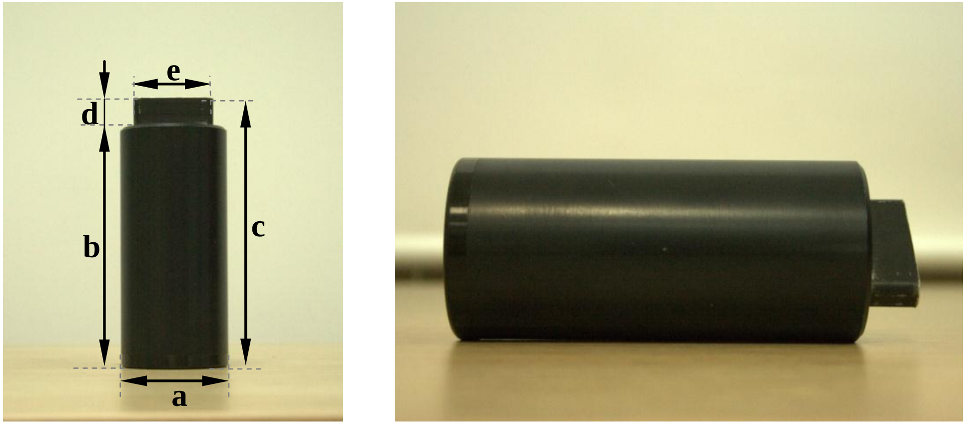
a=55.58 mm, b=35.41 mm, c=90.08 mm, d=14 mm, e=37.5 mm, f=41.95 mm

Figure 4.3. Ellipsoid Handle.



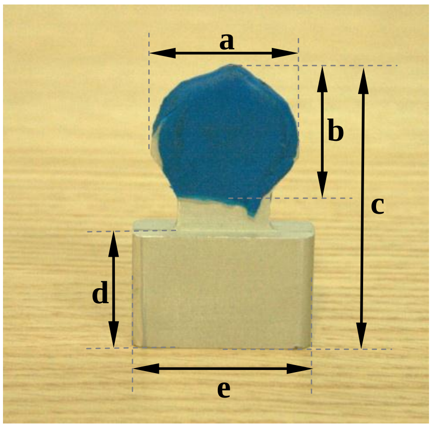
a= 59.98 mm, b= 20.10 mm, c=79.05 mm, d=14 mm, e=37.5 mm

Figure 4.4. Circular handle.



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

Figure 4.5. Cylindrical Handle.



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

Figure 4.6. Key Handle.

4.2.2. Holtain Harpenden Stadiometer

The stadiometer is a counter recording instrument, with an effortless counter balanced movement. It gives an accurate and direct reading of a subject's height. 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 4.7 shows the stadiometer.

4.2.3. Weighing Scale

Weighting scale is a measuring instrument for determining the weight or mass of an object. 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. Figure 4.8 shows the scale used in this study.

4.2.4. The Measuring Tape

A measuring tape is a flexible form of ruler. It consists of a ribbon of cloth, plastic, fiber glass, or metal strip with linear-measurement markings. It is a common measuring tool. To measure circumferences of wrist and forearm of the participants, the measuring tape was used in this study. Figure 4.9 shows the measuring tapes used in the laboratory in this study.

4.2.5. Caliper

Caliper is a device used to measure the distance between two opposite sides of the subjects including length and 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 4.10 shows the caliper used in this study.

4.2.6. Jamar Handgrip Dynamometer

Hand grip strength was measured while sitting by a hydraulic Jamar handgrip dynamometer (Model 5030J1, Sammons Preston Roylan, and Chicago, USA), which is considered a standard isometric grip strength testing device (Figure 4.11). The dynamometer accommodates various size hands because its handle adjusts to five grip positions: from 3.5 cm to 8.6 cm (1.375 to 3.375 inches), in 1.27 cm (0.5 inch) increments.

4.2.7. Adjustable height table and adjustable chair

For all postures, a remote controlled adjustable height table and an adjustable chair were used (Figure 4.12 and Figure 4.13). The height of adjustable chair was adjusted so that the upper legs of subjects were almost horizontal and their feet were flat on the ground.

Figure 4.7. Stadiometer (a) Front view (b) Side view (c) Indicator.

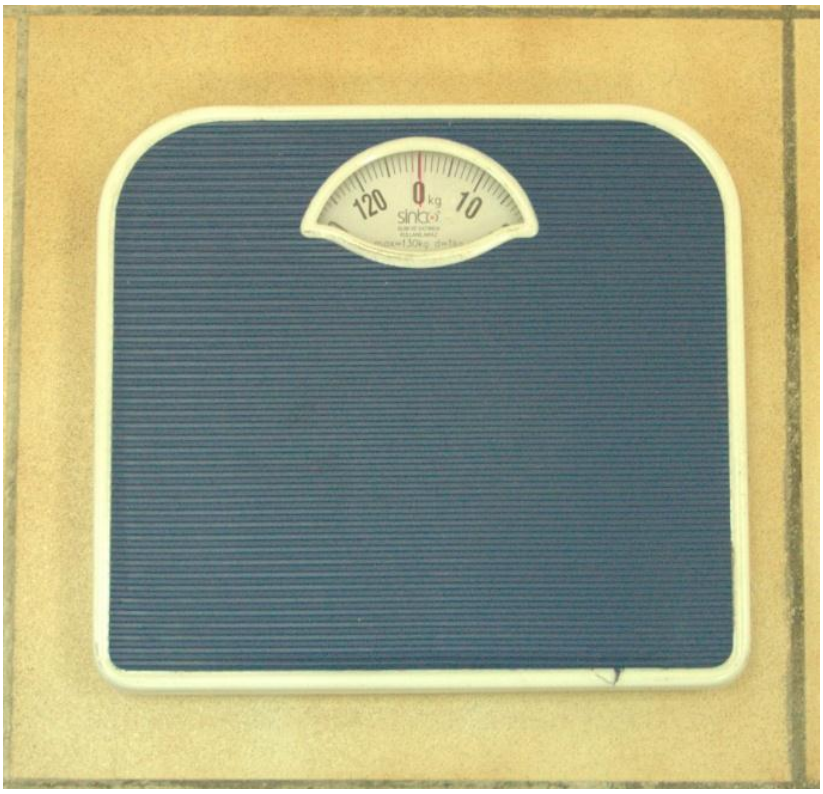


Figure 4.8. Mechanical scale.

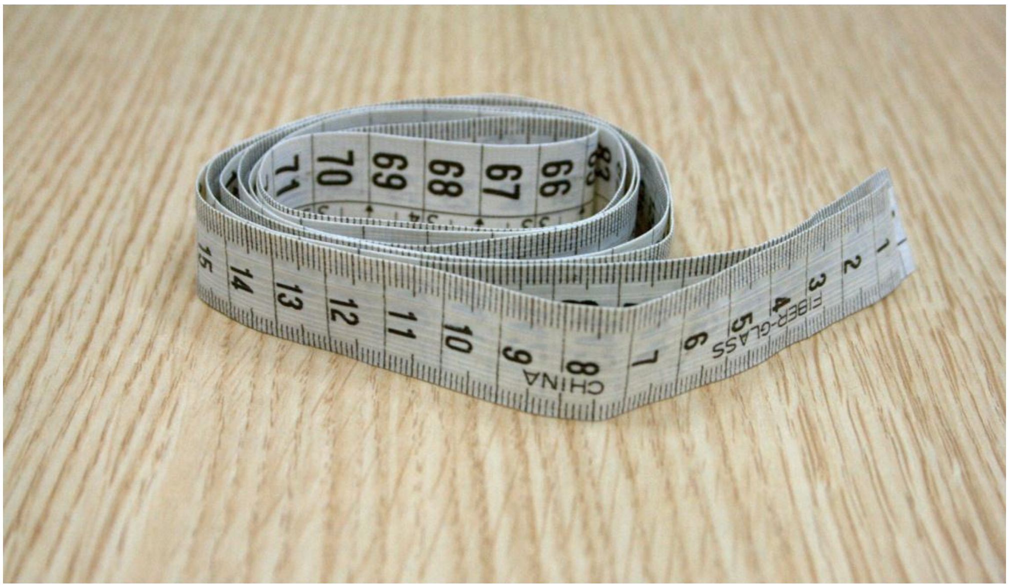


Figure 4.9. Tape measure.

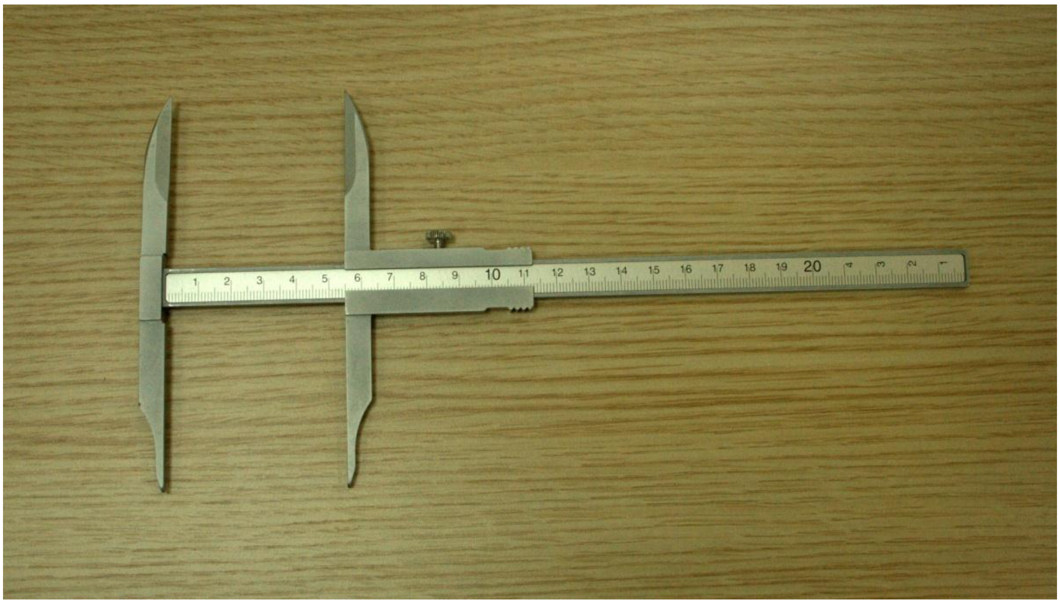


Figure 4.10. Sliding caliper.

Figure 4.11. Hydraulic Jamar handgrip dynamometer.

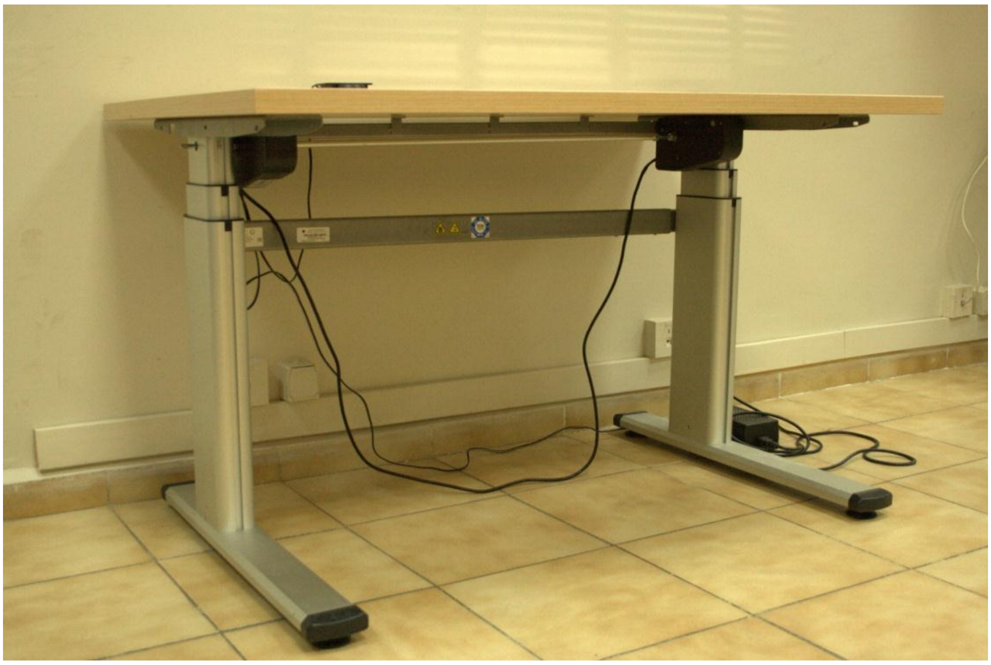


Figure 4.12. Remote-controlled height adjustable table.

Figure 4.13. Adjustable chair (a) Front view (b) Lateral view.

4.2.8. The Calibration Procedure of Torque Meter

The calibration of the equipment was checked before starting the experiments. 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.

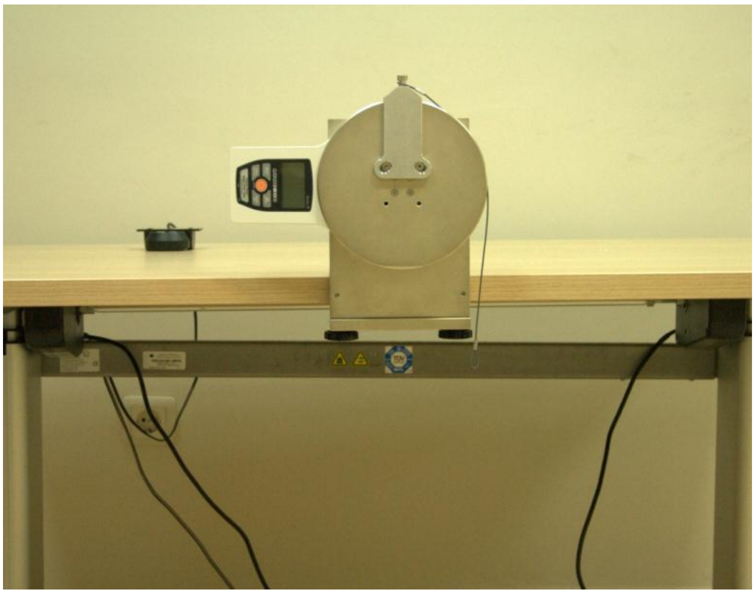


Figure 4.14. Checking calibration, before mounting weight.

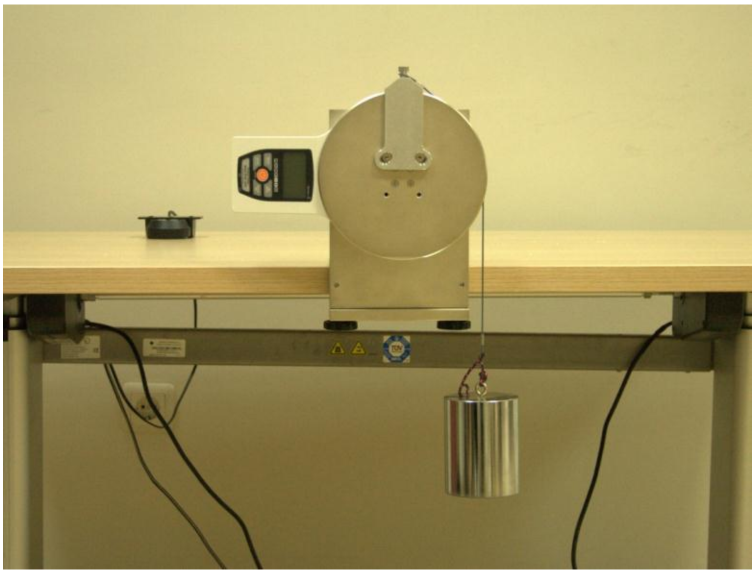


Figure 4.15. Checking calibration, after mounting weight.

Previously determined weights were hanged with the calibration kit (Figure 4.14 and Figure 4.15). 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, assuring an accurate calibration.

The calibration procedure is done according the procedure described in the CAP-TT01-250 Cap Torque Tester Manual.

Then all necessary hand torque strength measurements were done with different handles in standing and sitting positions.

4.3. Testing Procedure

Prior to any evaluation, each subject was given a brief description of the objectives and requirements of the study. Then, 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. 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 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). However, Turkish version was used for all subjects.

Before starting 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.

4.3.1. Anthropometric measurements

The following anthropometric measurements were taken.

- Height
- Body mass
- Wrist circumference
- Forearm circumference
- Hand length
- Hand breadth

All of this anthropometric data were recorded in “Personal Data Form” by the investigator after appropriate measurements.

Stature (body height) was measured by the stadiometer while subject stood fully erect with heel together and head oriented in the Frankfurt plane (ISO 7250) and weight was measured by a mechanical scale (Figures 4.16 and 4.17). This mechanical scale was checked for accuracy with known weights before the tests. The subjects wore comfortable, light clothes and did not wear any accessories which cause extra weight. In addition, the participant was not very hungry or full. 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 (Figure 4.19). Hand breadth was measured by sliding caliper; subject held forearm horizontal with hand stretched out flat, palm up (Figure 4.20). A tape measure is used to measure circumferences of wrists of the participants and while measurements subject hold forearm horizontal with outstretched, fingers extended (Figure 4.18). Finally, to measure forearm circumference of the participants with a tape measure, while person sits with the forearm supinated (Figure 4.21). While measuring circumference of forearm, subjects had a lightly squeezed fist. All anthropometric hand measurements were taken from the dominant side of the subject. Also almost all anthropometric measurements were measured according to ISO 7250: Basic human body measurements for technological design.

Figure 4.16. Measurement of height with stadiometer.

Figure 4.17. Measuring weight with the mechanical scale.

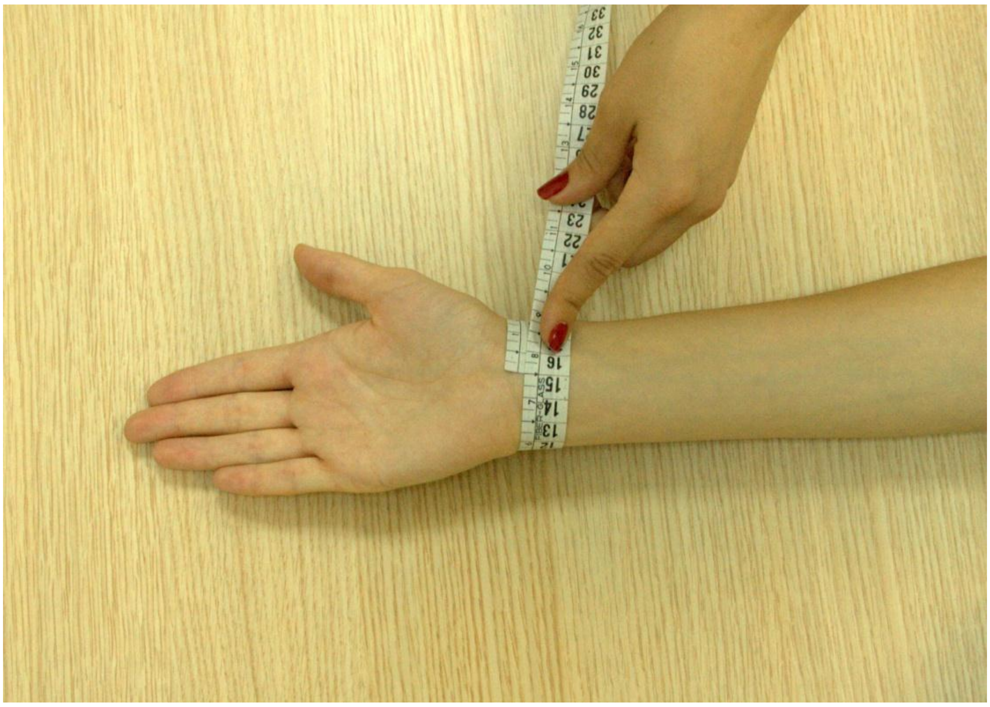


Figure 4.18. Measurement of circumference of wrist.

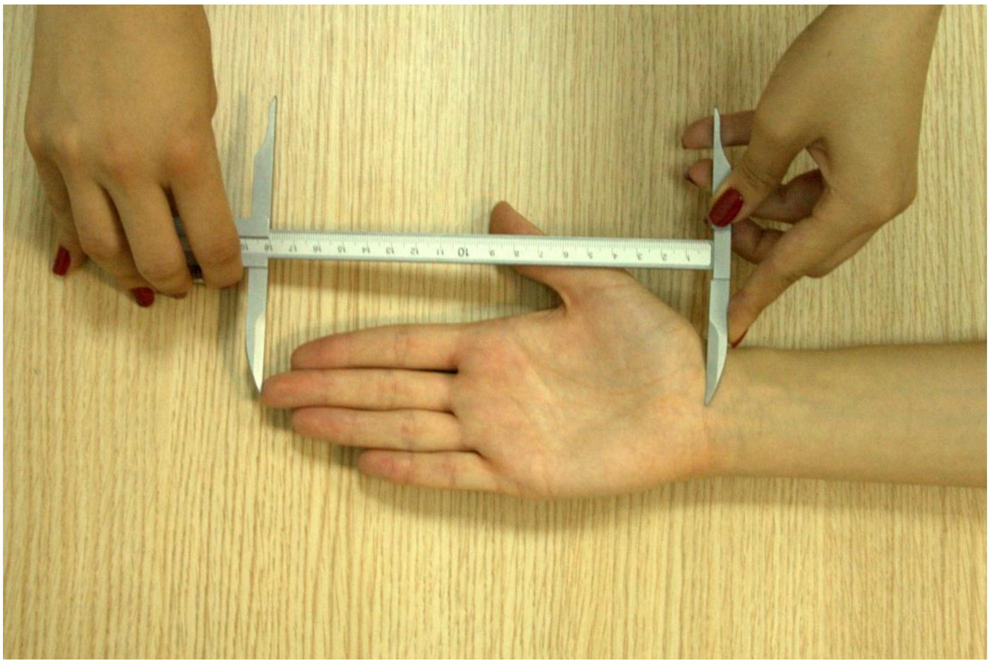


Figure 4.19. Measurement of hand length.

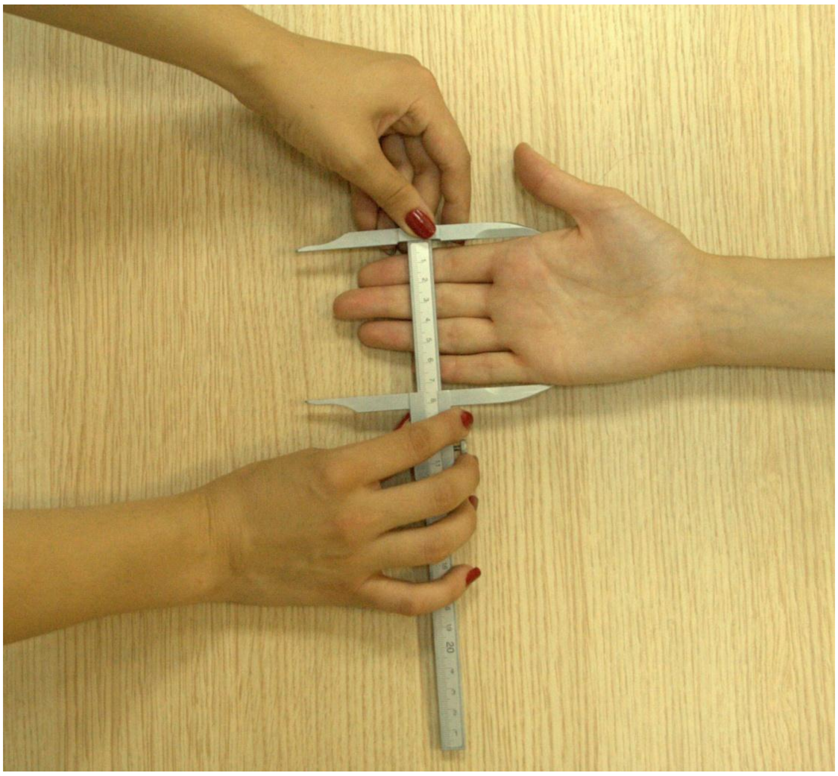


Figure 4.20. Measurement of hand breadth.

Figure 4.21. Measurement of circumference of forearm.

4.3.2. Grip Strength Measurement

4.3.2.1. Determination of preferred grip span. For maximum voluntary grip strength measurements with Jamar hand grip dynamometer, the preferred span is used. To determine the preferred span, the participants performed several trials tests with self-determined submaximal grip forces at five different grip span settings of the dynamometer. They were instructed to select the one that is comfortable and allowed the maximum force exertion capability based on judgment. For further details see Ekşioğlu and Silahlı (2012).

4.3.2.2. Grip Strength Measurements. 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, 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 % 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, the experimenter did not provide any feedback about the strength values to the subjects. Verbal encouragements, rewards, goal setting, competition and noise were also avoided. Laboratory was kept in normal room temperature.

4.3.3. Hand Torque Strength Measurement

After all anthropometric and grip strength measurements, the following hand torque strength measurements were taken. All of them are shown in Table 4.3

Table 4.3 Dominant hand torque strength measurements with four handle types in both sitting and standing postures.

Number	Measurements
1	Torque strength while sitting with ellipsoid handle
2	Torque strength while standing with ellipsoid handle
3	Torque strength while sitting with circular handle
4	Torque strength while standing with circular handle
5	Torque strength while sitting with key handle
6	Torque strength while standing with key handle
7	Torque strength while sitting with cylinder handle
8	Torque strength while standing with cylinder handle

There was a demonstration and practice period, before the actual testing, which allowed each subject to become familiar with the equipment and procedures so that they could perform the tests according to the instructions. Before the actual tests, the subjects shook their hands and fingers to speed up their blood circulation, as a warm-up period. Also they were instructed to wipe their hands thoroughly to prevent the possibility of sweaty hands affecting their hand torque strength. Equipment was also wiped each time.

After all these measurements and preparations, the experiments on hand torque strength started. The torque strength testing procedures also followed procedures outlined in the literature for the measurement of isometric muscle strength (Caldwell *et al.*, 1974). Therefore, first of all information about the test purpose and procedures were described to subjects. Subjects used only their dominant hand and 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. The average torque strength value of the middle 3 seconds of 5 seconds torque exertion time was taken as torque strength for that trial. 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 of the trial values was recorded as the subject's maximum voluntary hand torque strength. A 2 - min rest interval was given between two exertions, 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) For the standing position, subjects stood during testing and adopted free posture in order to replicate realistic scenarios (Daams, 1990) The testing device was adjusted and positioned at each subject's elbow height (Figures 4.24 and 4.26). 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).

(ii) For the sitting posture, a chair with adjustable height was used (Figure 4.13) and to minimize effects of the body positions on strength measurements, each subject adopted the testing position recommended by American Society of Hand Therapists (Fess, 1992; Bohannon, 1991), where a subject sat upright before the measuring device (Figures 4.23 and 4.25). 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, the feet are firmly flat on the floor.

Subjects in this study were required to grip the cylindrical handle with power grip, where the hand applies torque about the long axis of the cylindrical handle in "inward" torque. Therefore; sitting and standing postures for cylindrical handle differed from other three handles. Figures 4.25 and 4.26 show the postures. Grip methods for each handle type are shown in Figures 4.27, 4.28, 4.29 and 4.30.

Figure 4.22. Measurement of grip strength.

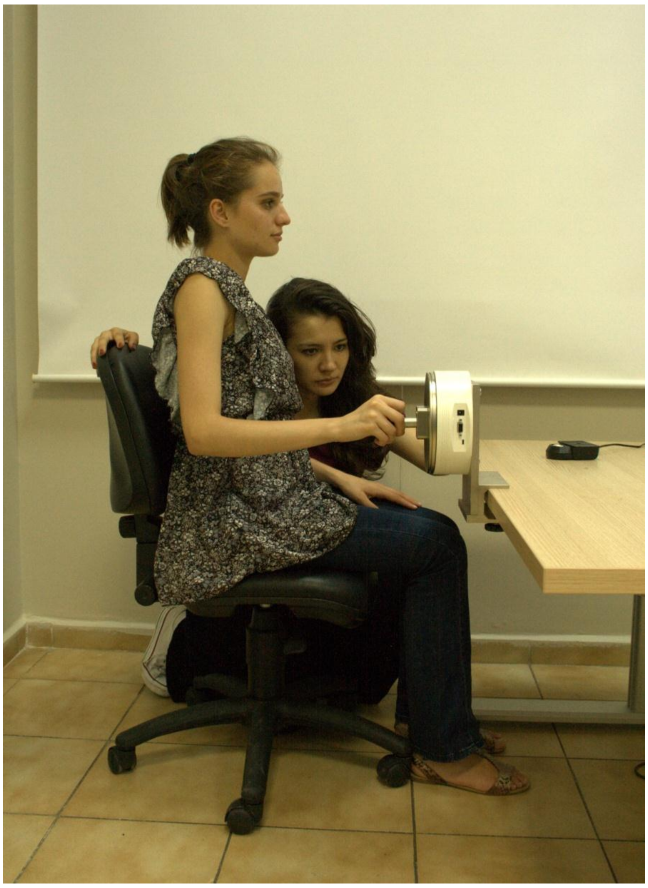


Figure 4.23. Measurement of hand torque strength while sitting (Ellipsoid, circular, key).

Figure 4.24. Measurement of hand torque strength while standing (Ellipsoid, circular, key).

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

Figure 4.26. Measurement of hand torque strength while standing (cylinder).

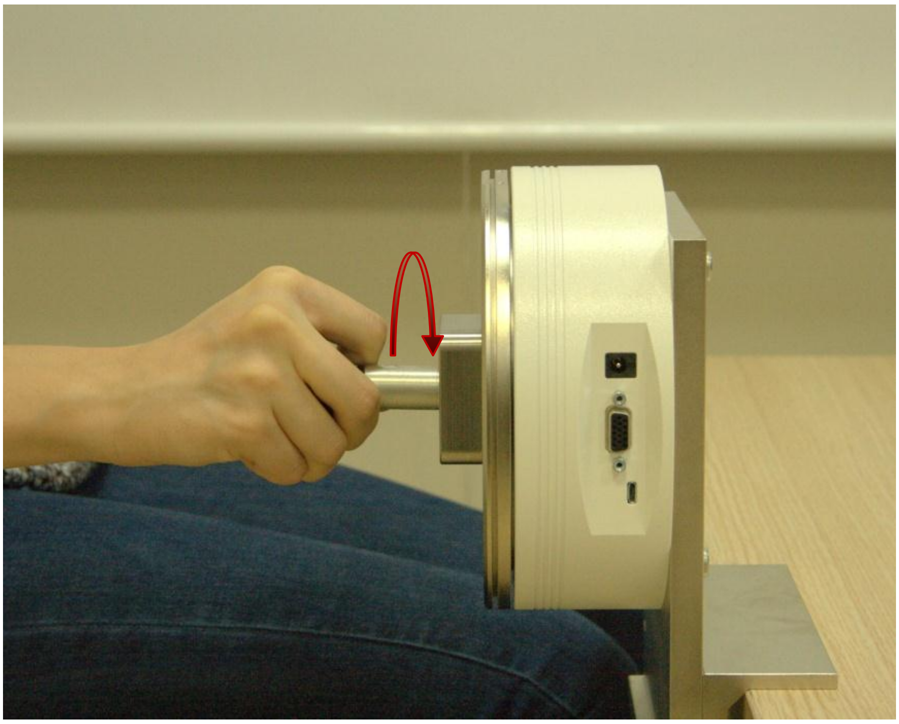


Figure 4.27. Grip method used when manipulating ellipsoid handle (Clockwise).

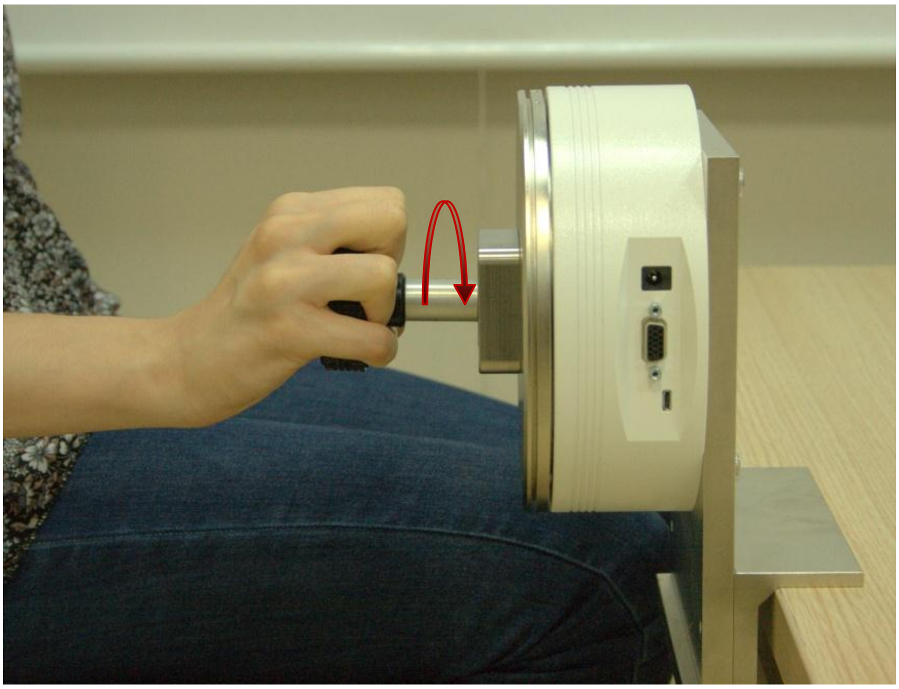


Figure 4.28. Grip method used when manipulating circular handle (Clockwise).

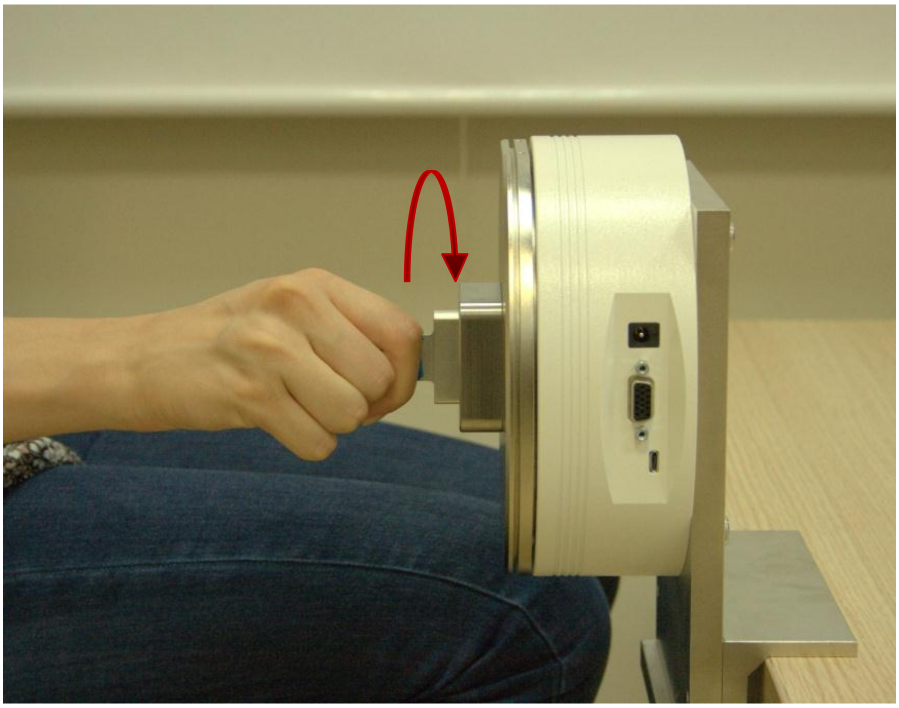


Figure 4.29. Grip method used when manipulating key handle (Clockwise).

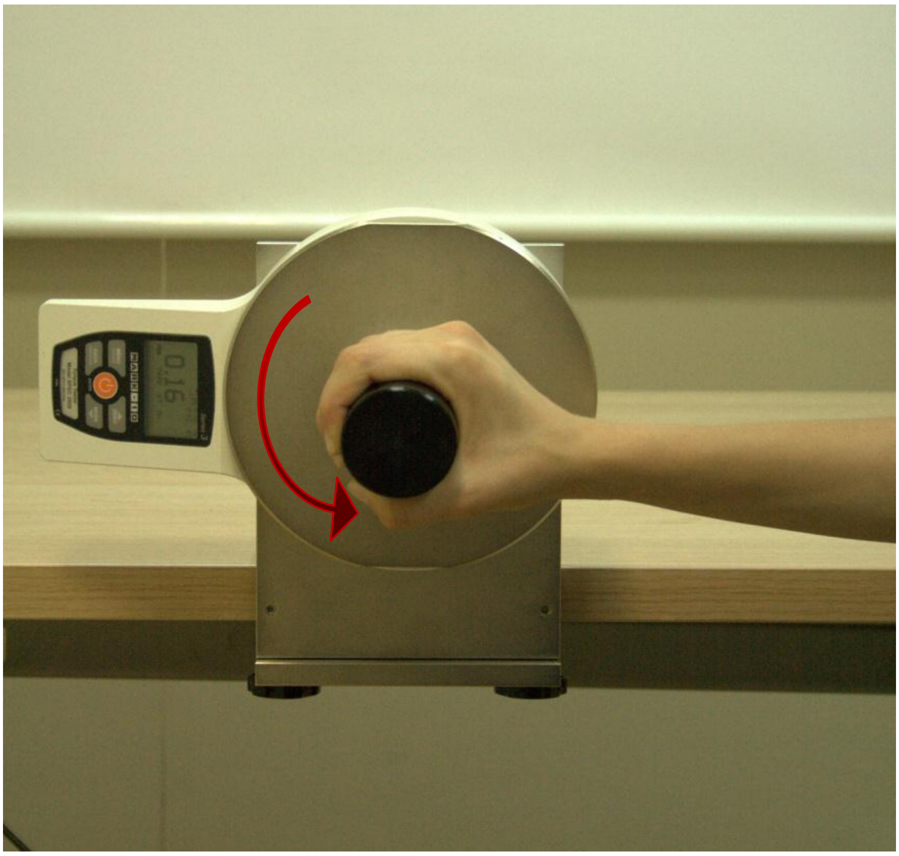


Figure 4.30. Grip method used when manipulating cylindrical handle (Counterclockwise).

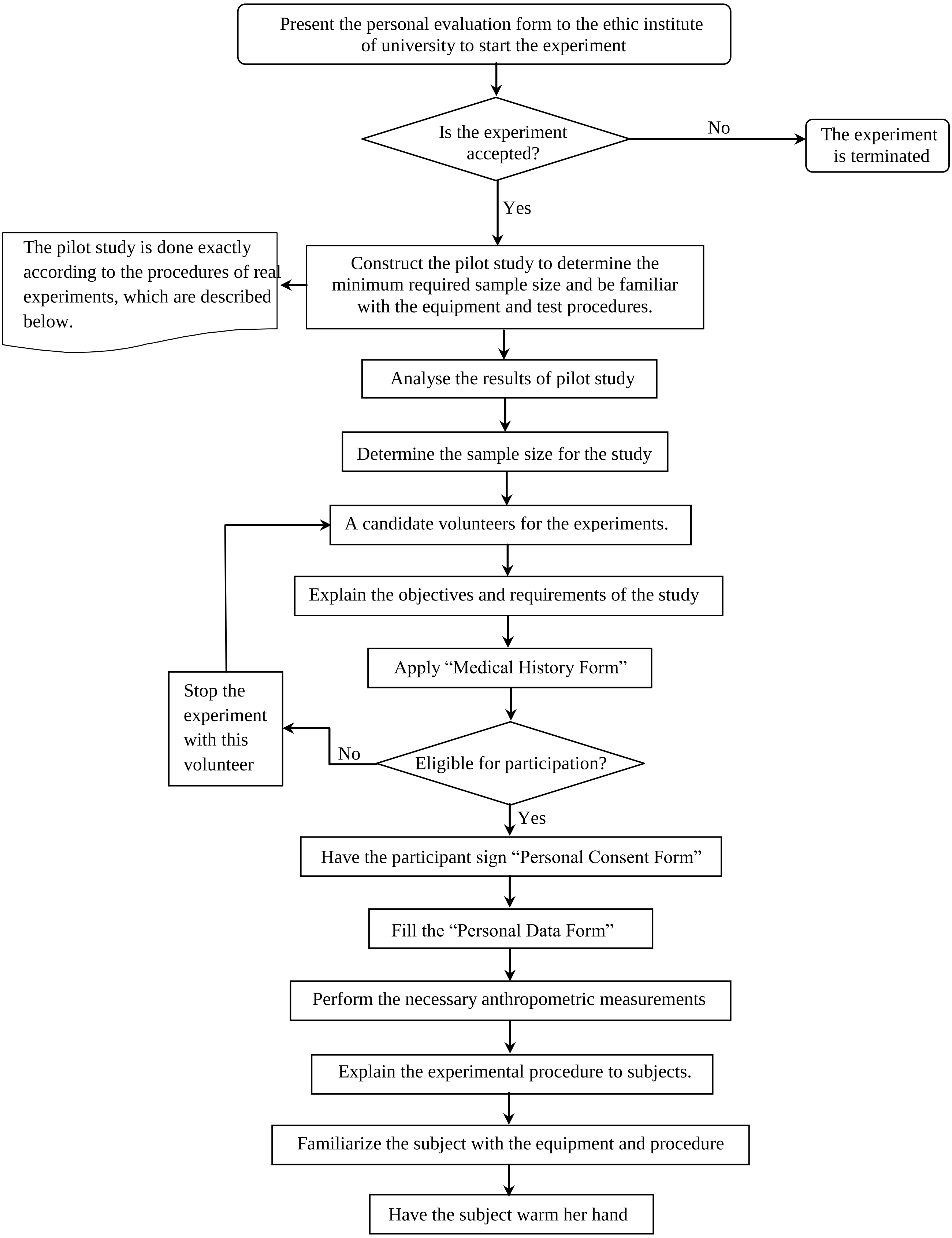


Figure 4.31. Flow chart of the experimental procedure.

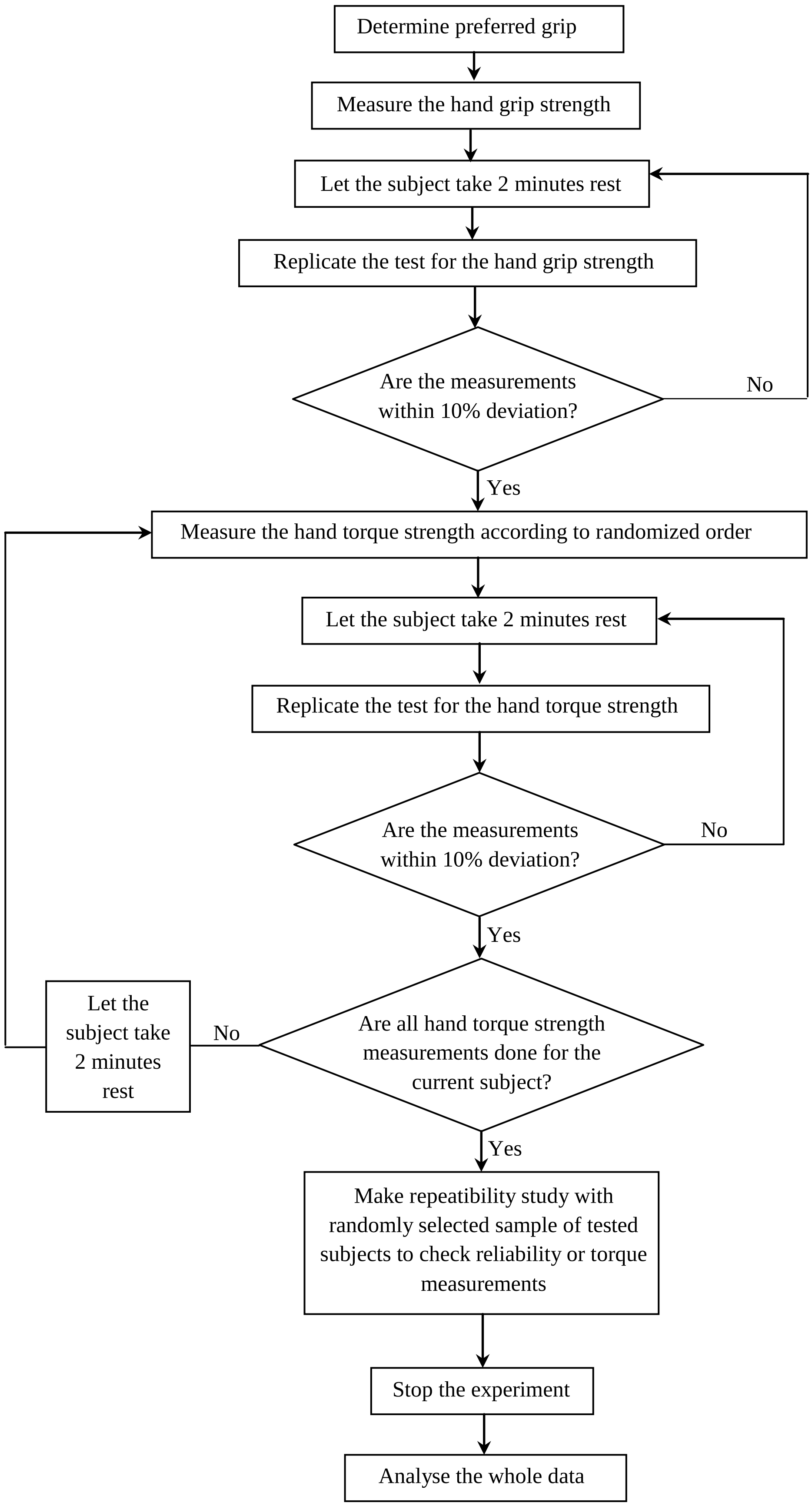


Figure 4.31. Flow chart of the experimental procedure (cont'd).

4.4. Experimental Design and Statistical Analysis

4.4.1. Experimental Variables

The dependent (response) variable for this study is maximum voluntary hand torque strength. There are five design factors (independent variables) in this study. These factors are posture, handle type, age group, occupation group and body mass index (BMI) group of the subjects. Levels of the factors can be seen in Table 4.4. Among these variables, posture and handle type are experimental factors. Each subject performed eight different combinations (4 handle types × 2 postures). Characteristics of the subjects like; age group, occupation group and BMI group, are classification factors.

Table 4.4 Design factors and levels of these factors.

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

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 her (his) height (kg/ m²) (Wikipedia, 2008)

$$\text{BMI (kg/m}^2) = \text{Body mass (kg) / Height}^2 \text{ (m}^2) \tag{4.1}$$

4.4.2. Experimental Conditions

The experimental task involved measuring dominant hand's maximum voluntary hand torque strength for four handle types at two postures, sitting and standing (eight treatment combinations : 4 handle types × 2 postures). Each strength test was performed at least twice. For each test, each subject performed eight test conditions randomly. There were 257 female subjects. Therefore, the number of recorded hand torque strength data points (test runs) was at least 257 * 8 * 2 =4112 (Table 4.5). 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 4.5 Experimental conditions.

	Posture															
	Sitting								Standing							
	Ellipsoid		Circular		Key		Cylindrical		Ellipsoid		Circular		Key		Cylindrical	
Sub-ject	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
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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

4.4.3 Experimental Model

4.4.3.1. Randomized complete block design. The randomized complete block design with subjects serving as blocks was found suitable for this 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). By blocking on the subjects, the power of the test can be increased by removing the effects of different subjects on hand torque strength. This would allow us to detect smaller differences between factor effects (Montgomery, 2005). After running ANOVA for females, all interaction effects were found non-significant with high p-values. Thus, in the model, interaction effects between treatments were neglected and only main effects were taken into consideration. Therefore, for this case, the reduced statistical model for randomized block design is:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \tau_k + \varepsilon_{ijk} \quad (4.2)$$

where y_{ijk} is the ijkth maximum voluntary hand torque strength, μ is the overall response mean (hand torque strength mean), α_i is the effect of ith level of posture, β_j is the effect of the jth level of handle type, τ_k is the effect of the kth block (subject) and ε_{ijk} is random sampling error NID (0, σ^2);
for $i = 1,2$ (posture), $j = 1,2,3,4$ (handle type), $k = 1,2,3,4,\ldots,257$ (subject)

The hypotheses of interest is:

$H_0 = \mu_1 = \mu_2 = \ldots = \mu_8$

H_1 = at least one μ_{ij} is different

4.4.3.2. Completely randomized design. For classification factors (BMI group, occupation group and age group) a separate ANOVA was done. After running this ANOVA for females, all interaction effects were also found non-significant with high p-values. Thus, in the model, interaction effects between treatments were neglected and only main effects were taken into consideration. Therefore, for this case, the model for complete randomized design is:

$$y_{klm} = \mu + \delta_k + \varphi_l + \vartheta_m + \varepsilon_{klm} \quad (4.3)$$

where, y_{klm} is klmth response (maximum voluntary hand torque strength) μ is the overall response mean (mean of max. voluntary hand torque strength), δ_k is effect of kth level of body mass index (BMI) group factor, φ_l is effect of lth level of occupation group factor, ϑ_m is the effect of mth level of age group factor and ε_{klm} is the random error component NID $(0,\sigma^2)$;
for $k = 1, 2$ (BMI group), $l = 1,2$ (occupation group), $m = 1, 2, 3, 4, 5$ (age group)

The hypotheses of interest is:

$H_0 = \mu_1 = \mu_2 = ... = \mu_{20}$

H_1 = At least one μ_{klm} is dif.

4.4.4 Pilot Study

A pilot study with randomly selected 50 female 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 experimental procedures and equipment,

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

4.4.5. Sample Size Determination

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

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

$$N = \left(\frac{1.96 \times CV}{a}\right)^2 \times 1.534^2 \quad (4.4)$$

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

CV is defined as the following:

$$CV = \frac{SD}{\bar{x}} \times 100 \quad (4.5)$$

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

In current study, true mean and standard deviation of the population are unknown, so these values are estimated by using the results of the pilot study. Relative accuracy is decided to be 5%. Therefore, sample size for females for 95% CI is calculated as;

$$N = \left(\frac{1.96 \times CV}{5}\right)^2 \times 1.534^2$$

Because CV values of maximum voluntary torque strength varies for each eight test combinations (Table 4.6), the calculation of required minimum sample sizes vary accordingly (Table 4.7). The largest of the calculated sample size, which corresponds to standing ellipsoid handle test combination, is taken as the minimum required sample size. That is at least 151 subjects are needed for required statistical power. However, a total of 257 subjects were used for the study to improve the statistical power even further.

Table 4.6 Sample Statistics.

	$\bar{x}$	SD	CV
Ellipsoid Sitting	27.16	5.34	19.64
Circular Sitting	31.95	5.67	17.74
Key Sitting	15.16	2.78	18.34
Cylinder Sitting	47.80	8.42	17.62
Ellipsoid Standing	28.84	5.88	20.39
Circular Standing	34.36	5.29	15.39
Key Standing	15.12	2.50	16.55
Cylinder Standing	50.17	9.03	18.00

Table 4.7 Minimum sample size for 95 % confidence and 5 % relative accuracy.

Ellipsoid Sitting	$N = \left(\frac{1.96 \times 19.643}{5}\right)^2 \times 1.534^2 = 139.518 = 140$
Circular Sitting	$N = \left(\frac{1.96 \times 17.735}{5}\right)^2 \times 1.534^2 = 113.745 = 114$
Key Sitting	$N = \left(\frac{1.96 \times 18.338}{5}\right)^2 \times 1.534^2 = 121.610 = 122$
Cylinder Sitting	$N = \left(\frac{1.96 \times 17.619}{5}\right)^2 \times 1.534^2 = 112.262 = 113$
Ellipsoid Standing	$N = \left(\frac{1.96 \times 20.393}{5}\right)^2 \times 1.534^2 = 150.380 = 151$
Circular Standing	$N = \left(\frac{1.96 \times 15.387}{5}\right)^2 \times 1.534^2 = 85.622 = 86$
Key Standing	$N = \left(\frac{1.96 \times 16.545}{5}\right)^2 \times 1.534^2 = 98.987 = 99$
Cylinder Standing	$N = \left(\frac{1.96 \times 17.999}{5}\right)^2 \times 1.534^2 = 117.155 = 118$

So the minimum required sample size is:

$$N = \left(\frac{1.96 \times 20.393}{5}\right)^2 \times 1.534^2 = 150.380 = \textcircled{151}$$

However to increase statistical power, size was increased and a total of 257 subjects were measured.

4.4.6. Statistical Analysis

Statistical Analysis was performed using Minitab 16.0. In the analysis, p-values ≤ 0.05 were accepted as significant and 0.05 <p-values ≤ 0.1 were accepted as marginal. For descriptive statistics: mean, standard deviation, range, confidence intervals, percentages and correlations of collected torque strength data were calculated. For inferential statistics, analysis of variance (ANOVA) was used to investigate the effects of posture, handle type, age group, occupation group and BMI group on hand torque strength, after checking the satisfaction of ANOVA assumptions.

(i) Normality assumption: The error terms (residuals) of the model must follow normal distribution centered at zero (ε ~ NID Normal (0, σ^2)). Check of normality can be made by plotting a normal probability plot of the residuals. If the NID (0, σ^2) assumption on the errors is satisfied, this plot should look like a sample from a normal distribution centered at zero.

Normality assumption is also checked quantatively 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 0.05, normal probability plot of the residuals for females was found approximately following normal distribution.

(ii) Independence assumption: There must not be any correlation between error terms (correlation of each value and the value before it) and correlation between independent variables and error terms

Plotting the residuals in time 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. 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)

Autocorrelation between residuals, and Pearson's correlation coefficients between independent variables and residuals were calculated for females, to prove that they were independent to each other. The plot of the residuals versus observation order for females 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.

(iii) Homogeneity of variance assumption: The variances of response variables for each treatment must not be significantly different from each other. Plot of residuals versus the fitted response were investigated for females. According to the plots this assumption was also approximately satisfied.

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)

Since the three assumptions of ANOVA were approximately satisfied, parametric ANOVA was used to investigate whether the independent variables have an influence on hand torque strength of females.

Tukey's test was used for post-hoc analysis. Tukey's test was selected, because while making pairwise comparisons, the Tukey's method results in a narrower confidence limit, which is preferable (Toothaker, 1993). Moreover, because of its simplicity and nearly accurate control of the overall error rate, Tukey's test is recommended for pairwise comparisons (Hochberg and Tamhane, 1987). For unbalanced case, Tukey's test is sometimes called Tukey-Kramer, but throughout the manuscript it will also be referred as Tukey's test. The hypotheses of this test are (Montgomery, 2005):

$$H_0: \mu_i = \mu_j$$
$$H_1: \mu_i \neq \mu_j \tag{4.6}$$

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):

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

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):

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

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. Moreover, a set of $100(1-\alpha)$ confidence intervals for all pairs of means can be constructed as follows

4.4.6.1. Regression Analysis. Following the ANOVA and multiple comparison tests, a regression analysis was performed to develop prediction equations for hand torque strengths of females. Stepwise and Best subsets approaches were 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.) The Best subsets approach was used to check the obtained models, it gives many different alternative sub models with Mallow's cp statistics to compare them. The general form of the multiple regression equation is as follows (Montgomery, 2005):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon \quad (4.9)$$

where y is the response (hand torque strength), β_0 is the constant, β_1, β_2,… are regression coefficients for independent variables, x_1, x_2 are regression variables and ε is the error term (normally and independently distributed, ≈NID $(0,\sigma^2)$).

Before starting the regression analysis, the satisfaction of the following assumptions was checked (Montgomery, 2005):

• *Linearity:* The relationship between the dependent and independent variables should be linear. Multiple regression procedures are not greatly affected by minor deviations from this assumption.

• *Normality:* The residuals of the independent variables must be normally distributed. This assumption can be checked by looking at the normal probability plots of residuals.

• *Multicollinearity must not exist:* If it exists, it means that there are redundant variables in the regression. This can be checked by looking at the variance inflation factor (VIF). VIF is desired to be smaller than 5.

• *Variance homogeneity:* The variances within groups must be equal.

• *Autocorrelation:* There must not be correlation between the errors because correlation affects the estimation of coefficients for the regression. Durbin-Watson statistic is used to verify this assumption. It is desired to be between 1.5 and 2.5.

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

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

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_n = 0$$
$$H_0: \beta_j \neq 0 \; for\ at\ least\ one\ j \; (j = 1, \ldots, n) \qquad (4.10)$$

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

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

5. RESULTS

5.1. Descriptive Statistics

5.1.1. Summary Statistics

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

Table 5.1. Characteristics of female participants.

Measurements	**Mean ± Std. Dev.**	**Min-Max**
Age (years)	43.61 ± 14.26	19 - 69
Stature (cm)	161.29 ± 6.01	145 - 175
Body mass (kg)	69.62 ± 12.95	42 - 110
Dominant Hand Length (cm)	17.19 ± 0.84	14 - 19.2
Dominant Hand Breadth (cm)	7.87 ± 0.47	6 - 9.1
Dominant Hand, Circumference of Wrist (cm)	16.76 ± 1.41	14 - 23.5
Dominant Hand, Circumference of Forearm (cm)	25.37 ± 2.59	17 – 34

Table 5.2 and Table 5.3 show represents descriptive statistics (mean, standard deviation (Std. Dev.) and range (min - max)) of the maximum voluntary static hand grip strength (in N) and of maximum voluntary static hand torque strength (in Nm) (for eight different test combinations) by age and occupation and also by age, respectively for dominant hand.

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

Results indicated that average maximum hand torque strength of manual workers was found stronger than non-manual workers in all hand tools and experimental postures.

It can be seen from Table 5.2, that the hand torque strength peaks between 30-39 years for non-manual and between 40-49 years for manual workers. For both groups 60-69 age group is the weakest.

Moreover, the mean values of hand torque values for four different handle types are 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.

Figure 5.1 shows torque strength distributions for eight test combinations. As can be seen, besides key torque strength, all are fairly symmetrical.

Table 5.2. Descriptive statistics of dominant hand static grip strength (in N*) and dominant hand static torque strength (in Nm **) by age and occupation.

Occupation by age group	**n**	**Grip Strength**	**Sitting**				**Standing**			
			Ellipsoid	**Circular**	**Key**	**Cylinder**	**Ellipsoid**	**Circular**	**Key**	**Cylinder**
All	257	251.6∓ 68.9 78.5- 470.7	2.74∓ 0.71 1.23- 4.84	3.30∓ 0.86 1.29- 5.33	1.59∓ 0.39 0.7- 3.56	5 ∓ 1.3 1.97- 8.54	2.96 ∓ 0.78 1.08- 4.98	3.51∓ 0.88 0.92- 5.54	1.65∓ 0.42 0.66- 3.13	5.3∓ 1.38 2.59- 8.42
Manual	130	268.5∓ 65.7 107.9- 470.7	2.86∓ 0.74 1.23- 4.84	3.55∓ 0.8 1.42- 5.33	1.64∓ 0.38 0.78- 2.66	5.37∓ 1.11 1.97 – 7.81	3.09∓ 0.82 1.11- 4.98	3.76∓ 0.8 1.63- 5.54	1.73∓ 0.43 0.7- 3.05	5.71∓ 1.2 2.83- 8.25
18-29	28	276.7∓ 54.3 176.5- 431.5	2.61∓ 0.68 1.23- 3.97	3.33∓ 0.73 2.27- 5.19	1.54∓ 0.32 0.92- 2.16	5.68∓ 1.13 4.01- 7.81	2.81∓ 0.73 1.81- 4.32	3.65∓ 0.6 2.52- 4.87	1.66∓ 0.39 1.04- 2.48	6.01∓ 1.21 3.33- 7.91
30-39	27	290.9∓ 56.3 186.3- 470.7	2.84∓ 0.63 1.82- 4.06	3.48∓ 0.58 2.31- 4.55	1.65∓ 0.37 0.99- 2.66	5.61∓ 0.98 2.93- 7.35	3.06∓ 0.7 1.11- 3.93	3.68∓ 0.71 2.03- 5.31	1.66∓ 0.34 1.07- 2.26	5.86∓ 0.92 3.74- 7.82
40-49	25	300.9∓ 71.5 166.7- 451.1	3.27∓ 0.8 1.72- 4.84	3.89∓ 0.88 1.42- 5.33	1.76∓ 0.39 1.09- 2.62	5.76∓ 0.81 3.28- 6.89	3.31∓ 0.74 1.78- 4.83	4.08∓ 0.86 2.43- 5.54	1.81∓ 0.47 1.02- 3.02	6.36∓ 1.05 3.66- 8.25
50-59	25	256.5∓ 64.4 176.5- 431.5	2.96∓ 0.77 1.58- 4.67	3.76∓ 0.92 1.66- 5.21	1.72∓ 0.41 0.94- 2.31	5.49∓ 0.96 3.59- 6.86	3.18∓ 1.02 1.28- 4.98	3.96∓ 0.9 1.87- 5.37	1.83∓ 0.5 1.19- 2.76	5.72∓ 0.93 4.34- 7.29
60-69	25	214.6∓ 47.8 107.9- 333.4	2.66∓ 0.71 1.77- 4.01	3.31∓ 0.76 1.49- 4.87	1.54∓ 0.39 0.78- 2.43	4.27∓ 0.98 1.97- 6.42	3.12∓ 0.88 1.72- 4.92	3.44∓ 0.8 1.63- 4.93	1.68∓ 0.47 0.7- 3.05	4.54∓ 1.12 2.83- 6.78
Non-manual	127	234.2∓ 68.2 78.5- 382.5	2.61∓ 0.65 1.34- 4.53	3.05∓ 0.85 1.29- 5.18	1.53∓ 0.4 0.7- 3.56	4.61∓ 1.38 1.97- 8.54	2.83∓ 0.71 1.08- 4.9	3.26∓ 0.89 0.92- 5.51	1.57∓ 0.39 0.66- 3.13	4.88∓ 1.44 2.59- 8.42
18-29	25	256.9∓ 50.4 186.3- 333.4	2.45∓ 0.64 1.53- 3.73	2.94∓ 0.69 2.03- 4.3	1.47∓ 0.34 0.97- 2.27	5.14∓ 1.5 3.04- 7.85	2.52∓ 0.65 1.3- 4.14	3.00∓ 0.84 0.92- 4.61	1.45∓ 0.3 0.97- 2.03	5.43∓ 1.5 3- 8.42
30-39	27	271.7∓ 44.4 196.1-353.0	2.85∓0.6 1.34- 3.75	3.21∓0.81 1.29- 4.91	1.73∓0.47 1.13- 3.56	5.10∓ 1.39 3.19- 8.54	3.13∓ 0.64 1.79- 3.94	3.62∓ 0.93 1.77- 5.51	1.77∓ 0.38 1.02- 3.13	5.31∓ 1.52 3.12- 8.1
40-49	25	257.1∓ 73.9 107.9- 382.5	2.85∓ 0.78 1.39- 4.53	3.40∓ 1.04 1.37- 5.18	1.59∓ 0.4 1.04 – 2.31	4.7∓ 1.37 2.71- 7.02	3.04∓ 0.83 1.58- 4.9	3.57∓ 0.97 1.96- 5.14	1.75∓ 0.44 1.06- 2.81	5.01∓ 1.38 2.92- 8.01
50-59	25	219.3∓ 52.0 88.3- 313.8	2.65∓ 0.59 1.39- 4.1	3.04∓ 0.66 1.65- 4.47	1.40∓ 0.31 0.82- 1.94	4.44∓ 1.18 2.43- 6.91	2.95∓ 0.63 1.63- 4.41	3.43∓ 0.77 1.97- 5.47	1.46∓ 0.32 0.66- 1.94	4.77∓ 1.39 2.66- 7.34
60-69	25	163.2∓ 58.1 78.5- 294.2	2.23∓ 0.38 1.44- 2.9	2.66∓ 0.87 1.53- 4.79	1.45∓ 0.38 0.7- 2.38	3.64∓ 0.85 1.97- 4.93	2.51∓ 0.58 1.08- 3.73	2.68∓ 0.47 1.77- 3.9	1.43∓ 0.33 0.89- 2.34	3.84∓ 0.75 2.59- 5.25

*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.

Age group	n	GS	Sitting				Standing			
			Ellipsoid	Circular	Key	Cylinder	Ellipsoid	Circular	Key	Cylinder
All	**257**	251.6 ± 68.9 78.5 - 470.7	2.74 ± 0.71 1.23 - 4.84	3.30 ± 0.86 1.29 - 5.33	1.59 ± 0.39 0.7 - 3.56	5 ± 1.3 1.97 - 8.54	2.96 ± 0.78 1.08 - 4.98	3.51 ± 0.88 0.92 - 5.54	1.65 ± 0.42 0.66 - 3.13	5.3 ± 1.38 2.59 - 8.42
18-29	**53**	267.37 ± 52.92 176.52 - 431.49	2.53 ± 0.66 1.23 - 3.97	3.14 ± 0.73 2.03 - 5.19	1.5 ± 0.33 0.92 - 2.27	5.42 ± 1.34 3.04 - 7.85	2.67 ± 0.7 1.3 - 4.32	3.35 ± 0.79 0.92 - 4.87	1.56 ± 0.36 0.97 - 2.48	5.73 ± 1.37 3 - 8.42
30-39	**54**	281.31 ± 51.15 186.33 - 470.72	2.84 ± 0.61 1.34 - 4.06	3.34 ± 0.71 1.29 - 4.91	1.69 ± 0.42 0.99 - 3.56	5.35 ± 1.22 2.93 - 8.54	3.1 ± 0.66 1.11 - 3.94	3.65 ± 0.82 1.77 - 5.51	1.72 ± 0.36 1.02 - 3.13	5.58 ± 1.27 3.12 - 8.1
40-49	**50**	279 ± 75.31 107.87 -451.11	3.06 ± 0.81 1.39 - 4.84	3.64 ± 0.99 1.37 - 5.33	1.68 ± 0.4 1.04 - 2.62	5.23 ± 1.23 2.71 - 7.02	3.17 ± 0.79 1.58 - 4.9	3.82 ± 0.95 1.96 - 5.54	1.78 ± 0.45 1.02 - 3.02	5.68 ± 1.39 2.92 - 8.25
50-59	**50**	237.91 ± 60.9 88.26 - 431.49	2.8 ± 0.69 1.39 - 4.67	3.4 ± 0.87 1.65 - 5.21	1.56 ± 0.4 0.82 - 2.31	4.96 ± 1.19 2.43 - 6.91	3.06 ± 0.85 1.28 - 4.98	3.7 ± 0.87 1.87 - 5.47	1.65 ± 0.46 0.66 - 2.76	5.25 ± 1.26 2.66 - 7.34
60-69	**50**	188.88 ± 58.7 78.45 - 333.43	2.45 ± 0.6 1.43 - 4.01	2.98 ± 0.87 1.49 - 4.87	1.5 ± 0.38 0.7 - 2.43	3.95 ± 0.97 1.97 - 6.42	2.82 ± 0.8 1.08 - 4.92	3.06 ± 0.76 1.63 - 4.93	1.55 ± 0.42 0.7 - 3.05	4.19 ± 1.01 2.59 - 6.78

Table 5.4. 95% confidence interval for mean for dominant Hand Grip Strength (in N*) and for Hand torque strengths (in Nm*) by age and occupation.

Age	N	Grip Strength	Sitting				Standing			
			Ellipsoid	Circular	Key	Cylinder	Ellipsoid	Circular	Key	Cylinder
Subjects	257	243.09- 260.03	2.65- 2.82	3.2- 3.41	1.54- 1.64	4.84 - 5.16	2.87- 3.06	3.41- 3.62	1.6- 1.7	5.13- 5.47
Manual	130	257.08- 279.88	2.73- 2.99	3.41- 3.69	1.57- 1.71	5.18- 5.56	2.95- 3.23	3.62- 3.9	1.65- 1.8	5.5- 5.92
18-29	28	255.65- 297.73	2.35- 2.88	3.04- 3.61	1.41- 1.66	5.24- 6.12	2.52- 3.09	3.42- 3.89	1.51- 1.81	5.54- 6.47
30-39	27	268.67- 313.19	2.59- 3.09	3.25- 3.71	1.51- 1.8	5.22- 5.99	2.79- 3.34	3.4- 3.96	1.52- 1.79	5.5- 6.23
40-49	25	271.36- 330.38	2.94- 3.6	3.53- 4.25	1.6- 1.92	5.43- 6.09	3.01- 3.62	3.72- 4.43	1.62- 2	5.92- 6.79
50-59	25	229.98- 283.10	2.64- 3.27	3.38- 4.14	1.55- 1.89	5.09- 5.88	2.76- 3.6	3.59- 4.33	1.63- 2.04	5.34- 6.11
60-69	25	194.83- 234.31	2.37- 2.95	2.99- 3.62	1.38- 1.7	3.86- 4.67	2.76- 3.49	3.11- 3.77	1.49- 1.88	4.08- 5
Non-manual	127	222.27- 246.21	2.49- 2.72	2.9- 3.2	1.46- 1.6	4.37- 4.85	2.71- 2.96	3.11- 3.42	1.51- 1.64	4.63- 5.13
18-29	25	236.13- 277.74	2.18- 2.71	2.65- 3.22	1.33- 1.61	4.52- 5.76	2.25- 2.79	2.65- 3.35	1.32- 1.57	4.81- 6.05
30-39	27	254.11-289.26	2.61-3.08	2.89-3.53	1.55- 1.92	4.55-5.65	2.88- 3.38	3.25- 3.99	1.63- 1.92	4.7- 5.91
40-49	25	226.59- 287.67	2.53- 3.17	2.97- 3.83	1.43- 1.76	4.14- 5.27	2.69- 3.38	3.16- 3.97	1.56- 1.93	4.44- 5.58
50-59	25	197.8- 240.76	2.4- 2.89	2.77- 3.31	1.27- 1.53	3.95- 4.93	2.69- 3.21	3.12- 3.75	1.33- 1.6	4.2- 5.35
60-69	25	139.21- 187.16	2.08- 2.39	2.3- 3.02	1.3- 1.61	3.28- 3.99	2.27- 2.75	2.48- 2.87	1.29- 1.56	3.53- 4.15

*N: Newton, *Nm: Newton meter

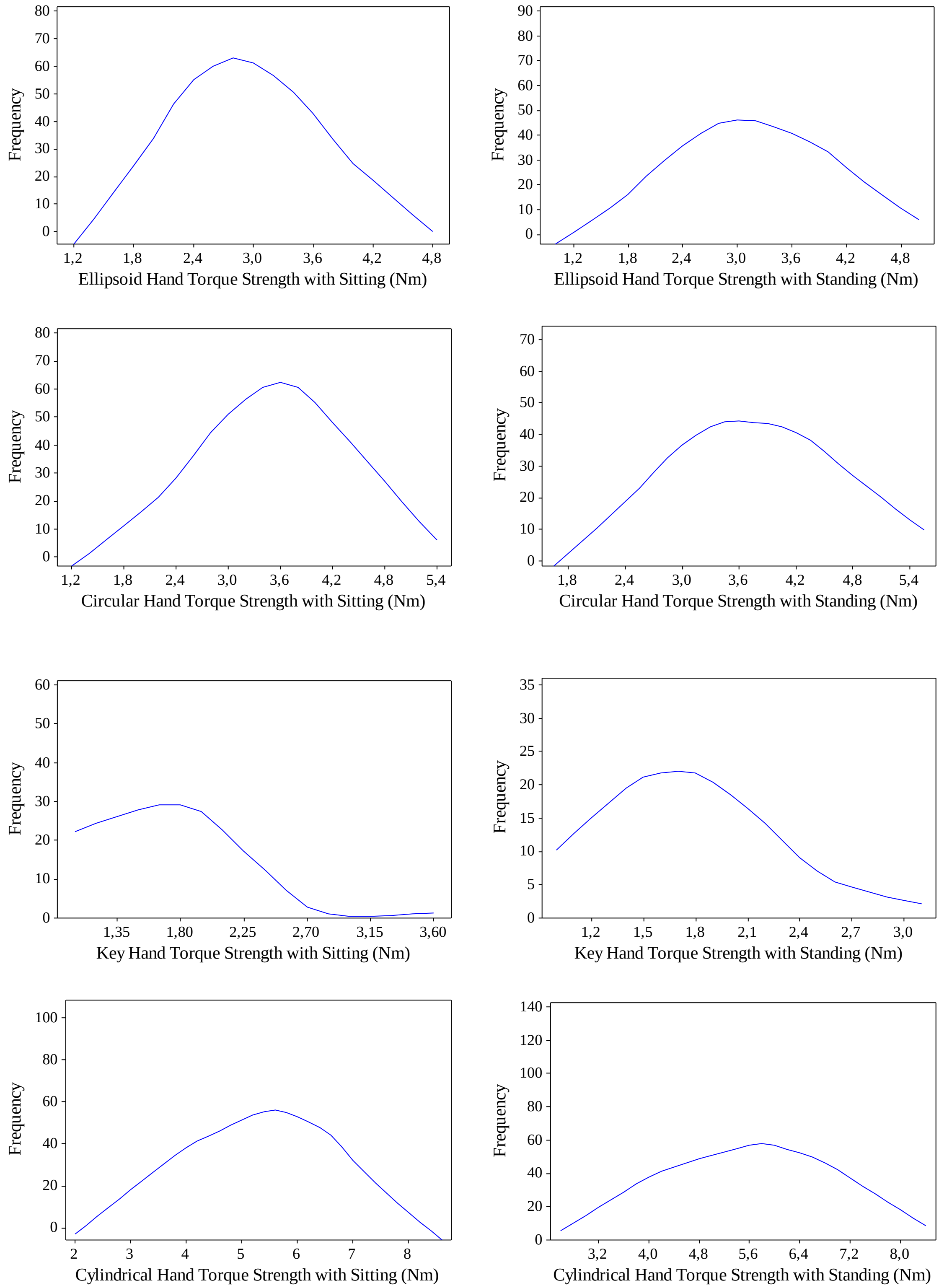

Figure 5.1. Distribution of strength data for eight different strength treatments.

5.1.2. Percentiles

In this part, the percentiles of the measured values were calculated for each testing position (Table 5.5). Moreover, percentiles of eight 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 percentiles in each test position.

Position		Percentiles							Std. Dev.
		1	5	25	50	75	95	99	
Sitting	Ellipsoid	1.37	1.74	2.21	2.62	3.24	3.96	4.66	0.71
	Circular	1.40	1.79	2.68	3.33	3.89	4.86	5.20	0.86
	Key	0.81	1.01	1.29	1.56	1.83	2.27	2.64	0.39
	Cylinder	2.15	2.97	3.96	4.98	6.00	6.94	7.83	1.30
Standing	Ellipsoid	1.21	1.76	2.41	2.95	3.53	4.31	4.91	0.78
	Circular	1.68	2.03	2.88	3.49	4.09	5.00	5.51	0.88
	Key	0.80	1.05	1.35	1.60	1.91	2.39	3.03	0.42
	Cylinder	2.72	3.15	4.23	5.26	6.46	7.56	8.16	1.38

Table 5.6. Hand torque strength percentiles for occupation groups.

Occupation Group	Position / Handle		Percentiles							Std. Dev.
			1	5	25	50	75	95	99	
Manual	Sitting	Ellipsoid	1.34	1.81	2.28	2.90	3.44	4.03	4.79	0.74
		Circular	1.44	2.29	3.04	3.55	4.01	5.00	5.29	0.80
		Key	0.82	0.98	1.41	1.68	1.89	2.29	2.65	0.38
		Cylinder	2.26	3.44	4.49	5.56	6.22	6.92	7.77	1.11
	Standing	Ellipsoid	1.16	1.85	2.44	3.14	3.64	4.62	4.96	0.82
		Circular	1.70	2.42	3.15	3.76	4.36	5.07	5.53	0.80
		Key	0.80	1.08	1.43	1.69	1.97	2.50	3.04	0.43
		Cylinder	2.88	3.37	4.81	5.85	6.60	7.58	8.14	1.20
Non-Manual	Sitting	Ellipsoid	1.36	1.61	2.19	2.52	3.04	3.73	4.46	0.65
		Circular	1.31	1.67	2.48	2.95	3.71	4.59	5.14	0.85
		Key	0.73	1.04	1.23	1.49	1.77	2.24	3.23	0.40
		Cylinder	2.06	2.73	3.57	4.41	5.71	6.98	8.35	1.38
	Standing	Ellipsoid	1.14	1.65	2.38	2.78	3.43	4.02	4.76	0.71
		Circular	1.14	1.96	2.66	3.08	3.90	4.95	5.50	0.89
		Key	0.72	1.00	1.30	1ç56	1.79	2.28	3.04	0.39
		Cylinder	2.61	2.89	3.76	4.50	6.20	7.71	8.33	1.44

Table 5.7. Hand torque strength percentiles for age groups.

Age group (years)	Handle type	Sitting				Standing			
		Percentile				Percentile			
		5	50	95	SD	5	50	95	SD
18-29	Ellipsoid	1.65	2.43	3.76	0.66	1.68	2.52	4.19	0.70
	Circular	2.14	3.14	4.40	0.73	1.87	3.28	4.65	0.79
	Key	0.96	1.49	2.19	0.33	1.05	1.60	2.17	0.36
	Cylindrical	3.10	5.57	7.72	1.34	3.28	5.69	7.92	1.37
30-39	Ellipsoid	1.86	2.78	3.80	0.61	1.89	3.36	3.93	0.66
	Circular	2.04	3.40	4.43	0.71	2.22	3.64	5.34	0.82
	Key	1.13	1.70	2.29	0.42	1.10	1.72	2.21	0.36
	Cylindrical	3.48	5.40	7.27	1.22	3.27	5.74	7.99	1.28
40-49	Ellipsoid	1.74	3.18	4.58	0.81	1.72	3.31	4.55	0.79
	Circular	1.62	3.85	5.11	0.99	2.28	3.85	5.34	0.95
	Key	1.08	1.56	2.41	0.40	1.14	1.70	2.71	0.45
	Cylindrical	2.95	5.64	6.85	1.23	3.33	6.00	7.87	1.39
50-59	Ellipsoid	1.70	2.65	4.14	0.69	1.76	3.02	4.83	0.85
	Circular	1.71	3.42	5.02	0.87	2.00	3.68	5.24	0.87
	Key	0.89	1.54	2.28	0.40	0.94	1.57	2.50	0.46
	Cylindrical	3.06	4.95	6.70	1.19	2.97	5.47	7.28	1.26
60-69	Ellipsoid	1.62	2.36	3.92	0.60	1.56	2.67	4.62	0.80
	Circular	1.57	3.04	4.73	0.87	1.88	2.94	4.51	0.76
	Key	0.88	1.45	2.25	0.38	0.91	1.54	2.30	0.42
	Cylindrical	2.14	3.97	5.90	0.97	2.78	4.19	6.30	1.01

5.2. Correlation Analysis

A correlation analyses (Pearson) were performed. Table 5.8 displays the Pearson correlation matrix between strength values of eight different treatment combinations. There are high positive correlation coefficients and p-values < 0.001.

Table 5.9 displays Pearson product-moment correlation coefficients between hand torque strengths and measured anthropometric measures of subjects. With weak correlation coefficient value, age was only found significantly and negatively correlated with cylinder sitting and cylinder standing treatments. Precisely, we can say that dominant hand breadth and dominant hand forearm circumference are significantly and positively correlated with almost all hand torque strength. Hand grip has the highest positive and significant correlation with all eight hand torque strength combinations.

Table 5.8 Pearson correlations between hand torque strengths of eight treatment combinations.

Strength	**Ellipsoid sit**	**Ellipsoid stand**	**Circul. sit**	**Circul. stand**	**Key sit**	**Key stand**	**Cylinder sit**
Ellipsoid stand	0.757* < 0.001**						
Circular sit	0.617 < 0.001	0.582 < 0.001					
Circular stand	0.586 < 0.001	0.615 < 0.001	0.709 < 0.001				
Key sit	0.468 < 0.001	0.453 < 0.001	0.423 < 0.001	0.452 < 0.001			
Key stand	0.398 < 0.001	0.434 < 0.001	0.355 < 0.001	0.487 < 0.001	0.760 < 0.001		
Cylinder sit	0.502 < 0.001	0.385 < 0.001	0.532 < 0.001	0.470 < 0.001	0.311 < 0.001	0.307 < 0.001	
Cylinder stand	0.484 < 0.001	0.361 < 0.001	0.520 < 0.001	0.483 < 0.001	0.284 < 0.001	0.277 < 0.001	0.872 < 0.001

*Pearson correlation coefficient; **p-value

Table 5.9 Pearson correlations between hand torque strengths and anthropometric data.

Strength	Ellipsoid sit	Ellipsoid stand	Circul. sit	Circul. stand	Key sit	Key stand	Cylinder sit	Cylinder stand
Age	-0.049 0.431	0.033 0.596	-0.066 0.294	-0.085 0.173	-0.072 0.253	- 0.035 0.575	-0.378 < 0.001	-0.359 < 0.001
Height	-0.044 0.481	0.003 0.963	-0.055 0.376	0.016 0.797	0.023 0.708	0.079 0.205	0.023 0.717	0.071 0.256
Weight	0.183 0.003	0.157 0.012	0.181 0.004	0.148 0.018	0.130 0.037	0.159 0.011	0.092 0.143	0.138 0.027
BMI	0.197 0.002	0.152 0.015	0.195 0.002	0.132 0.035	0.119 0.056	0.124 0.047	0.080 0.200	0.105 0.094
DHL	0.079 0.208	0.042 0.500	-0.004 0.943	0.015 0.816	0.074 0.239	0.118 0.059	0.087 0.165	0.123 0.050
DHB	0.234 < 0.001	0.191 0.002	0.304 < 0.001	0.252 < 0.001	0.192 0.002	0.212 0.001	0.175 0.005	0.210 0.001
DHWC	0.180 0.004	0.193 0.002	0.170 0.006	0.121 0.053	0.128 0.040	0.147 0.019	0.067 0.284	0.086 0.168
DHFC	0.226 < 0.001	0.203 0.001	0.197 0.002	0.252 < 0.001	0.194 0.002	0.274 < 0.001	0.089 0.155	0.104 0.097
Hand Grip Str	0.423 < 0.001	0.327 < 0.001	0.457 < 0.001	0.460 < 0.001	0.438 < 0.001	0.428 < 0.001	0.449 < 0.001	0.430 < 0.001

Table 5.10 represents Pearson correlation coefficients between anthropometric measures and also age and hand grip strength. Age is significantly but negatively correlated with height and hand grip strength. It is significantly and positively correlated with weight, BMI, dominant hand breadth, dominant hand wrist circumference and dominant hand forearm circumference. All hand-arm measurements (DHL, DHB, DHWC and DHFC) are positively and significantly correlated with each other. Hand grip strength had significant positive correlation with height, DHL, DHB and DHFC.

Table 5.10. Pearson correlations between anthropometric data.

Strength	Age	Height	Weight	BMI	DHL	DHB	DHWC	DHFC
Height	-0.184 0.003							
Weight	0.332 < 0.001	0.120 0.054						
BMI	0.389 < 0.001	-0.273 < 0.001	0.919 < 0.001					
DHL	-0.017 0.784	0.442 < 0.001	0.281 < 0.001	0.107 0.087				
DHB	0.153 0.014	0.149 0.017	0.515 < 0.001	0.445 < 0.001	0.469 < 0.001			
DHWC	0.415 < 0.001	0.093 0.138	0.723 < 0.001	0.666 < 0.001	0.345 < 0.001	0.595 < 0.001		
DHFC	0.282 < 0.001	0.061 0.328	0.730 < 0.001	0.679 < 0.001	0.261 < 0.001	0.515 < 0.001	0.645 < 0.001	
Hand Grip Str.	- 0.429 < 0.001	0.215 0.001	0.053 0.398	-0.034 0.590	0.225 < 0.001	0.256 < 0.001	0.026 0.677	0.173 0.006

5.3. Factor Effects Analyses: ANOVA and Post-hoc Analyses

ANOVA summaries of hand torque strength can be seen in Table 5.11 and Table 5.12. In the ANOVA models, since the interaction effects were not significant, they were neglected. Therefore, while calculating sum of squares, only significant main effects were taken into consideration. These types of sum of squares were known as adjusted sum of squares.

Two separate ANOVA analyses were performed.

(1) For experimental independent variables: Complete randomized blocked design
(2) For classification independent variables: Complete randomized design.

Table 5.11 Blocked analysis of variance table for hand torque strength.

Source	DF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Subject (Block)	256	851.28	851.28	3.325	7.18	<0.001
Handle type	3	3310.68	3310.68	1103.561	2382.91	<0.001
Posture	1	20.91	20.91	20.91	45.16	<0.001
Error	1795	831.291	831.291	0.46		
Total	2055	5014.165				

Table 5.12 Analysis of variance table for hand torque strength.

Source	DF	Sequential SS	Adjusted SS	Adjusted MS	F	P
Age Group	4	112.28	116.73	29.18	12.41	<0.001
BMI Group	1	6.68	6.68	6.68	2.84	0.092
Occup. Group	1	95.957	72.39	72.39	30.78	<0.001
Error	1993	4686.82	4686.82	2.35		
Total	1999	4901.73				

Results taken from blocked design indicate that hand torque strength is significantly affected by both, handle type and posture. The complete randomized design shows that age group and occupation group have significant effects on hand torque strength while BMI group has marginal effect. Only two BMI groups were included in the analysis, since there were only seven underweight subjects.

Independent t-tests were performed for smoking habit and exercise, and it was found that, with high p-values (p-value=0,20 and p-value=0.37), these two variables do not have significant effect on hand torque strength

To determine which factor levels were significantly different; multiple comparisons were made for factors which have more than two factors. For this purpose, Tukey’s tests were used. The results explained in the following:

5.4.1. Age Effect

Figure 5.2 shows box plot of mean hand torque strength of females for different age groups. In Table 5.13, results of Tukey’s test can be seen for different age groups. Results show that third age group (40 - 49) is the strongest group whereas the fifth age group (60-69) is the weakest one. It can be also seen that third age group (40-49) had marginally higher hand torque strength than first age group (18-29).

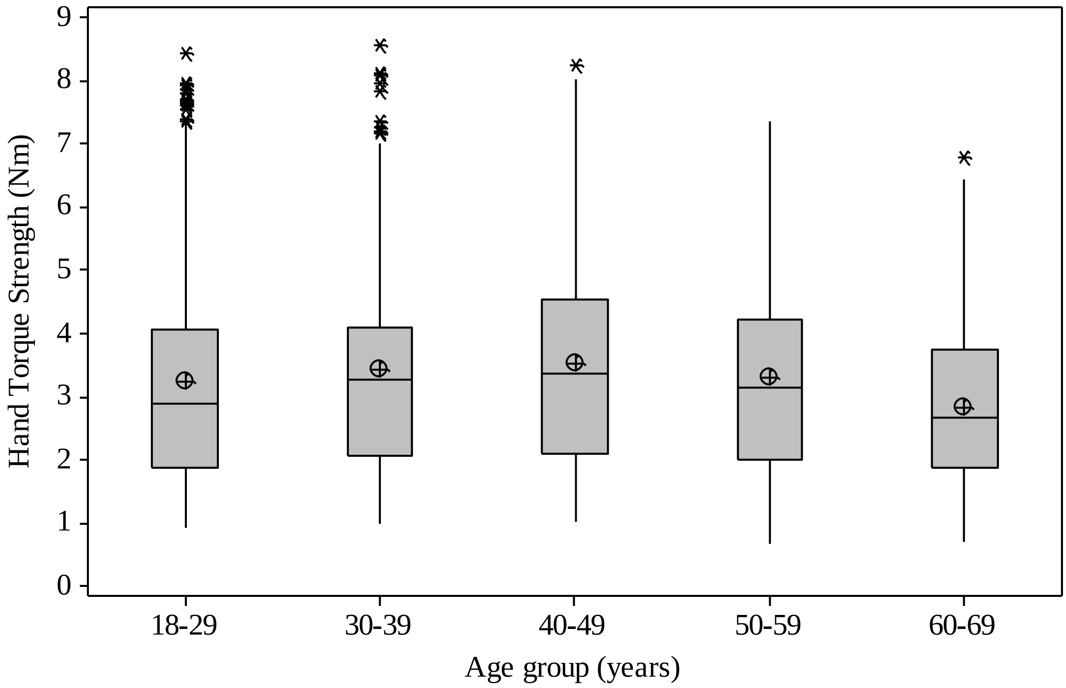

Figure 5.2. Box plot of hand torque strength for different age groups.

Table 5.13 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	0.170	0.106	1.612	0.489
Group 3 - Group 1	0.269	0.108	2.497	0.091
Group 4 - Group 1	0.058	0.108	0.541	0.983
Group 5 - Group 1	-0.427	0.108	-3.962	< 0.001
Group 3 - Group 2	0.099	0.107	0.920	0.889
Group 4 - Group 2	-0.112	0.107	-1.045	0.834
Group 5 - Group 2	-0.597	0.107	-5.568	< 0.001
Group 4 - Group 3	-0.211	0.109	-1.929	0.302
Group 5 - Group 3	-0.696	0.109	-6.367	< 0.001
Group 5 - Group 4	-0.485	0.109	-4,438	< 0.001

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

5.4.2. Hand Tool Effect

In Figure 5.3 box plot of mean hand torque strength values for different hand tools can be seen for females. Group 1 represents the Ellipsoid handle, Group 2 represents the Circular handle, Group 3 represents the Key handle and Group 4 represents the cylindrical handle. Tukey's test results indicated that the mean strength values of each group are significantly different. The highest strength values were observed at cylindrical handle while the lowers was observed at key handle.

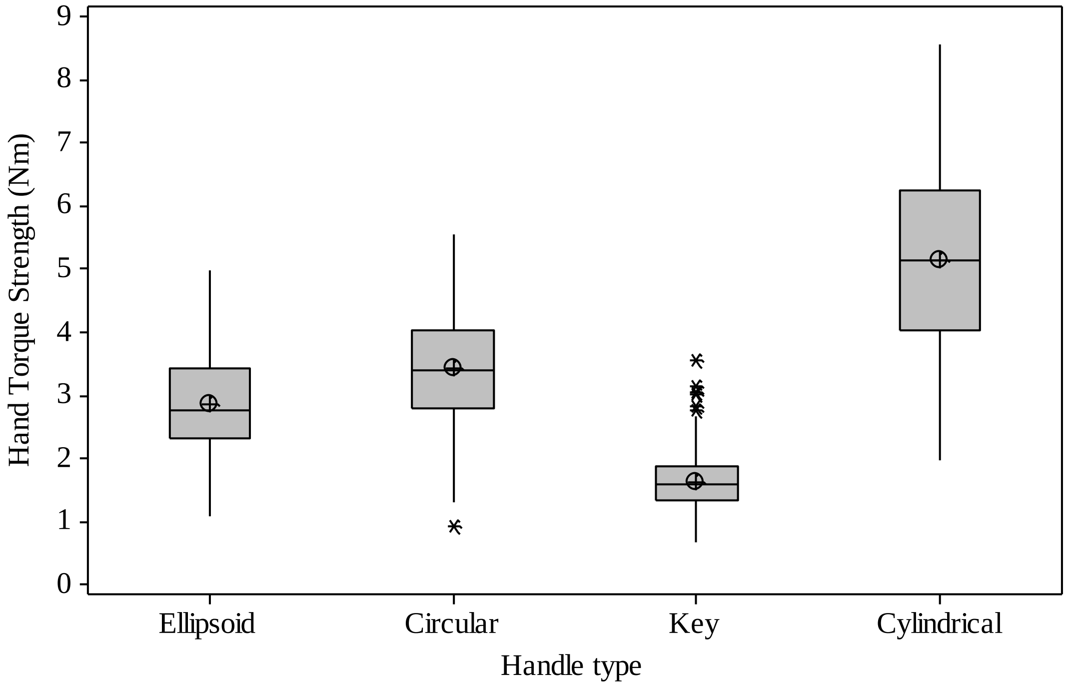

Figure 5.3. Boxplot of mean grip strength of females for hand tools.

Table 5.14. Results of Tukey test for hand tools.

Tool Group Difference	Difference of Means	SE of Difference	T- value	Adj. p-value
Group 2 - Group 1	0.558	0.057	9.82	< 0.001
Group 3 - Group 1	-1.231	0.057	-21.66	< 0.001
Group 4 - Group 1	2.296	0.057	40.40	< 0.001
Group 3 - Group 2	-1.789	0.057	-31.48	< 0.001
Group 4 - Group 2	1.738	0.057	30.58	< 0.001
Group 4 - Group 3	3.527	0.057	62.06	< 0.001

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

5.4.3. Posture Effect

In Figure 5.4 box-plots of mean hand torque strength values for different postures can be seen for females. ANOVA results showed that there is statistically significant difference between these two posture groups. Subjects exerted larger hand torque strengths while standing.

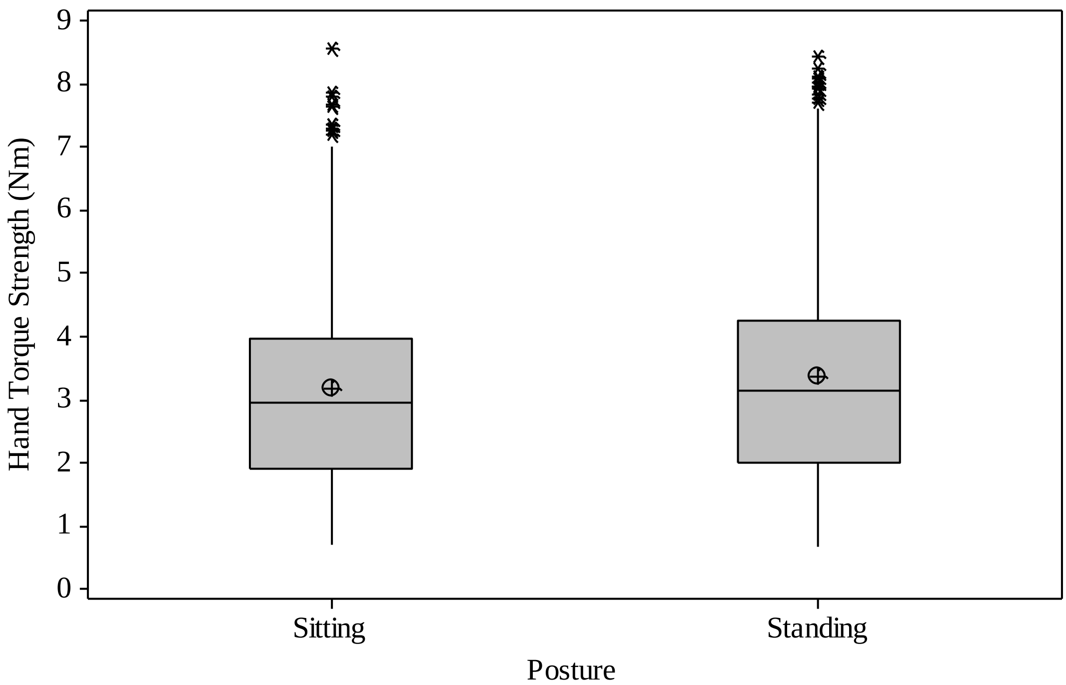

Figure 5.4. Box plot of mean grip strength of females for body posture.

5.4.4. Occupation Effect

The hand torque strengths of the subjects were also significantly different for each occupation group. Figure 5.5 shows the box plot of mean hand torque strength values of different occupations for females. As it was concluded from ANOVA, there is a statistically significant difference between occupation groups, and it is obvious that manual group is stronger than non-manual group.

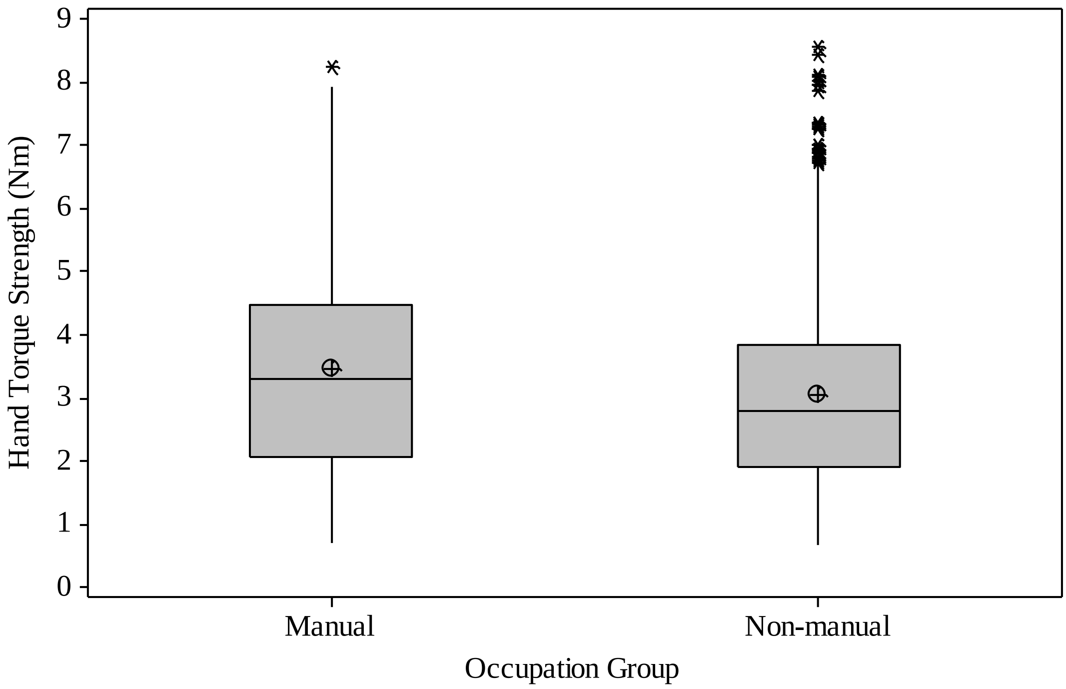

Figure 5.5. Box plot of mean grip strength for different occupation groups.

5.4.5. BMI Effect

As it seen from Figure 5.6, only two BMI groups (normal and overweight) were used in comparisons. Due to only seven underweight subjects, this group was excluded. It is seen from the Figure 5.3, overweight group is stronger than the normal group. But as it was explained in ANOVA results, this difference is marginally significant.

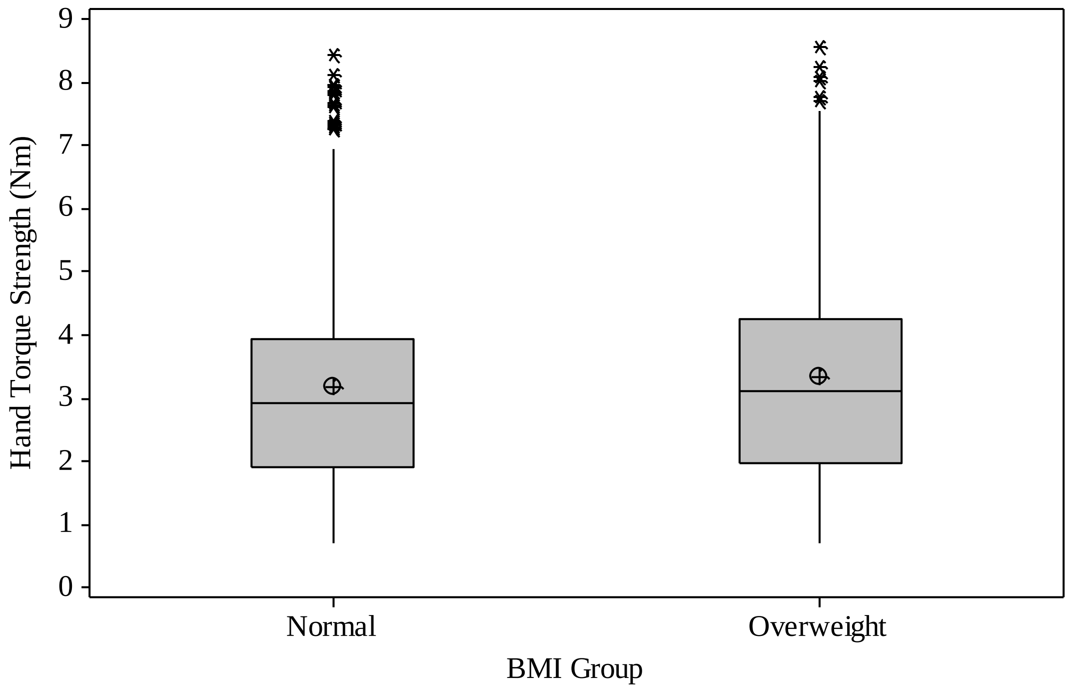

Figure 5.6. Boxplot of hand torque strength of females for different BMI groups.

5.5. Checking ANOVA Assumptions

5.5.1. Normality Test

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 (α= 0.05) in Minitab 16.0. According to Anderson- Darling normality test, the p-values of residuals of hand torque strength data are < 0.05. Another procedure to prove normality is to investigate the normal probability plots of the residuals which were shown in Figure 5.7. Since the plots approximately resemble a straight line, the underlying error distribution for females is normal.

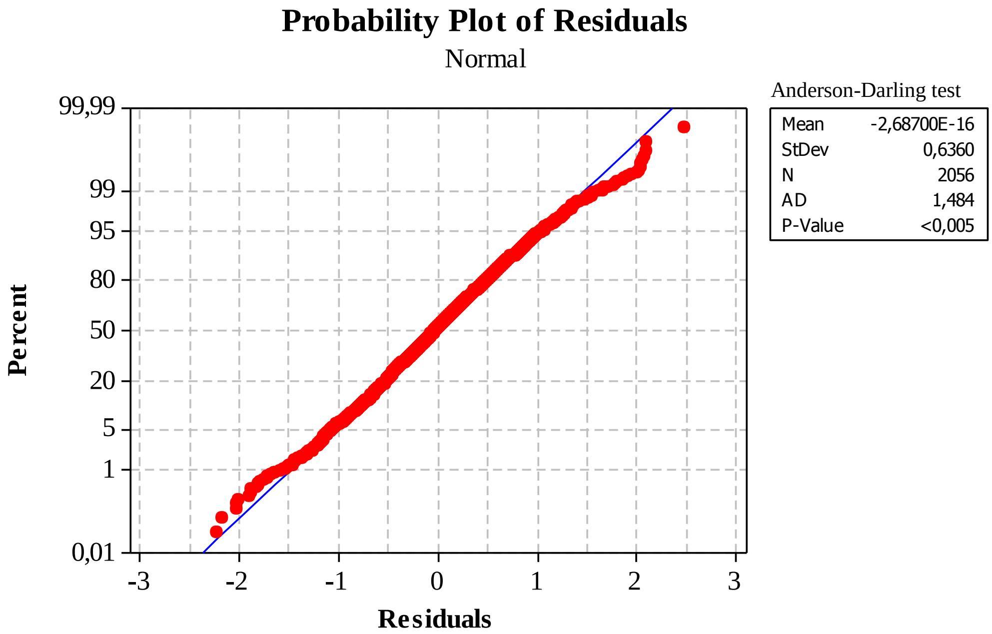

Figure 5.7. Normal probability plots of residuals of hand torque strength data for Blocked Anova.

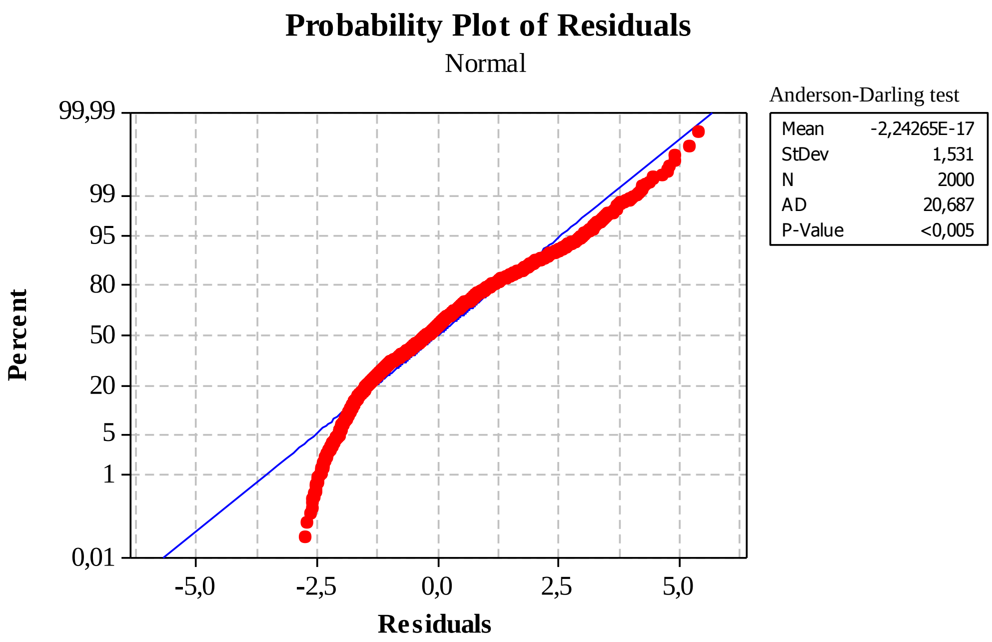

Figure 5.8. Normal probability plots of residuals of hand torque strength data for ANOVA.

5.5.2. Independence Test

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

The plot of the residuals versus observation order for females is shown in Figure 5.9 and 5.10. There is no reason to suspect any violation of the independence assumption.

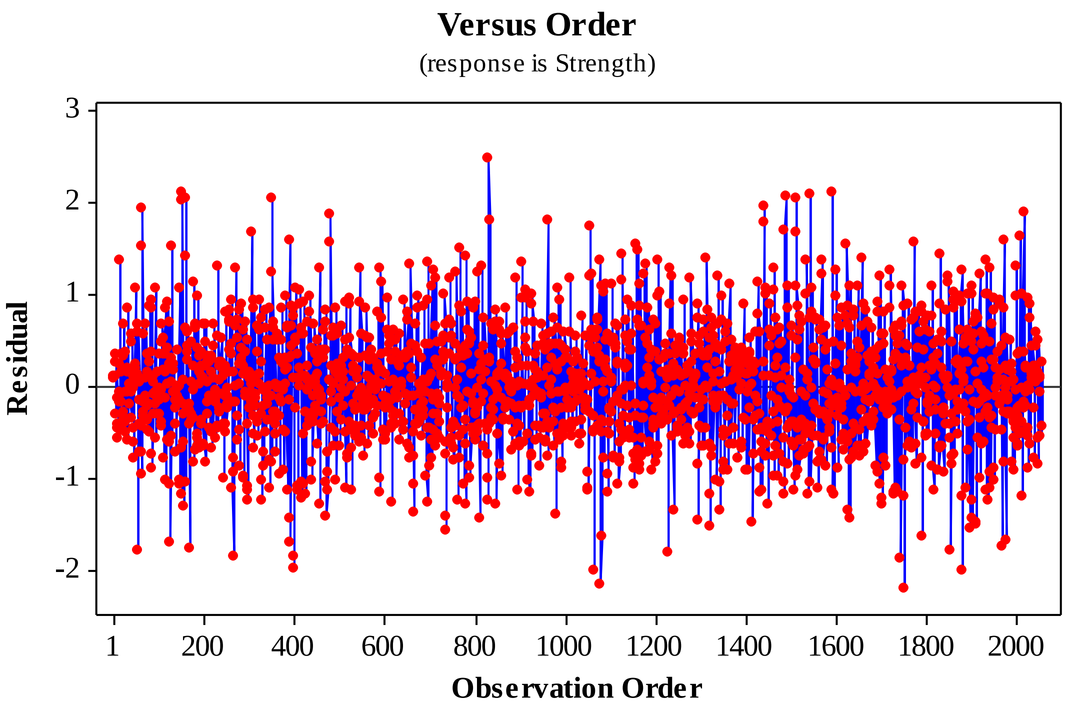

Figure 5.9. Plot of residuals versus observation order for blocked ANOVA.

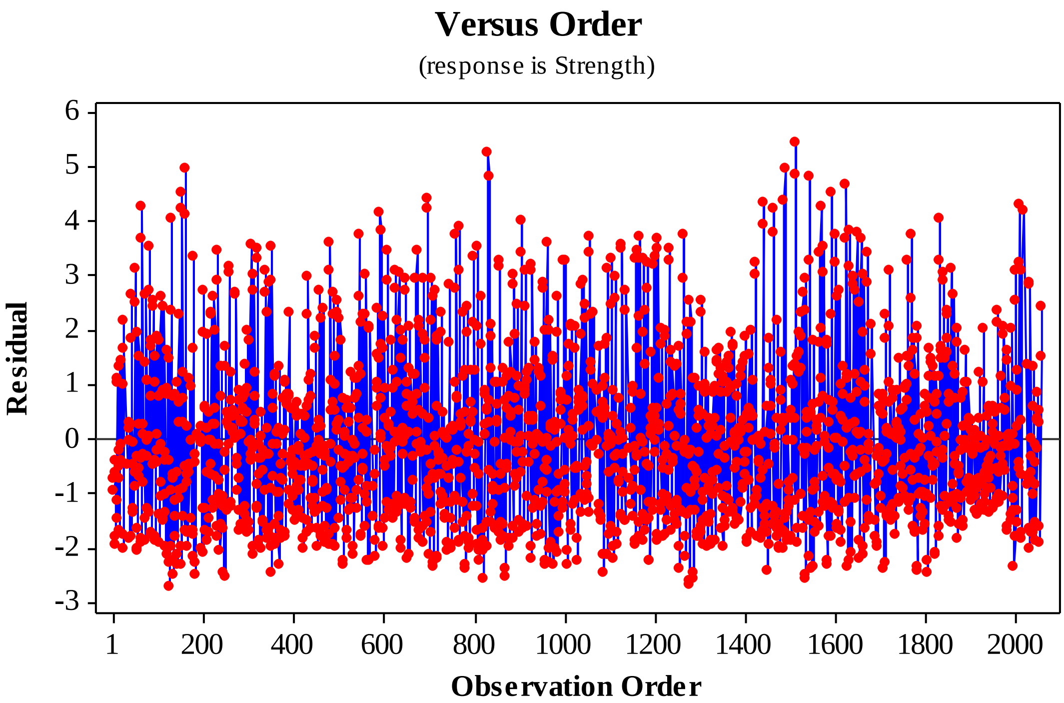

Figure 5.10. Plot of residuals versus observation order for ANOVA.

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

Table 5.15. Correlation coefficients between independent variables and residuals.

Residuals	**Age Group**	**Tool Group**	**Posture**	**Occupation**	**BMI**
Residuals	- 0.000	- 0.000	0.000	-0.000	0.000
P-value	1.000	1.000	1.000	1.000	1.000

5.5.3. Variance Equality Test

The last assumption about ANOVA is that variances of response variables for each treatment must not be different from each other (homogeneity assumption). Therefore, the residuals should be unrelated to any other variable including the predicted response. A simple check is to plot the residuals versus the fitted values. This plot should not reveal any obvious pattern (Montgomery. 2005).

In Figure 5.11 and 5.12, plot of residuals versus fitted values for females can be seen. In Figure 5.11, for the blocked ANOVA, the particular pattern can be seen; therefore the assumption of equality of variances is not quite met. So it is important to underline that p-values may not be as accurate as indicated.

For the second ANOVA, in Figure 5.12, no unusual structure is apparent. Therefore, variance equality assumption was satisfied.

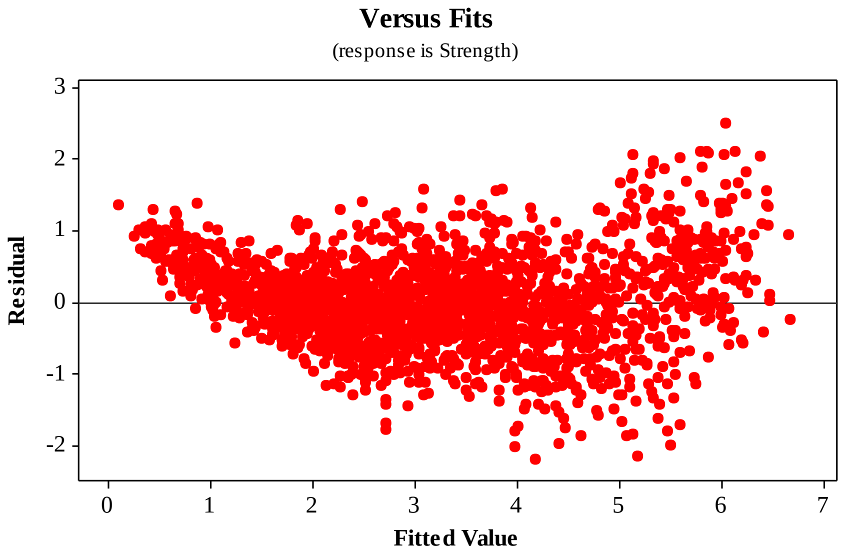

Figure 5.11. Plot of residuals versus fitted values for blocked ANOVA for females.

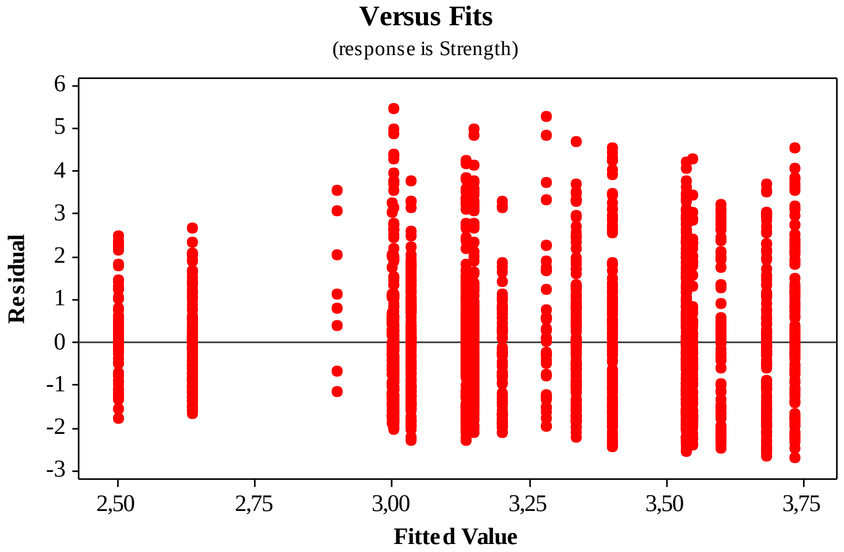

Figure 5.12. Plot of residuals versus fitted values for ANOVA for females.

All of the assumptions about ANOVA were approximately satisfied, therefore parametric ANOVA was used to test factor effects.

5.6. Regression Analysis of Hand Torque Strength Values

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

For developing the best regression equation, Best Subsets Regression Analysis and Stepwise Regression techniques were used. Interaction effects were neglected and only the main effects were taken into consideration.

5.6.1. Regression Model of Hand Torque Strength for Females

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

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \varepsilon \qquad (5.1)$$

where, $\beta_0$is the constant, $\beta_1$is the regression coefficient of age, $\beta_2$is the regression coefficient of tool, $\beta_3$is the regression coefficient of posture, β_4 is the regression coefficient of occupation, β_5 is the regression coefficient of BMI, ε is the error term, x_1 is the regressor variable of age, $x_2$is the regressor variable of tool (1, 2, 3 or 4), $x_3$is the regressor variable of posture (1 or 2), x_4 is the regressor variable of occupation group (1 or 2) and x_5 is the regressor variable of BMI

In addition to these predictors, anthropometric variables were also added to regression model to predict strength. They were added according their correlation with hand torque strength.

In Table 5.16 there are nine different model alternatives represented.

Table 5.16. Different regression model alternatives.

Regression Models	S	R^2 (%)	R^2adj. (%)	Cp
Model 1	0.814079	73.02	72.84	15
Model 2	0.814066	72.99	72.84	13
Model 3	0.809012	73.35	73.18	14
Model 4	0.808721	73.34	73.20	12
Model 5	0.810125	73.22	73.10	10
Model 6	0.815159	72.87	72.77	9
Model 7	0.841115	71.12	71.00	9
Model 8	0.847404	70.67	70.57	8
Model 9	0.911130	66.03	65.98	4

Model 1: Age, height, weight, BMI, DHL, DHB, DHCW, DHCF, hand grip strength, handle type, posture and occupation

Model 2: Age, BMI, DHL, DHB, DHCW, hand grip strength, handle type, posture and occupation

Model 3: Age, age^2, weight, BMI, DHB, DHCW, DHCF, hand grip strength, handle type, posture and occupation (only significant variables added to model)

Model 4: Age, age^2, weight, BMI, DHCW, hand grip strength, handle type, posture and occupation

Model 5: Age, age^2, BMI, hand grip strength, handle type, posture and occupation

Model 6: Age, age^2, hand grip strength, handle type, posture and occupation

Model 7: Age, age^2, BMI, handle type, posture and occupation

Model 8: Age, age^2, handle type, posture and occupation

Model 9: Handle type

When all of the models are checked, Model 4 is determined as most appropriate model by stepwise and best subsets regression but multicollinearity between weight and BMI was high in this model, so model 5 is accepted to use in order to predict strength.Table 5.17 presents analysis of variance table of regression model (model 5).

Since p value < 0.05 it is clear that at least one of the regressor variables contributes significantly to the model.

Table 5.17. Analysis of variance table of regression model.

Source	DF	SS	MS	F	P
Regression	9	3671.37	407.93	621.56	<0.001
Residual Error	2046	1342.80	0.66		
Total	2055	5014.17			

After that, some trials were done with Stepwise Regression Analysis and Best Subset Regression Analysis, the equation that has the maximum R^2 adj value 73.1 and Mallows' statistic C_p 15.6 was accepted as regression equation. The regression equation for females can be seen in Table 5.18.

Table 5.18. Regression analysis results of hand torque strength for females.

Predictor	Coef.	SE Coef.	T	P	VIF
Constant	2.7169	0.1991	13.64	<0.001	
Age	0.049819	0.009019	5.52	<0.001	51.636
Age^2	-0.0006156	0.0001002	-6.02	<0.001	53.447
BMI	0.020471	0.003975	5.15	<0.001	1.361
Hand grip strength	0.0040030	0.05053	12.67	<0.001	1.480
Handle type 1	-2.29639	0.05053	-45.44	<0.001	1.500
Handle type 2	-1.73818	0.05053	-34.40	<0.001	1.500
Handle type 3	-3.52729	0.05053	-69.80	<0.001	1.500
Posture 1	-0.20171	0.03573	-5.64	<0.001	1.000
Occupation 1	0.19234	0.03939	4.88	<0.001	1.215

Therefore, the best regression equation for female hand torque strength for the considered variables is:

Hand torque strength = 2.72 + 0.0498×Age - 0,000616×Age^2 + 0.0205×BMI + 0.00400×Hand Grip Strength – 2.3×Ellipsoid – 1.74×Circular – 3.53×Key – 0.202×Sitting + 0.192×Manual

(S = 8.26068, R^2= 73.2% , R^2 adj = 73.1% , Cp = 15.6)

where, age is in years, BMI is in kg/m^2, hand grip strength is in N.

5.6.2. Regression Equations of Hand Torque Strength for Specific Purposes

For different combinations of handle type (ellipsoid handle, circular handle, key handle and cylindrical handle), posture (sitting and standing) and occupation (manual and non-manual), sixteen different regression models were developed. This is done due to the fact that specific applications can be done by using any of these regression models. Table 5.19 represents a summary table of these sixteen regression models.

Table 5.19 Summary table of sixteen regression models.

Models	**Occupation**	**Posture**	**Handle**	**Predictors**
Model 1	Manual	Sitting	Ellipsoid	Age, age^2, DHCW, Log(handgrip)
Model 2	Manual	Standing	Ellipsoid	Age, age^2, DHCW, Log(handgrip)
Model 3	Manual	Sitting	Circular	Age, age^2, DHB, Log(handgrip)
Model 4	Manual	Standing	Circular	Age, age^2, DHCF, Log(handgrip)
Model 5	Manual	Sitting	Key	Age, age^2, DHL, DHL^2, DHB^2 DHCF, Log(handgrip)
Model 6	Manual	Standing	Key	DHCF, Log(handgrip)
Model 7	Manual	Sitting	Cylinder	Age, age^2, DHL, Log(handgrip)
Model 8	Manual	Standing	Cylinder	Age, age^2, DHL, Log(handgrip)
Model 9	Non-manual	Sitting	Ellipsoid	Age, age^2, hand grip strength
Model 10	Non-manual	Standing	Ellipsoid	Age, age^2, hand grip strength, $(\text{hand grip strength})^2$
Model 11	Non-manual	Sitting	Circular	Age, height, hand grip strength
Model 12	Non-manual	Standing	Circular	Age, age^2, DHL, DHL^2, hand grip strength
Model 13	Non-manual	Sitting	Key	Hand grip strength
Model 14	Non-manual	Standing	Key	Age, age^2, age^3, hand grip strength
Model 15	Non-manual	Sitting	Cylinder	Age, height, $height^2$, BMI^2, hand grip strength
Model 16	Non-manual	Standing	Cylinder	Age, height, $height^2$, $weight^2$, DHL, hand grip strength

Table 5.20. Summary results table of sixteen regression models.

Models	**S**	**R^2 (%)**	**R^2adj. (%)**	**Cp**
Model 1	0.662540	23.2	20.8	5
Model 2	0.772884	14.4	11.6	5
Model 3	0.713330	23.0	20.6	5
Model 4	0.712301	22.8	20.3	5
Model 5	0.330144	29.3	25.2	8
Model 6	0.391963	19.4	18.2	3
Model 7	0.895354	37.0	35.0	5
Model 8	0.986266	35.0	32.9	5
Model 9	0.097698	22.1	20.2	4
Model 10	0.631239	23.9	21.4	5
Model 11	0.716599	30.4	28.7	4
Model 12	0.209474	30.9	28.0	6
Model 13	0.097209	20.3	19.7	2
Model 14	0.322887	32.2	30.0	5
Model 15	0.111942	29.2	26.2	6
Model 16	1.226320	30.5	27.1	7

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

In order to ensure the regression assumptions, some transformations were done to both independent and dependent variables.

Another important issue is that within each handle type, regression models were tried to be combined for sitting – standing and manual – non-manual. In Table 5.21 these models are represented.

Table 5.21. Models that were combined.

Combinations	S	R^2 (%)	R^2adj. (%)
Model 1 - Model 2	0.724005	17.5	16.2
Model 7 - Model 8	0.948500	35.1	34.1

5.7. Repeatability study

A repeatability study was done to ensure the reliability of measurements. Twenty one subjects were measured twice at least a week later. These subjects were randomly selected subjects from tested subjects. All measurements were taken in the exactly same experimental procedure. The reproducibility of the measurements was high, no statistically significant differences occurred between the first and second testing ($p = 0.999$).

6. DISCUSSION

6.1. Discussion of the Current Study Results

Results indicate that handle type is the most significant factor on hand torque strength. This finding is similar with the finding of study by Mital (1986) where the strong correlation was found between the tool type and hand torque strength. Kim and Kim (2000) also found that the magnitude of torque exertion is significantly affected by the type of tool. In the current study, the hand torque strength values recorded for cylindrical handle is considerably higher than the values with other three handles. The lowest hand torque strength values were exerted with key handle. This can be explained by the type of grip, handle characteristics (dimensions, shape, surface finish etc.) and force direction.

Results indicate that higher hand torque strength is generally exerted in standing posture compared with the sitting posture. This finding is also consistent with the findings of the study of Mital and Sanghavi (1986). However this finding may not be significant in practical applications.

Age is also found significant factor on hand torque strength. There is a curvilinear relationship between age and hand torque strength. Hand torque strength peaking somewhere between 40 and 49 years of age and decreasing thereafter. Results indicate that first four age groups (from 18 to 59 years old) are not significantly different from each other while group five (60 – 69 years) is significantly different and lower than other four age groups. Slob (2000) reported that strength increases rapidly in the teens, more slowly in the early twenties, reaches a maximum by the middle to late twenties, remains at this level for five to ten years, and thereafter declines slowly but continuously.

Occupation is another significant factor that has influence on hand torque strength. According to the results, manual subjects have significantly higher strength values than non-manual subjects. It 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).

The statistical results also indicated that normal and overweight BMI groups are only marginally significantly different from each other. However the difference is small to be considered significant in practical applications.

An expected result is that the hand grip strength is significantly and positively correlated with hand torque strength. Therefore, it became the main predictor of the regression models.

Results show that hand length is not significantly correlated with hand torque strength. Nagashima and Konz (1986) have also reported that hand length is not correlated significantly with torque. Height is not significantly correlated with hand torque strength also. However, hand breadth, hand forearm circumference and hand wrist circumference are significantly but weakly correlated with some strength values of eight different treatments.

Another interesting result is that regular exercise and smoking habit do not have significant effect on hand torque strength.

6.2. Comparison with Other Studies

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. The studies in the literature vary in sample size, sample type, measure used, experimental procedure, experimental posture, age range, methods and handles used. Therefore, it can be said that there is no study in the literature overlapping the current study to compare the results.

But still 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:

- Swain, Shelton, Rigby (1970)
- Kim, Kim (2000)
- Peebles, Norris (2002)
- Miller, Nair, Baratz (2005)
- Gugari, Okamura (2007)

For cylindrical handle, the most similar studies for comparison:

- 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)

For key handle, the most similar studies for comparison:

- Peebles, Norris (2002)

are used to compare with the current study but for ellipsoid handle, no study in the published literature was found to compare.

Some of the results of current study were compared to other most related and close studies in literature. Even though, all of the related studies were explained in detail in the literature review part, some specific information about them are given once more.

(a) Current study vs. Miller, Nair and Baratz (2005):

Miller, Nair and Baratz (2005) conducted a study to measure 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 to them 13 (9 Male, 4 Female) subjects (with arthritis of the thumb carpometacarpal joint) with average age 58±8 were measured as well. 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 female subjects with dominant hand, and in sitting position twisting strength was found as follows 1.44 Nm for 5 cm diameter disk and 2.2 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 (diameter of 5.99 cm) was 3.3 Nm. 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. The difference in diameters, materials of the handles and even gripping method might be an important factor for this difference in the hand torque strength.

Table 6.1. 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**	**DF**
Miller, Nair, Baratz	46	1.44	0.41	0.060	-1.86	-23.01	< 0.001	129
Current Study	257	3.30	0.86	0.054				

Table 6.2. 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**	**DF**
Miller, Nair, Baratz	46	2.20	0.63	0.093	-1.10	-10.25	< 0.001	78
Current Study	257	3.30	0.86	0.054				

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

Peebles and Norris (2003) conducted a comprehensive study to measure 6 different strength types (finger push strength; pinch-pull strength; hand grip strength; wrist-twisting strength; opening strength; push and pull strength) with 150 subjects from UK population whose ages range from 2 to 86 years. 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.

Circular knob used in Peebles, Norris's study was 40 mm in diameter and 20 mm in depth, circular handle used in current study was 60 mm in diameter and 20 mm in depth. 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 6.3, 6.4, 6.5 and 6.6).

Table 6.3. 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**	**DF**
Peebles, Norris	7	3.50	1.30	0.49	0.16	0.32	0.762	6
Current Study	52	3.34	0.80	0.11				

Table 6.4. 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	DF
Peebles, Norris	13	3.00	1.30	0.36	-0.78	-2.11	0.055	13
Current Study	108	3.78	0.87	0.08				

Table 6.5. 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	Diff.	T- value	p- value	DF
Peebles, Norris	6	3.50	0.60	0.24	-0.16	-0.58	0.578	7
Current Study	48	3.66	0.86	0.12				

Table 6.6. 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	DF
Peebles, Norris	10	2.60	0.60	0.19	-0.37	-1.70	0.110	15
Current Study	44	2.97	0.71	0.11				

Moreover, in the study of Peebles and Norris (2003), the butterfly nut is also used in torque exertion experiment. The gripping method used in torque measurement of butterfly nut resembles the gripping method of the key of the current study. The depth and length of the butterfly nut is different from the length and depth of key used in the current study. But still they were compared, at least to see the results. 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 6.7. 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	DF
Peebles, Norris	7	2.40	0.40	0.15	0.81	5.09	0.001	7
Current Study	52	1.59	0.36	0.05				

Table 6.8. 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	DF
Peebles, Norris	13	2.80	0.70	0.19	1.05	5.29	<0.001	13
Current Study	108	1.75	0.42	0.04				

Table 6.9. 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	DF
Peebles, Norris	6	2.70	0.50	0.20	1.06	4.97	0.004	5
Current Study	48	1.64	0.43	0.06				

Table 6.10. 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	DF
Peebles, Norris	10	2.30	0.60	0.19	0.76	3.79	0.003	11
Current Study	44	1.54	0.43	0.07				

(c) Current study vs. Kim and Kim (2000):

In another study, Kim and Kim (2000) conducted a laboratory experiment to determine the maximum volitional torque exertion capabilities of Korean people. The main aim was to investigate the effects of body posture and of different types of common non-powered hand tools on torque capabilities. 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.

Among these 15 postures 2 of them are similar to the posture in the current study. These two postures are sitting and standing postures, handle at the elbow height with the horizontal tool axis. In addition, among five hand tools one of them (cylindrical handle), is similar to the handle used in the current study. Kim and Kim (2000) conducted the study where female 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 no statistical difference between the studies in sitting posture (p=0.22). However, there is statistical difference between studies in standing posture (p=0.022).

Table 6.11. 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**	**DF**
Kim, Kim	15	5.96	2.23	0.58	0.82	1.26	0.22	21
Current Study	25	5.14	1.50	0.30				

Table 6.12. 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**	**DF**
Kim, Kim	15	6.94	2.08	0.54	1.51	2.45	0.022	22
Current Study	25	5.43	1.50	0.30				

(d) Current study vs. Seo *et al.* (2007):

Seo *et al.* (2007) conducted a study in USA, to measure maximum torque, grip force, total normal force, and fingertip/ thumb force. Twelve subjects (6 F and 6 M) with age ranging from 21 to 35 years 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. Subjects were seated with an elbow flexed about 90º and forearm horizontal, and grasped a vertical cylindrical handle with the right hand in a power grip.

Even though, diameters and gripping methods differ, the results of t-tests, indicate that there is no statistical difference between rubber cylindrical handle and handle of the current study, and there is a statistical difference for aluminum cylindrical handle.

Table 6.13. 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**	**DF**
Seo *et al.*	6	3.50	2.10	0.86	-2030	-2.28	0.071	5
Current Study	41	5.53	1.51	0.24				

Table 6.14. 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	DF
Seo *et al.*	6	2.80	1.70	0.69	-2.73	-3.72	0.01	6
Current Study	41	5.53	1.51	0.24				

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

Imrhan and Jenkins (1999) investigated the effects of four variables, which were – surface finish, wrist action, arm position and hand laterality, on torqueing capabilities of American males and female adults in simulated maintenance tasks. Ten male (from 28 to 43 years old) and ten females (from 25 to 40 years old) generated torques on a 2.25 in (57.2 mm) diameter cylindrical handle over 24 different test conditions. Subjects were required to grip handles bare-handed with power grip in comfortable standing posture.

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: 25-40).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DF
Imrhan, Jenkins	10	4.68	0.39	0.12	-1.28	-6.67	<0.001	38
Current Study	50	5.96	1.04	0.15				

After all comparisons, it can be said that, in the literature there is not such a comprehensive study like the current one. It also has a considerable sample size which increases its consistency and reliability. Apart from sample size, the classification and consideration of manual and non-manual subjects is done, which makes the current study unique in this field.

Table 6.16. Summary of comparisons.

Population of Turkey vs.	**Country**	**% Diff.**	**t-value (p-value)**	**Handle Type**	**Age Range**	**Posture**
Seo *et al.* (2008)	USA	36.7	-2.28 (0.071)	Cylindrical handle (dia:57.8 mm rubber)	21-35	Sitting
Seo *et al.* (2008)	USA	49.3	-3.72 (0.01)	Cylindrical handle (dia: 57.8 mm aluminum)	21-35	Sitting
Miller, Nair & Baratz (2005)	USA	56.0	-23.01 (<0.001)	Disk (dia:5 cm)	19-74	Sitting
Miller, Nair & Baratz (2005)	USA	33.0	-10.25 (<0.001)	Disk (dia:7.5 cm)	19-74	Sitting
Peebles, Norris (2003)	UK	-4.8	0.32 (0.762)	Disk (dia:4 cm)	21-30	Standing
Peebles, Norris (2003)	UK	20.6	-2.11 (0.055)	Disk (dia:4 cm)	31-50	Standing
Peebles, Norris (2003)	UK	4.4	-0.58 (0.578)	Disk (dia:4 cm)	51-60	Standing
Peebles, Norris (2003)	UK	12.5	-1.7 (0.110)	Disk (dia:4 cm)	61-70	Standing
Peebles, Norris (2003)	UK	-50.9	5.09 (0.001)	Butterfly nut	21-30	Standing
Peebles, Norris (2003)	UK	-60.0	5.29 (<0.001)	Butterfly nut	31-50	Standing
Peebles, Norris (2003)	UK	-64.6	4.97 (0.004)	Butterfly nut	51-60	Standing
Peebles, Norris (2003)	UK	-49.4	3.79 (0.003)	Butterfly nut	61-70	Standing
Kim, Kim (2000)	Korea	-16.0	1.26 (0.22)	Cylindrical handle (dia:34 mm)	18-29	Sitting
Kim, Kim (2000)	Korea	-27.8	2.45 (0.022)	Cylindrical handle (dia:34 mm)	18-29	Standing
Imrhan, Jenkins (1999)	USA	21.4	-6.67 (<0.001)	Cylindrical handle (dia: 57.2 mm aluminum)	25-40	Standing

% Difference = 100 x (mean for Pop. of Turkey - mean for comparison nationality)/mean of Pop. of Turkey

7. CONCLUSIONS

The aim of the study was estimating the maximum voluntary hand torque strength capacity of adult female population of Turkey. The data were collected in both sitting and standing with four handle types. Statistical analyses were performed to investigate the effects of posture, handle type, age, occupation, BMI and some anthropometric variables. Prediction models for hand torque strength were developed and comparisons were made with some studies on other nationalities in the literature.

Based on analysis results, the following conclusions can be drawn;

(i) Static hand torque strength norms of adult female population of Turkey were established.

(ii) The hand torque strength peaks between 30-39 years for non-manual and between 40-49 years for manual workers. However, the differences from 18 to 59 year are insignificant. The oldest age group (60-69 years) has significantly lower hand torque strength than the other four age groups.

(iii) Means of hand torque strength values for normal and overweight body mass index groups are marginally different from each other.

(iv) Manual workers have significantly higher hand torque strength values than non-manual workers.

(v) The mean hand torque strength values for sitting and standing postures are also significantly different from each other. Higher strength values are recorded while subjects are in standing postures. 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) Hand breath, wrist circumference and forearm circumference are significantly correlated with eight different strength types. However, hand length is not significantly correlated with strength values.

(viii) Hand grip strength values are significantly correlated with strength values of eight different hand torque strength positions.

(ix) Regular exercise (sport), smoking habit and preferred grip span do not have significant effect on hand torque strength.

(x) This study investigated the effect of occupation on hand torque strength, which was not investigated before in any hand torque studies. 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. At the same time, this study has focused on relationship between body posture and hand torque strength.

Overall it can be said that this study is a comprehensive study on hand torque strength combining almost all factors in a single study.

7.1. Recommendations for Future Research

Whilst not all hand torque strength data ‘gaps’ could be filled in this study, it is hoped that this study is an initial and profound step in estimating hand torque strength of population of Turkey.

In this study the age of population was between 18 and 69. Data on hand torque strength of children and older adults 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.

It is hoped that further studies will be undertaken in order to clarify the problems which remain unsolved in the current study.

APPENDIX A: FORMS

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

1. 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.

2. 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.

3. 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 and some hand measurements are also measured during study and are also recorded on “Personal Data Form”.

4. 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 sorununuz oldu mu?
- ☐ Daha önce kalp veya göğüs ağrısı şikâyetiniz oldu mu?
- ☐ Daha önce kalp çarpıntısı sorununuz oldu mu?
- ☐ Kalbinizde tekleme oldu mu?
- ☐ Anormal ECG veya EKG teşhisiyle karşılaştınız mı?
- ☐ Nefes alırken herhangi bir zorluk çektiğiniz oldu mu?
- ☐ Otururken veya uyurken nefesiniz kesildi mi?
- ☐ Böbrek sorunundan dolayı diyaliz makinesine bağlanmakta mısınız?
- ☐ Romatoid arterit hastalığına yakalandınız mı?

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

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

Aşağıdaki sorunlarla ilgili ilaç alıyorsanız, çarpı işaretiyle işaretleyiniz.

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

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

A.3. Personal Consent Form

In this thesis study, the aim is to determine the maximum wrist twisting force statistics of Turkish female 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 females 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 % 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 Zerife Recep or Ph. D. 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 bayanlarının 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 bayanlarının kullanımına uygun bir şekilde tasarlanması için kullanılabilecektir. 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.
3. 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.

4.

5. Deneylerden önce katılımcılar çok aç, fazla tok veya uykusuz olmamalı, zararlı maddeler tüketmemelidirler. Deneylerin sonunda, küçük çaplı kas yorgunluğu gerçekleşebilir.

6.

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 Zerife Recep 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	
Smoking habit	
Exercise per week	

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. Dominant Hand Grip Strength Data of the Subject

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

3. Dominant Hand Torque Strength Data of the Subject

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 4 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 kuvvet ölçeri sıkabildiğiniz kadar sıkarak yaklaşık 1-2 saniyede maksimum kuvvetinize ulaşın. Maksimum kuvvetinizi yaklaşık 4 saniye boyunca sürdürmeye çalısın.

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		Knob		Key		Cylinder		Ellipsoid		Knob		Key		Cylinder	
		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	3	3	7	7	6	6	4	4	2	2	8	8	5	5	1	1
	MVC	1.96	2.03	2.43	2.60	1.06	1.04	3.66	4.11	2.17	2.24	2.08	2.38	1.11	1.18	4.01	3.96
2	Order	5	5	6	6	4	4	8	8	3	3	7	7	2	2	1	1
	MVC	1.53	1.37	2.48	2.34	2.22	2.24	4.30	3.80	1.79	1.84	2.55	2.79	1.18	1.30	4.34	4.41
3	Order	2	2	6	6	3	3	5	5	7	7	8	8	1	1	4	4
	MVC	3.02	2.72	2.74	2.69	1.06	1.11	5.29	4.92	3.02	2.72	4.11	3.97	1.35	1.27	4.79	4.67
4	Order	6	6	3	3	8	8	4	4	7	7	1	1	5	5	2	2
	MVC	2.29	2.79	3.02	2.78	1.70	1.77	5.12	5.33	3.43	3.16	3.11	2.83	1.23	1.11	6.16	6.20
5	Order	1	1	4	4	3	3	8	8	6	6	5	5	7	7	2	2
	MVC	2.91	2.77	3.56	3.53	1.51	1.56	5.20	5.22	3.25	3.34	3.70	3.70	1.51	1.60	6.05	5.95
6	Order																
	MVC																
7	Order																
	MVC																
8	Order																
	MVC																
9	Order																
	MVC																
10	Order																
	MVC																
,	Order																
,	,																
,	,																
,	MVC																
257	Order	3	3	8	8	6	6	7	7	4	4	1	1	2	2	5	5
	MVC	2.94	2.61	2.99	3.43	1.31	1.50	4.65	3.95	3.11	3.50	3.66	3.52	1.21	1.20	5.43	5.54

APPENDIX C: REGRESSION EQUATIONS

C.1. Equation Models for Full Data

Hand torque strength	- Nm
Age	- Years
Height	- Cm
Weight	- Kg
BMI	- kg/m2
DHL	- Cm
DHB	- Cm
DHCW	- Cm
DHCF	- Cm

Model 1. The regression equation is

Torque Strength = 4.58574 – 0.00506135×Age – 0.00557007×Height – 0.000870807×Weight + 0.0127251×BMI – 0.0818408×DHL + 0.12545×DHB + 0.041776×DHCW – 0.000926138×DHCF + 0.00460045×Hand Grip – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.169093×Manual

Model 2. The regression equation is

Torque Strength = 4.02029 – 0.00482405×Age + 0.013872×BMI – 0.0984278×DHL + 0.125206×DHB + 0.0322259×DHCW + 0.00455477×Hand Grip – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.169983×Manual

Model 3. The regression equation is

Torque Strength = 2.08776 + 0.0478387×Age – 0.000606047×Age^2 - 0.0106336×Weight + 0.0365743×BMI + 0.033204×DHB + 0.0404606×DHCW + 0.0029874×DHCF + 0.00397824×Hand Grip – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting + 0.18145×Manual

Model 4. The regression equation is

Torque Strength = 2.25836 + 0.0485518×Age – 0.000613368×Age² - 0.0101066×Weight + 0.0363527×BMI + 0.0465904×DHCW + 0.00403478×Hand Grip – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.187982×Manual

Model 5. The regression equation is

Torque Strength = 2.71686 + 0.0498187×Age – 0.000615644×Age² + 0.0204708×BMI + 0.00400301×Hand Grip – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.19234×Manual

Model 6. The regression equation is

Torque Strength = 3.04164 + 0.0545273×Age – 0.000633391×Age² + 0.00409171×Hand Grip – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.259927×Manual

Model 7. The regression equation is

Torque Strength = 3.23676 + 0.0779885×Age – 0.00103033×Age² + 0.0232179×BMI – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.306117×Manual

Model 8. The regression equation is

Torque Strength = 3.61933 + 0.0840551×Age – 0.00106097×Age² - 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle – 0.201706×Sitting Posture + 0.385867×Manual

Model 9. The regression equation is

Torque Strength = 5.14657 – 2.29639×Ellipsoid Handle – 1.73818×Circular Handle – 3.52729×Key Handle

C.2. Equation 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

Ellipsoid (sitting) = - 6.58 + 0.0889×Age – 0.000917×Age² + 0.0888×DHCW + 2.46× log(hand grip strength)

Model 2. The regression equation is

Ellipsoid (standing) = - 5.14 + 0.0594×Age – 0.000556×Age² + 0.108×DHCW + 2.05×log(hand grip strength)

Model 3. The regression equation is

Knob (sitting) = - 7.38 + 0.0658×Age – 0.000650×Age² + 0.352×DHB + 2.72×log(hand grip strength)

Model 4. The regression equation is

Knob (standing) = - 5.21 + 0.0713×Age – 0.00076×Age² + 0.0615×DHCF + 2.42×log(hand grip strength)

Model 5. The regression equation is

Key (sitting) = 18 + 0.0274×Age – 0.000278×Age² - 2.43×DHL + 0.0691×DHL² + 0.00701×DHB² + 0.0254×DHCF + 1.33×log(hand grip strength)

Model 6. The regression equation is

Key (standing) = - 2.31 + 0.0432×DHCF + 1.2×log(hand grip strength)

Model 7. The regression equation is

Cylinder (sitting) = - 8.28 + 0.0987×Age – 0.00132×Age² + 0.247×DHL + 3.24×log(hand grip strength)

Model 8. The regression equation is

Cylinder (standing) = $- 8.93 + 0.113\times Age - 0.00150\times Age^2 + 0.312\times DHL + 3.07\times \log(\text{hand grip strength})$

Model 9. The regression equation is

Log ellipsoid (sitting) = $0.0383 + 0.0105\times Age - 0.000114\times Age^2 + 0.000624\times \text{Hand Grip Strength}$

Model 10. The regression equation is

Ellipsoid (standing) = $1.67 + 0.0767\times Age - 0.00083\times Age^2 - 0.00857\times \text{Hand Grip} + 0.000027\times(\text{Hand Grip Strength})^2$

Model 11. The regression equation is

Knob (sitting) = $8 + 0.00568\times Age - 0.0427\times Height + 0.00720\times \text{Hand Grip Strength}$

Model 12. The regression equation is

$(\text{Knob (standing)})^{1/2} = 14.1 + 0.0279\times Age - 0.000292\times Age^2 - 1.53\times DHL + 0.0439\times DHL^2 + 0.00162\times \text{Hand Grip Strength}$

Model 13. The regression equation is

Log key (sitting) = $0.0039 + 0.000717\times \text{Hand Grip Strength}$

Model 14. The regression equation is

Key (standing) = $- 2.66 + 0.265\times Age - 0.00591\times Age^2 + 0.000042\times Age^3 + 0.00244\times \text{Hand Grip Strength}$

Model 15. The regression equation is

Log cylinder (sitting) = $15.8 - 0.00341\times Age - 0.186\times Height + 0.000570\times Height^2 + 0.000096\times BMI^2 + 0.000455\times \text{Hand Grip Strength}$

Model 16. The regression equation is

Cylinder (standing) = $213 - 0.0383\times Age - 2.53\times Height + 0.00779\times Height^2 + 0.000243\times Weight^2 - 0.180\times DHL + 0.00443\times \text{Hand Grip Strength}$

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