AN ESTIMATION OF ISOMETRIC GRIP STRENGTH CAPABILITY OF ELDERLY POPULATION OF TURKEY

by

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B.S., Industrial Engineering, Yıldız Technical University, 2010

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

Graduate Program in Industrial Engineering
Boğaziçi University
2019

ACKNOWLEDGEMENTS

Although writing a thesis may seem like a literature that one person completes within a year, it is a collective production process. For this reason, I would like to express my endless gratitude to the people who have contributed to this thesis as much as I did.

First of all, I would like to thank Prof. Dr. Mahmut Ekşioğlu for being the best mentor I can ever have and for his academic support. You created my road map, inspired me, and removed the stones from my path every time I stumbled upon a rock.

My family and friends, you all have been my greatest spiritual strength. You gave me the motivation to go on when situations turned out to be not as expected, and you reminded me how strong I was. You have been my greatest chance and thank you all for your presence.

Finally, I would like to express my gratitude to all the participants that contributed to this study with their devotion which made me complete my work. The data you provided for my thesis is very important. Your priceless efforts contributed me, my perspective and helped me grow mentally as a person. I wish you nothing but happiness, health and joy.

ABSTRACT

AN ESTIMATION OF ISOMETRIC GRIP STRENGTH CAPABILITY OF ELDERLY POPULATION OF TURKEY

The ability to perform daily tasks and industrial work are highly dependent on the capacity of the hands. Grip strength gives information on overall hand functioning. Since grip strength is reduced with the age, it significantly and adversely affects daily activities of the elderly people. This is true especially when they interact with products requiring grip strength. Hence, to make the lives of elderly people easier and more comfortable, the product designers need the strength data of elderly. As far as we know from the literature, there is no such study for the elderly population of Turkey. Therefore, it is a need to establish such database for the elderly population of Turkey. The main aim of this study is to estimate the isometric grip strength values of elderly (over 70) people of Turkey. Secondery aims are: investigating the effects of gender, age, height, weight and occupation on grip strength and comparing the strength data of elderly population of Turkey with the strength data of population of other countries. For the purpose, 251 elderly participants (composed of 126 Males & 125 Females) aged from 70 to 98 were recruited. As a result of study, grip strength of the elderly population of Turkey was estimated. In agreement with other studies, male subjects were found stronger than female subjects for each age group. Age was the most important factor affecting hand grip strength of both genders. Occupation did not significantly affect the grip strength. On the other hand, BMI had significant effect on male grip strength while height was found significantly correlated with grip strength response for both genders. There was also a significant and positive relationship between grip strength and hand length and hand breadth for both genders. Grip strength of elderly population of Turkey was found significantly lower compared to some of world populations and the same or significantly higher compared to some other world populations.

ÖZET

TÜRKİYE YAŞLI NÜFUSUNUN STATİK EL-KAVRAMA KAPASİTESİNİN TAHMİNLEMESİ

Fiziksel işlerin ve günlük aktivitelerin birçoğu el-kavrama kapasitesine bağlıdır. El-kavrama; bize sadece el kuvveti ve kapasitesi hakkında değil, tüm iskelet ve kas sistemin kuvveti, fiziksel kapasitesi hakkında bilgi verir. İnsan kas gücünün yaş ile ters orantılı olarak azaldığı bilinen bir gerçektir. Bu sebepten toplumların, önemli bir kısmını oluşturan yaşlılar, günlük yaşamlarında birçok zorlukla karşılaşırlar. Yaşlılara ait el-kavrama kuvvetinin ölçümlenmesi ve bu verilerin bir referans değeri oluşturması, toplumun hem iş kapasitesi verimliliğini arttıracak hem de yaşlı insanların günlük yaşamlarında daha az kuvvet uygulayacakları ürünleri tasarlanmasına yardımcı olacaktır. Kuvvet verileri evrensel olmamakla birlikte uluslar arasında farklılık göstermektedir. Bu çalışmanın amacı, Türkiye'de yaşayan yaşlı nüfusun maksimum statik el-kavrama kuvveti dağılımının cinsiyet, yaş, meslek ve vücut özelliklerine bağlı olarak hesaplanması, fiziksel iş gücü gerektiren mesleklerin, bölgesel faktörlerin, Anadolu insanın ilerleyen yaşlarında el-kavrama kuvveti üzerindeki etkilerinin incelenmesidir. Ülkemizde konu ile ilgili çalışmalar olmakla birlikte, yaşlı insanların el-kavrama kuvvet dağılımına ilişkin detaylı bir veri tabanı bulunmamaktadır. Bu amaçla, herhangi zihinsel, büyük bir fiziksel engeli ve ciddi bir sağlık sıkıntı olmayan, farklı meslek gruplarındaki ve yaşları 70 ile 98 arasında olan, 126 erkek ve 125 kadın katılımcının el-kavrama kuvveti ölçümleri gerçekleştirildi. İstatistiksel analizlerden sonra, diğer çalışmalarda olduğu gibi erkeklerin ortalama el-kavrama kuvvetleri kadınlara göre %37 daha fazla olduğu görüldü. Baskın elin baskın olmayan ele göre istatistiksel olarak kuvvetli oldugu belirlendi. Erkekler de vücut kitle endeksi, el-kavrama kuvvetinde etkiliyken, kadınlar için istatistiksel olarak belirgin bir farklılığı bulunmadı. El uzunluğu ve el genişliğinin hem kadınlarda hem de erkekler de kavrama kuvvetine etkisi olduğu görüldü. Diğer ülkelerde yapılan çalışmalarla karşılaştırıldığında, Türkiye'de yaşayan yaşlı nüfusun ortalama el-kavrama kuvvetinin, bazı toplumların ortalama el-kavrama kuvvetinden daha fazla iken bazılarından göre ise, eşit veya daha az olduğu sonuçlarına varıldı.

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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 j^{th} block receiving the i^{th} treatment
α	The percentage of relative accuracy desired
ε_{klm}	NID $(0,\sigma^2)$ random error component
ε_{ij}	Random error
μ	Overall mean

LIST OF ACRONYMS/ABBREBIATIONS

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

MS	Mean of squares
MVC	Maximum voluntary contraction
MW	Manual worker
N	Newton
n	Sample size
NDGS	Non-Dominant Grip Strength
NDH	Non-Dominant Hand
NDHB	Non-Dominant Hand Breadth
NDHFC	Forearm circumference of non-dominant hand
NDHL	Non-Dominant Hand Length
NDHWC	Wrist circumference of non-dominant hand
NID	Normally and independently distributed
Nm	Newton×meter
SD	Standard deviation
SE	Standard error
SS	Sum of squares
VIF	Variance inflation factor
yrs	Years

1. INTRODUCTION

The definition of ergonomics includes “the application of engineering design to the study and production of safe and efficient human-machine systems” (Dempsey *et al*., 2006). It is related with (1) protecting workers from serious physical or mental harm, (2) maximizing health, safety and well-being, (3) optimizing performance and efficiency, (4) maximizing productivity and quality, (5) maximizing product usability and user acceptance, (6) improving quality of life (Ekşioğlu, 2013). In another words, the aim of ergonomics is to provide that all human-made tools, devices, equipment, machines, environments and their organizations improve the well-being of humans and their performance directly or indirectly (Elbert *et al*., 2018).

Many manual jobs require huge strength that exceed the individual’s capacity. It is known that working with excessive force, awkward posture, repeatedly increase the risk of musculoskeletal disorders of the upper extremity (Chaffin *et al*., 2006). Therefore, to know person’s capability under specified circumstances is essential for efficient work design and injury prevention (Mital and Kumar, 1998 part 1). Measurement of human strengths has crucial importance to know individual’s capacity and to determine the capacity of the population and reference values. These norms are utilized to design for health, safety, comfort and productivity of workforce and consumers also for clinical purposes (Ekşioğlu, 2016).

Hand grip strength is a simple but well-established indicator of overall muscle strength. (Wang *et al*., 2018). It is also a measure of overall upper extremity muscle strength and correlated with lower extremity strength (Bohannon, 1998). According to Kroemer (2006), ergonomics has aimed to design technical system for a broad population and it should be considered that there are some special users and their needs should be known. We may say that the elderly people are special group of population, and it is desired to consider their physical limitations in the design of products for daily use (Hu *et al*., 2007). For this reason, not only norms of adult and young people but also elderly people norms are required for designing products considering the loss of strength for elderly people.

To sum up, anthropometric and strength data have been collected for number of different populations so far. However, these strength norms may not be useful for worldwide and every population, since it may lead some cross-national problems (Bohannon *et al*., 2006) To obtain normative data of hand grip strength in a population, Bohannon *et al*. (2006) performed a meta-analysis of 12 papers published between 1985 and 2006 studying adult grip strength. The mentioned study stated the needs of further grip strength data for the age groups of 75-79, 80-84 and 85+ years.

That's why to focus on grip strength of elderly people is essential to fill this gap. There are some studies which are established the hand grip strength norms of adult population of Turkey. Ekşioğlu (2016) conducted study to obtain maximum voluntary isometric grip strength capacity of population of Turkey, as a function of gender, age, occupation, body mass, hand, posture and support. However, the study age group was up to 70 and did not include above 70+ years of elderly population of Turkey.

The main aim of this study is to estimate maximum voluntary grip strength data for elderly population of Turkey. Furthermore, to investigate the effects of occupation, age and Body Mass Index (BMI) and some anthropometric measurements on the maximum grip strength of the mentioned population.

2. LITERATURE REVIEW

2.1. Overview

In many production processes, force exertion is a fundamental activity through which the productive phase is planned (Mital and Kumar, 1998 part 1). When a job requires exertions above a person' volitional strength, it increased the risk of injury. Therefore, many strength studies have been conducted for redesigning the jobs to assure only people perform such jobs safely (Chaffin *et al*., 2006). To obtain the strength norms for populations is important part of these studies. On the other hand, considering the population aging and the increase in life expectancy for elderly people require specific studies focused on capacities of elderly people.

In this section, general information on muscle strength, strength types, grip strength are mentioned. In addition, the studies that are conducted on hand strength especially elderly people are included.

2.2. Strength

Strength is one of the great interests of ergonomic and human factors engineering that has vital importance with designing safe and desirable jobs, also equipment for minimizing associated costs and preventing work related musculoskeletal disorders (cumulative trauma disorders) (Ekşioğlu, 2016).

Definition of maximum strength is the capacity to produce force or torque with a maximum voluntary muscle contraction (Gallagher *et al*., 1998). Strength is the maximum force that a group of muscles can develop under prescribed conditions. Muscular strength is a human property is defined by using psychophysical methods which is demonstrated subjectively with acceptable maximum force or torque capability by a person. That should be noted, it needs to the muscle to be activated voluntarily (Chaffin *et al*., 2006).

2.2.1. Types of Muscle Strength

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

2.2.1.1. Static (Isometric) Strength. Isometric muscle strength is the capacity of muscles to produce force or torque by a single maximal voluntary exertion. The body segments and muscle length remain unchanged in static strength (Mital and Kumar, 1998). Static muscular strength may be accepted the performance limit of a population (Chaffin *et al*., 2006). For that reason, measuring static strength is rather preferable. Performance of static strength is affected by person's body posture, duration of force exertion, rest periods between exertions, the measurement device and person's conditions (Gallagher *et al*., 1998).

2.2.1.2. Dynamic Strength. By definition, dynamic strength requires motion that resulting of muscle length and body segment changes (Mital and Kumar, 1998). The dynamic strength needs the movement of the objects which is being held by a person. This motion provides to distinguish static strength from dynamic strength. From the biomechanical perspective, motion of body segments requires more muscle force to overcome inertia and accelerate the body segment masses Dynamic strength is grouped into three according to their conditions (Chaffin *et al*., 2006).

- Isoinertial strength: Constant external loads are moved.
- Isokinetic strength: The velocity of the movement at the specific joint is constant.
- Isotonic strength: Muscle tension is constant while velocity is changed.

2.2.2. Measurement of Muscle Strength

Although most of the work and daily activities require dynamic forces, isometric muscle tests are conducted more often, because measuring dynamic strength is more complicated and relatively difficult to administer (Kroemer, 1999). In additon to that, the basic procedures for testing isometric (static) strength are well-established (Gallagher *et al.*, 1998).

Since measurement of static strength is easier, the values of static strength have reported by many researchers and the standardized procedure have evolved (Caldwell *et al*., 1974). Caldwell Regimen is proposed one of the most important and standard procedure for static muscle strength testing.

According to Caldwell protocol, before start to test the subject should be informed about the objectives of the study and the procedures. Immediately after, subjects were told to increase their maximum exertion (without jerking) in 1 second and held it for 4 second. Instructor should be pay an attention any factor that may affect the subject's performance such a giving feedback or creating competition. Instructions should be given to the subjects during the experimentation period. The subject should start with the instructor's "increase to maximum exertion (without jerking) in about one second and maintain the maximum effort for four seconds" command. There should be at least two minutes break between the trials and the trials should be within 10% variation. Furthermore, mean, standard deviation, minimum and maximum values and skewness of the data should also be reported (Caldwell *et al*., 1974).

Protocols by Kroemer (1970) and Chaffin (1975) give essentially the same information with Caldwell Regimen. Their recommendations include the duration of exertion which should be at least 3 seconds, rest period should be from 30 sec to 2 min that depending on exertion time, measuring device, body position should be standardized, giving correct instruction to subject, and and reporting both the strength data and the anthropometric data of the subjects (Chaffin *et al*., 2006).

American Society of Hand Therapists introduced a standard testing position for measuring static hand strength which is accepted and applied by many researchers. Recommendations of ASHT consist of sitting in a straight-backed chair, shoulder adducted and neutrally rotated, elbow flexed at 90 degrees, forearm in neutral posture and not supported, wrist at 0 – 30 degrees extension and 0 – 15 degrees ulnar deviation (Fess, 1992).

2.3. Hand Grip Strength

Hand grip strength is a measurement of hand functioning. It is often used in clinical settings as an indicator of overall physical strength and health (Wang *et al*., 2018). It is also measured of overall upper extremity muscle strength and correlated with lower extremity strength (Bohannon, 1998). The ability to perform not only industrial but also many daily tasks are highly dependent on the capacity of the hands. Measurement of grip strength gives an information about hand function which is used as a predictor for treating hand injuries and determining disability risk factors (Mathiowetz *et al*., 1985).

The elderly people are most probably to encounter many difficulties with their daily activities as hand strength diminishes with age and diseases (Mat Jais *et al*., 2018). It has been proved that grip strength is considerably associated with the age (Sayer and Kirkwood, 2015). Reduced muscle strength significantly influences living activities of the elderly people (Hu *et al*., 2007). Hence, loss of muscle strength cause limitations of performance and disability in older people. To build a normative data of grip strength for elderly population can be used to create design data for products, tasks, equipment, and so forth.

In literature, many studies investigated the factors of grip strength are affected.These are listed as follows but not limited; orientation to the work surface, height, weight, body mass index (BMI) and loss of muscle mass with increasing age, body posture, type of tool, grip span, resting period, repetition, duration of exertion, gender, age, anthropometric dimensions, preferred hand (handedness), worker or subject (Adams, 2006; Almeida Silva *et al*., 2013; Ekşioğlu, 2004 and 2016).

2.4. Hand Grip Strength Studies

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

The study of Mathiowetz *et al.* (1985) was one of the most accepted pioneers that aimed to obtain extensively normative data in literature. It was consisted of 310 male and 328 female subjects, from 20 to 94 years (with a mean age of 49.03 yrs) and (with a mean age of 49.75 yrs) for males and females respectively. The study was conducted with standardized procedure and positioning was recommended by The American Society of Hand Therapists (ASHT) in 1981. Jamar hand dynamometer was used with fixed to second span (4.76 cm) when measuring hand grip strength. During test, “the subjects were seated upright on a chair with feet planted flat on the ground, shoulders adducted with hands in neutral rotation and flexion, and elbows flexed at 90°, with the forearm in neutral position”. (Fess, 1992). The maximum value of grip strength was recorded between three trials for each hand and each strength test. Their study showed that dominant hand stronger than non-dominant in addition to that gender and age were significantly had effect on grip strength response. The grip strength response was negatively correlated with age for both genders and males were stronger for each age group.

Desrosiers *et al.* (1995), measured the grip strength of randomly selected 360 subjects aged from 60 years to 94 years with the Jamar dynamometer and the Martin Vigorimeter to determine the effects of age and gender on grip strength. Anthropometric data (body weight, body height, hand length, hand circumference), work characteristics, subjective health conditions and current activity level at the same time were used in the study. Subjects applied three consecutive grip strength measures with each hand with an interval approximately 30 second between each measurement and highest of three trials were examined. The study showed that grip strength performance diminished with increasing age in both genders (women: $r = -0.37$ to – 0.47 and men: $r = -0.55$ to -0.60, depending on the hand) predominantly subjects who are aged 80 years and older, grip strength of men were consistently higher than women ($p < 0.0001$) and right-handed subjects are stronger than those who are left-handed ($p < 0.0001$).

Desrosiers *et al.* (1995) investigated effect of elbow position on grip strength for elderly people. 49 elderly male subjects who did not have upper-extremity impairment with average 71.1 ± 7.9 years (from 60 to 84 years) and only right handed were recruited. They were measured with two different elbow positions: full extension and 90° of flexion with a Jamar dynamometer. As a measurement procedure, American Society of Hand Therapists recommendations were taken into consideration. The participants were seated on a standard-height chair without armrests with shoulder adducted and neutrally rotated, forearm in neutral position, and wrist in light extension (0° to 30°). The grip strength was measured three times for both hands and for each position. The maximum and average of three trials were recorded. Results showed that no significant difference between two positions for right hand, however in the left hands grip strength was higher when the elbow is flexed.

Peebles and Norris (2003) conducted a comprehensive study 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 with the aim of satisfy as many designed needs as possible. (i) Finger push strength, (ii) pinch-pull strength, (iii) handgrip strength, (iv) wrist twisting strength, (v) opening strength, and (vi) push and pull strength were collected from each participant. 65 males (aged between 2 to 80 years) and 88 females (aged between 2 to 86) were measured using a hand grip dynamometer with handle separations of 30, 50 and 70 mm for five seconds with their dominant hand, while standing and adopting a free posture. In the study the optimum handle diameter was found 70 mm for 71-80 years old males and 71 to 86 females, while younger preferred 30 mm and 50 mm. They also reported that males were generally significantly stronger than females. Moreover, strength decrease with age from around 50 years and mean of grip strength values were found 373.3 ± 30.3 N for males 225.4 ± 48.5 N for females with aged 71-80. Since there were not male subjects over 80 years old, the results of grip strength in that age group was found 160.1 ± 29.3 N for females.

Xiao *et al*. (2005) conducted a comprehensive study which investigate the relationship grip strength with gender, job group and anthropometric dimensions but age for Chinese population (146 males and 47 females). The main purpose of the study was generating normative data that enable predicting the strength capacity of a desired population to utilize for ergonomic purposes. During the tests, the subjects were seated posture and dynamometer was held with palm facing up. The subject performed three trials, one warm-up trial at 48 per cent effort and two trials at MVC, and average of two trials (in which they reached to their maximum for one second and held them three seconds) were reported as the grip strength result. The study demonstrated the mean grip strength of females was about 50 per cent lower than the males. In terms of occupation group industrial workers and students had higher mean strengths than administrators for males, and industrial workers had higher mean strengths than students. They also showed that weight had significant effect on grip strength for males and females while height had only for males.

Contrary to Xiao, Hu *et al.* (2007) investigated age related maximum grip strength and its relationship with anthropometric dimensions for elderly Chinese population. The all subjects were in a state of good health with aged between 65.2–85.1 and 65.0–80.7 for males and females respectively. The participants were grouped into three as 65–69, 70–74 and 75 + according to their age. were measured by using Smedley's handgrip dynamometer has two parallel bars which can be adjusted according to hand size. They found the mean grip strength value 38 kgf for males, and 21 kgf for females which males had almost twice the strength of females.

Bohannon *et al.* (2006) conducted a study in order to consolidate grip strength data which obtained by using Jamar dynamometer and followed with the recommendations of the American Society of Hand Therapists. 12 different sources (3,317 subjects) were used for the meta-analysis. Means and 95% confidence intervals are reported for both hands and genders in 12 age groups (20–24, 25–29, 30–34, 35–39, 40–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74, 75+ years). The study provides better comparison for individual studies. The study showed that right hand is stronger than left for each age group except over 75 years old for both genders.

Another study that examined differences of grip strength values with age and sex from Brazil was conducted by Schlüssel *et al.* (2008). They aimed to represent references values of hand grip strength of heathy adults. Subjects for each gender, stratified six groups (20-29, 30-39, 40-49, 50-59, 60-69, 70+) according to their age. BMI were calculated and grouped as underweight, normal and overweight. Beside anthropometric measurements, hand grip strength was measured for both hands by using Jamar mechanical dynamometers. The instrument was adjusted according to hand size of the subjects to obtain best strength and the participants were tested three times and the best of trials was recorded. They were stood with both arms pending sideways to the body with the dynamometer facing outwards the body. The dominant and non-dominant hand values were combined and reported as right-left hand. They found that grip strength reached at maximum at 30-39 aged group and after increased significantly for both genders. Elderly subjects who are over 70 years old, were weakest for both genders as expected 31.8 ± 0.79 (kgf) and 17.2 ± 0.41 (kgf) for males and females respectively. BMI was significantly associated with grip strength for both gender while it was considerably much more effective for males within each group. On the other hand, even there were high differences between grip strength within BMI groups for each age group, it decreased significantly for over 70 years old subjects.

Wu *et al.* (2009) investigated effects of grip strength data across age groups from 20 to over 80 years. They aimed to generate normative data of Taiwan Chinese population and compare with consolidated norms. In head to head comparison with the norms, they used same standard procedure by the American Society of Hand Therapists (ASHT). Jamar dynamometer and Martin-type anthropometer were used for measurement and gender, age, palm length, grip span, grip position, and left/right hand were defined as variables of the response. 244 males and 238 females subject were recruited for the study and they were categorized into 12 groups with 5 years interval. They measured maximum volitional contraction for the four different positions, and for each position by using five different spans. Results showed grip span had significant relation with forearm position, gender and age. Span (2) 4.76 cm provided the maximum strength among other spans which followed by span (3). Additionally, palm length was most significant factor on grip strength response after gender and age. Supination was found most effective position despite other positions were not statistically significant. When it comes to compare with consolidated norms Taiwanese grip strength was weaker in general.

Sin *et al.* (2009) conducted a study to compare physical capacity and hand grip strength responses between elderly Koreans with elderly Korean immigrations. In that study, 102 males, 192 females Koreans subjects were recruited while number of Korean immigrations subjects were 49 males and 38 females. Data were collected the voluntary participants who live in senior centers and apartments. While measuring grip strength for all the subjects Jamar hydraulic hand dynamometer was used. Height, weight, muscle extremity such as mid-upper arm and mid-calf circumferences were also measured. Age and gender were independent variables of hand grip strength, BMI, mid-upper arm, mid-calf circumferences and physical activities. It was shown as expected age is significantly correlated in physical activities and hand grip strength. Men were more physically active and had stronger hand grip strength response than women, whereas women had higher BMI scores than men for both two samples which are Koreans and immigrations.

Another aged focused study was conducted by Kaur (2009). The objective was to investigate changes in hand grip strength with aging between rural and urban Jat females. 600 female subjects (300 rural, 300 urban) between the ages of 40 and 70 years were recruited. The grip strength measurement was taken three times for each hand and maximum of them was Some anthropometric variables such height, weight, biceps and triceps skinfold thicknesses were also measured. The study was concluded that grip strength decreased with increasing age for rural as well as urban females for both hands. Regardless of age the average grip strength of rural females was higher than urban females' grip strength response for both right and left hand.

It is well known fact that the risk of incidence depended on muscle strength such fallings and fractures increase in direct proportion to age. In order to identify solid capacity of elder people and to develop preventive strategies, functional muscle strength and hand grip strength reference values are required. Ribom *et al.* (2011) researched the strength values of 999 male subjects aged between 70-80 years. They measured hand grip strength together with functional muscle strength by time stand test and narrow walk test. The subjects who suffered from musculoskeletal diseases such as the daily pain, hip or knee prostheses or any other condition that would have effects on physical effort were excluded. A Jamar hydraulic hand dynamometer was used for grip strength test. They were asked to sit in a standard chair and performed two trials for each hand. Result of the study grip strength refences values were reported with the mean 41 ± 8 kg in the right hand and 40 ± 8 kg in the left hand. When they compared the results within same age group from previous studies, hand grip strength response was higher than other nationalities which are Brazil and Spain. They asserted that it might be derived from the size of the Scandinavians subjects who are larger than Brazilian and Spanish.

Several studies have investigated strength of upper and lower extremity functions reduced with age. Another study that searched age-related dexterity and relationship between grip strength is an investigation of Samuel and Rowe's (2012). Beside previous studies, the study was not limited with to knee and elbow joints, it compared loss of hand grip strength and hip and knee moments with increasing age. The healthy elder participants were recruited from senior centers, church groups and older adult exercise groups. 42 males and 40 females aged between 60 to 88 years were measured three times for each hand by using the Jamar dynamometer. They proved that grip strength significantly correlated with muscle hip and knee muscle moments for elderly people. The grip strength reduced 27% for the 80 years old when it is compared with 60 years old for the combined data males and females. Another considerable result of the study, hip and knee moments were more affected by aging than was grip strength.

Demura *et al.* (2011) measured 15 elderly males and 15 elderly females (aged between 62 and 68) to examine the difference of hand grip power in elderly men and women. For testing, MVC (maximum voluntary contraction) and the moving velocity of the loads used to calculate hand grip power which were measured by YH100 dynamometry device (Yagami, Japan) in this study. It is composed of a rotary encoder attached to a fixed pulley, variable load and a recording device. The device can measure and record the moving velocity of the load when the load was pulled up by hand grip movement. The participants were asked to sit in an adjustable ergometric chair. Their arm was supported by an armrest and positioned in a sagittal and horizontal, with the forearm vertical and the hand in a semi-prone position. The grip width could be arbitrarily adjusted for each subject. Subjects were tested twice with their right hand and maximum response was recorded. The results showed that MVC was significantly greater in males (36.7 ± 4.9 kg) than females (22.5 ± 3.1 kg). It is also showed that irrespective of loss of muscle volume with age, beside hand grip strength, males had superior hand grip power with all trials which led to be superior than those of females.

Aoki and Demura (2011) conducted another experimental study to determine the age-level difference of the maximum voluntary contraction (MVC) and hand grip power in females. 15 young and 15 elderly females were measured by using the dynamometry device (YH100, Yagami, Japan). The experimental procedure that include measurement of hand grip strength and the moving velocity was the same with previous study they had conducted (Demura *et al*., 2011). They also calculated grip muscle powers for 30, 40 and 50% maximum voluntary contraction. The study reported that the MVC was significantly higher in the young females (32.8 - 3.0 kg) than in the elderly females (22.5 - 3.1 kg). It is also found out that the young females had superior hand grip power with all loads however the peak velocity which was used to calculate hand grip power together with MVC, had an insignificant difference between two age group.

Aging process can interfere daily activities and physical performance of elder people. To determine the body alternations and to find out effect of decreasing muscle strength, many studies were conducted. Almeida Silva *et al.* (2013) evaluated the influence of anthropometric variables and age on grip strength as well as flexibility with that purpose. Totally 416 (283 females and 133 males) elderly subject were tested by using a manual hydraulic dynamometer (Takei Kiki Kogyo Dynamometer) which can be adjusted according to hand size. Weight and height were measured to calculate BMI, Triceps skinfold (TSF) and arm circumference were measured to assess muscle mass. The subjects were grouped according to gender (male and female) and age group (60 to 69 yrs, 70 to 79 yrs, and 80 + yrs). The result of the study indicated that age had negative and significant correlation with hand grip strength in both females and males. BMI was significantly and positive correlated only for females while circumferences of arm had positive correlation both genders. The mean value of hand grip strength was 19.1± 6.1kg for females while it was 31.0 ± 8.8kg for males which is significantly higher. On the contrary, higher mean value of BMI was observed in females. When it is compared within age groups, there is significant difference, only for females.

Liao *et al*. (2014) conducted a study on grip strength measurement in older adults. 249 subjects (113 women and 136 men) between the ages of 66 and 79, who were local citizens residing in their own houses in Taiwan and comprehend the requirements of the study participated in the experiment. Grip strength of the subjects was tested in three different commonly used positions, which are: (i) sitting, elbow flexed 90°, (ii) sitting, elbow flexed 90°, and (iii) standing, elbow fully extended with the dominant hand only. During testing, a minimum of 5-minute interval was provided between positions. JAMAR hand dynamometer was used to measure the grip strength performance; it was concluded that grip strength was significantly greater in the standing position with the elbow fully extended than in the other two positions and there is a high correlation between the two positions which are sittin with elbow flexed 90° and standing with elbow flexed 90°.

Koopman *et al.* (2014), measured the hand grip strength of 923 (480 males and 443 females) local inhabitants aged 50 years and older in Ghana throughout 2009 and 2010 using a JAMAR hand dynamomteter. In addition to gender and age of the participants; weight, height and socio-economic factors such as tribe of the participant, household property value, access to safe drinking water have been considered in the analysis. The hand grip strength of the subject was measured by performing one grip test for each hand while he/she was standing with arms parallel to the body and the highest measurement has been recorded. The results of the study have been compared with the results in western communities specifically with the Dutch reference population and it was concluded that hand grip strength in Ghana is lower than the Dutch population and it declines at a similar rate over age in rural Africa and western populations.

Ramlagan *et al.* (2014), investigated the effects of social factors and health variables on hand grip strength with a sample of 3840 men and women regarding different population groups aged 50 years or older in South Africa. In the experiment, sociodemographic characteristics, cognitive capacity, health variables, and anthropometric measurements were examined in order to evaluate the effects of gender, cognitive capacity, functional ability, health status, depression, tobacco use, alcohol use, height and weight, physical activity, chronic diseases, economic or wealth status on hand grip strength. Hand grip strength of the subjects was measured by performing grip test for each hand by repeating the grip exercise twice for each hand, and the highest value of the two measurements were taken into consideration in the analysis. Linear multivariate regression analysis was performed, and results indicated that in multivariate analysis; younger age, greater height and lower functional disability were found for both men and women to be significantly associated with grip strength and the mean overall hand grip strength was 37.9 kgs for men and 31.5 kgs for women.

Shahida *et al.* (2015) measured elderly Malaysians with the aim of develop a database including hand grip strength and anthropometric dimensions. 56 males (age range 60-79 years, mean: 66.88, SD: 5.35) and 56 females (age range: 60-82 years, mean: 66.98, SD: 5.16) were participated to the experiment. The subjects were recruited according to some criteria, community-dwelling elder people which means do not live in a care homes and not suffer from health problems may influence hand grip strength were selected. The maximum voluntary hand grip strength of the dominant hand was measured using Jamar hand dynamometer. The study showed that stature, sitting hip breadth, wrist circumference, hand circumference and heel ankle circumference are significantly correlated with hand grip strength. Especially, stature was found the most significant correlations with grip strength, which followed by eye height (standing) and shoulder height as expected. The male subjects are taller than females, and most of their anthropometric measurements are larger than females, as expected Malaysians elderly males are stronger than females with the mean grip strength 271.64 ± 69.01 N for males and 159.30 ± 58.03 N for females.

Sternang *et al*. (2015) have studied the effects of multiple risk factors on grip strength in older adults. In the study, grip strength of 849 participants (504 women, 345 men) have been measured with a Collin hand grip dynamometer (0-70 kg) between 1986 - 2010 and at least one grip strength value of all participants has been included in the analysis. Participants applied six attempts (three with each hand) to the dynamometer and the highest score of all attempts has been considered as the subject's grip strength score. The effects of several risk factors on grip strength have been investigated in the study including age, education level, socio-economic status, marital status, body weight, height, self-reported health, depression, stress, mean arterial pressure (MAP), lipids, morbidity, smoking and physical activity. The participants were categorized into three age groups; age groups 1 (born 1935-49), age group 2 (born 1919-34) and age group 3 (born 1900-18) to analyze for which age group the effects of potential risk factors were significant. The results showed that estimated average grip strength level for women at age 67 was 21.63 kg and decreased about −0.19 kg/year between 50 and 67 years of age and −0.45 kg/year between 67 and 96 years of age, where in men, estimated average grip strength level at age 72 was 36.28 kg and the expected yearly decrease was −0.51 kg/year between 50 and 72 years of age and −0.95 kg/year between 72 and 96 years of age. The risk factors associated with lower grip strength differed between men and women, in women; depressive symptoms, perceived stress, musculoskeletal disorder and dementia had effect on lower levels of grip strength, whereas in men, higher physical activity, higher MAP and cardiovascular disorder caused lower grip strength levels.

Martin *et al.* (2015) examined the association between age, grip strength and hand dexterity. According to study reduced hand dexterity related with increased age as a stemmed from decline in musculoskeletal strength and mass. 60 females ages ranged from 18 to 86 and 57 males aged between 20 and 93 years were measured while sitting upright, with their elbows by their left and right sides, and flexed to right angles- neutral wrist position. Grip strength of the participants were measured by using an adjusted handgrip dynamometer (Takei Scientific Instruments, Japan) for both hand while dexterity measured with 'Vienna Test System: Motor Performance Series Work-board' only for dominant hand. These series of motor tests include (i)steadiness; (ii) tracking; (iii) aiming; (iv) tapping. Subjects were asked the squeezed the dynamometer with maximum effort for at least 5 seconds and maximum of three trials was recorded. The study reported that increased age was related to decreased strength, grip strength declined linearly 0.25 kg for each year of age. Another finding of the study that decreased strength was significantly associated with decreased hand dexterity.

Another study focused on loss of muscle strength (dynapenia) among elder people was conducted by Bohannon and Magasi (2015). They aimed to generate refences values and t-scores for grip strength for young adults and identify dynapenia in older people. The subjects were composed of two groups as 178 males and 212 females with age ranges of 60–85 years, 152 males and 406 females aged between 20 and 40 years. Gender, ethnicity, hand dominance, age, height, and weight were asked to all subjects as part of standardized questionnaire. Measurement procedure was conducted in consideration of the suggestions of American Society of Hand Therapists. The participants were measured for each hand by using a Jamar dynamometer in its second handle position, while they were seated with their arms by their sides and elbows flexed 90°. Regardless of hand, maximum value was recorded as a grip strength measure both N and kg. The elder subjects were stratified into five group as 60-64, 65-69, 70-74, 75-79, 80-85. In that study, t-scores of young adults were calculated in order to identify older adults with age-related loss in grip strength. Results of the study show that the elder males significantly stronger than elder females within each age group. Grip strength was found to generally decrease with age for both genders, but for women it increased after 80 years old even if just a drop.

Ekşioğlu (2016) conducted a study with 128 male and 83 female subjects aged between 18 and 69 to determine normative grip strength of population of Turkey. The another aim of the study was to investigate the effects of gender, age and anthropometric measurements such; age, height, body mass, body mass index, hand length, hand breadth, and wrist circumference on grip strength. The subjects were grouped into 10- year age bands as follows: (18 - 29), (30 - 39), (40 - 49), (50 - 59) and (60 +). They classified into two main group according to their job which are manual and non-manual. The participants were measured four different postures for both dominant and non-dominant hands. They performed two trials and the maximum result was recorded for the grip strength response for each posture and hand separately. Results showed that males had higher strength than females with largest difference as similar to previous studies. Age had significant effect on the grip strength, especially after 50 years old grip strength decreased significantly for both genders. However, when occupation group was assessed there was no significant difference between manual employees and non-student non-manual employees.

The elderly people who are over 60 years dramatically increased in the last decades in Indian population rather like many other populations. Therefore, Gunasekarana *et al.* (2016) aimed to develop normative data of functional capacity measurements which consist of Gait speed, maximum grip strength and thirty seconds chair stand test and is lacking in older Indians. According to American Physical Therapy Association (2001) gait is person walks which is characterized by rhythm, cadence, step length, stride length, and speed. It is a measure of lower body strength while grip strength is a measure of upper limb. That’s why composed of two measurements were utilized to understand the functional status of older adults. Thirty seconds chair test is another easiest way to measure functional capacity. Participants were asked to sit with their feet resting flat on ground and then stand up from and sit down on the chair, without using their hands, for thirty seconds. 723 healthy participants (494 males and 229 females), above the age of 60 years were recruited for the test. The grip strength measurement was taken with Hand Dynamometer while sitting in a chair with arm support. The subjects were tested 3 times in each hand and the maximum of the six values was chosen as the grip strength. They have concluded that maximum grip strength declined with increasing age while increased with in direct proportion to BMI in both genders, except in males with BMI >30.

Maranhao Neto *et al.* (2017) aimed to compare body size effect which are body mass, fat-free mass, body height on hand grip strength among elder people. Allometric normalization method was utilised in order to investigate best body size variable. Additional to these measurements, age, sex and physical activities were taken into consideration. The study was conducted with 123 men (aged between 60–87 years) and 140 women (aged between 60–90 years) who admitted Elderly Care Center of the Open University of the Third Age (UNATI). Measurements of weight, height and waist circumference were taken at the same time with hand grip strength for each subject Lafayette dynamometer (model 78010 Lafayette, IN, USA) was used for grip strength measurement and the values were recorded as maximum of two trials for both hands. Prominently, males were heavier, taller, stronger and had more fat-free mass than females. Study resulted with body height is the most appropriate variable for body size adjustment. When three of body size variables compared with adjusted hand grip strength that was calculated by absolute hand grip strength divided by each body size, adjusted grips strength with body height was the most significant. In other words, the study enabled that the body height should be used instead of body-mass and fat-free mass when it is considered to investigate the effect of hand grip strength for elder people. The means of actual hand grip strengths were 35.3 ± 7.3 kg, 21.2 ± 5.6 kg for men and women respectively.

Mat Jais *et al.* (2018) conducted a study to obtain normative grip strength data of elderly population of Singapore. They aimed to investigate changes in grip strength against resistive torque force. Therefore, they collected 3 types of measurement; hand static grip, grip with resistive pronation, and grip with resistive supination from participants for each hand. 233 (99 males and 134 females) healthy Singaporean subjects aged 60 and older recruited for this study. They were categorized into 6 groups; 60-64, 65-69, 70-74, 75-79, 80-84, and over 85. Multifunctional hand strength measurement device with a nonrotating torque sensor which is similar with standard hand dynamometer was used. It is validated with the gold standard Jamar dynamometer. Participants were measured according to Mathiowetz *et al*. which recommend to subjects to seat upright on a chair with feet planted flat on the ground, shoulders adducted with hands in neutral rotation and flexion, and elbows flexed at 90, with the forearm in neutral position. It is expected to maintain their grip at maximum strength for up to 10 seconds. Results showed that, males are significantly stronger than females across all age groups. Static grip strength was at maximum value when it is compared to pronation torque and supination torque. Contrary to expectations the subjects aged older than 85 were stronger than the younger group.

Wang *et al.* (2018) summarized grip strength measurement obtained in 2011- 2012 and 2013-2014. The purpose of the study was to compare normative grip strength data obtained from an original and an intergroup replicative cohort of the National Health and Nutrition Examination Survey (NHANES) to validate them and to generate normative reference values derived from the consolidation of data from the 2 groups. The subjects aged 6 and older had been recruited by NHANES. Some of the participants were excluded which were unable to hold dynamometer or missing arms etc. After all elimination 13676 participants aged between 6 and 80 years remained for the final analysis with a comparable 49.6% males and 50.4% females. The first group included 6546 participants which are obtained 2011 to 2012 and 7130 participants were from the second cycle which was 2013 to 2014. The Takei digital dynamometer, model T.K.K.5401 was to measure maximum grip strength response and NHANES Muscle Strength Procedures Manual was the guide of testing procedure. The subjects were asked to stand with elbow extended, and wrist in neutral position. Both dominant and non-dominant hand were tested 3 times with 60 sec rest time. This is the first validation study of literature. The difference between previous studies of grip strength were statistically insignificant, therefore results which were stratified to gender, age and side have been confirmed. However, the study noted the NHANES study did not use a standardized positioning and protocol. Nonetheless, the stability of the NHANES grip strength responses was supported.

Sarcopenia means loss of strength which decreasing with age. As it mentioned previous, there are many studies that investigate relationship between loss of muscle strength with functionality and physical performance in elderly people. Neves *et al.* (2018), were also conducted one of the studies that aimed to focus on preventive measures, less expensive, to minimize body changes that occur due to inadequate aging. 141 males with mean age 71 (65 to 91) and 246 females with mean age 71 (65 to 90) totally 387 subjects were tested for grip strength by using a manual hydraulic dynamometer while sitting on an armless chair, with elbow flexed at a 90° angle, forearm in neutral position, three times. Some body dimensions data were also collected together with physical performance. Differently from many studies, in this study was dependent variable on the skeletal muscle prediction equation. Results showed as expected men’s physical performance was higher than elder female for each physical test. The handgrip strength was the best correlated with the skeletal muscle mass equations for elderly people. Many studies from literature have proved that hand strength correlates with upper extremity strength and general body strength which justified by the good correlation that founded between grip strength variable and the SMM.

Porto *et al.* (2019) also investigated muscle weakness resulting from physiological changes in the musculoskeletal system depended on age. Hence, they aimed to determine the association between hand grip strength and trunk, hip, knee, and ankle muscle group strengths. 150 elder people from 60 to 80 from community were recruited. The subjects performed the grip strength test only for dominant hand by using Jamar manual dynamometer. The procedure of grip strength test was conducted according to recommendations of American Society of Hand Therapy. The test was performed three times and mean of three trials was recorded as grip strength response. As Bohannon (1998) mentioned that grip strength is measure of overall muscle strength, result of the study also showed grip strength response significantly and highly correlated with global muscle strength as well as hip, knee and trunk. Hence, it claimed that grip strength can be used as screening tool of loss of global muscle strength for elder people.

2.4.1. Summary and Critics of Findings

To summarize all studies and to be able to see their lacks, classifications according to location, gender, posture, factor, dynamometer type, measured that used in the analyses and age groups were done (Table 2.1 and Table 2.2).

Table 2.1 shows that several studies investigated grip strength at different postures such as; sitting on a chair without armset or supported with armset, standing flexed condition, standing extended condition or standing with free posture. While several studies in the literature have investigated posture effect on grip strength, some of the studies did not mention the effect of posture on grip strength. Therefore, influence of posture on grip strength for elderly people has not quantified sufficiently.

There have been several previous studies researched age effect on grip strength with many other anthropometric dimensions. Especially for elderly people, decreased muscle cross section area is one of the top factors that has been investigated among different age groups. While occupation of elderly people has not been taken into consideration, current physical activitiy level and functional abilitiy have been investigated by respectable amount of studies. Moreover, the effects of gender, hand, economic status, alcohol and tabacco consumptions were also investigated.

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

- Males are stronger than females.
- Dominant hand is stronger than non-dominant hand.
- Mean male grip strength is higher than female grip strength.
- The effect of age and body alteration with aging has been investigated in many studies. Grip strength of elderly people is affacted by loss of muscle mass and general muscle strength. It had a positive and significant correlation with arm muscle circumference and arm muscle area in both genders. Strength decreases with age from around 60 years and this decrease is dramatic after 80 years for both genders.
- The magnitude of hand grip strength is strongly influenced by body mass, height and in parallel with Body Mass Index (BMI).
- Physical activitiy has positive effect on grip strength, but heavy and strenous physical activity has a negative impact.
- The grip strength is also influenced by posture and grip span. There are studies which have found that higher grip strength was exerted in the standing posture compared to the sitting posture. But there are also some studies, finding this difference statistically insignificant for elderly people.

Table 2.1. Summary of studies in literature.

Source	**Location**	**Sample type**	**Measure used**	**Dynamometer**	**Grip span**	**Posture**	**Measured Hand**	**Support**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**	**Factor**
Liao *et al*. (2014)	Taiwan	M: 136/ W: 113 (above 65 years) average 72.8	Mean of three trials	Jamar dynamometer	Preferred span	•Sitting-flexed position, •Standing-flexed condition, •Standing-extended position	Dominant	No	•Age •Gender •Body Height •Body Weight •BMI	NM	5 sec	•Body Posture •Health •Age •Gender
Desrosiers *et al*. (1995)	Canada	M:180 / W:180 (60-69 yrs, 70-79 yrs, and 80 yrs and older)	Max of three trials	Jamar dynamometer & The Martin vigorimeter	Fixed with second handle position	•Sitting on chair without armrests	Both hands	No	•Body Weight •Body Height •Hand Length •Hand •Circumference	30 sec	NM	•Age •Gender •Health •Hand circumference •Hand Dominance •Height •Weight •Work •Characteristics •Current Activity Level •Frequency of Current Manual Activities

**NM: Non-mentioned*

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

Source	**Location**	**Sample type**	**Measure used**	**Dynamometer**	**Grip span**	**Posture**	**Measured Hand**	**Support**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**	**Factor**
Koopman *et al*. (2014)	Africa	923 inhabitants; 50 years and older 480 M aged from 58 to76; 443 F aged from 56 to 70	Max of trials for each hand	Jamar dynamometer	Adjusted	•Standing in an upright position with arms parallel the body	Both hands (max was reported)	No	•Body Weight •Body Height •BMI	NM	NM	•Age •Gender •Body Height •Body Weight •BMI •Tribe •Socio-economic •Status
Demura *et al*. (2011)	Japan	15 M (age mean 65.6 yrs) 15 F (age mean 65.0 yrs)	Max of two trials	The hand dynamometry device (YH100, Yagami, Japan)	Arbitrarily adjusted	•Sitting chair and the hand in a semi-prone position	Right-handed	Yes	NM	NM	NM	•Gender •Body Height •Body Weight
Bohannon and Magasi (2015)	USA	558 Subjects (from 20–40 yrs) 390 Subjects (from 60–85 yrs)	Max of trials for each hand	Jamar dynamometer	Second handle position	•Sitting	Both hands (max was reported)	NM	•Height •Weight	NM	NM	•Age •Gender

**NM: Non-mentioned*

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

Source	Location	Sample type	Measure used	Dynamometer	Grip span	Posture	Measured Hand	Support	Anthropometric measures taken	Rest time	Squeeze time	Factor
Aoki and Demura (2011)	Japan	15 young F (21.5 ± 1.4 yrs) 15 elderly F (65.0 ± 2.6 yrs)	Max of trials for each hand (each was performed twice)	The hand dynamometry device (YH100, Yagami, Japan)	Arbitrarily adjusted	•Sitting chair and the hand in a semi-prone position	Right-handed	Yes	NM	NM	NM	•Age •Loads
Martin *et al.* (2015)	UK	60 F (50 ± 21 yrs) & (range 18–86 yrs) 57 M (48 ± 18 yrs) & (range 20–93 yrs)	Max of three trials	Handgrip dynamometer (Takei Scientific Instruments, Japan)	Adjusted	•Sitting	Both hands	NM	NM	60 sec	5 sec	•Grip Strength •Age •(i: Steadiness; ii: Line tracking; iii: Aiming; iv: Tapping)
Kaur (2009)	India	600 Jat F (rural=300, urban=300) (from 40 to 70 yrs)	Max of three trials	Hand Dynamometer (analogue model, range 0–100kg, Japan)	NM	NM	Both hands	NM	NM	NM	NM	•Age •Hand •Region •Height •Weight •Body massindex •Biceps and triceps skin foldt hickness
Desrosiers *et al.* (1995)	Canada	49 M (71.1 ± 7.9 yrs) aged between 60 to 84 yrs	Mean and Max of three trials are both reported	Jamar dynamometer	Fixed with second handle position	•Sitting on a chair without armrests.	Both hands	No	•Height •Weight •biceps and triceps skinfold thicknesses	30 sec	NM	•Age •Position

**NM: Non-mentioned*

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

Source	**Location**	**Sample type**	**Measure used**	**Dynamometer**	**Grip span**	**Posture**	**Measured Hand**	**Support**	**Anthropometric measures taken**	**Rest time**	**Squeeze time**	**Factor**
Ramlagan *et al.* (2014)	South Africa	3840 Subjets (44.1% men, 55.9% women)	Max of trials for each hand (each was performed twice)	Smedley's Hand Dynamometer (mechanic)	Adjusted by turning the handle to move it up or dow	NM	Both hands	No	•Height •Weight	NM	5 secs	•Cognitive capacity •Functional ability •Subjective health •Depression •Tobacco use •Alcohol use •Height •Weight •Physical activity •Chronic diseases •Economic or wealth status
Sternang *et al.* (2015)	Sweden	345 M & F with aged between 50-88 years	Max of trials for each hand (each was performed three trials)	Collin Hand Grip Dynamometer (0-70 kg)	NM	NM	Both hands	NM	•Height •Weight	NM	NM	•Age, •Education level, •Socio-economic status, •Marital status, •Body weight, •Height, •Self-reported health, •Depression, •Stress, •Mean arterial pressure (MAP), •Lipids, •Morbidity, •Smoking •Physical activity

**NM: Non-mentioned*

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

Source	Location	Sample type	Measure used	Dynamometer	Grip span	Posture	Measured Hand	Support	Anthropometric measures taken	Rest time	Squeeze time	Factor
Hu *et al.* (2007)	China	50 M aged between 65-85 yrs; 58 F aged between 65-81 yrs		Smedley's Hand Dynamometer (mechanic) (CWL-I; range: 0–100 kg, graduation: 1 kg)	Adjusted	NM	Dominant	NM	•Height •Weight •Waist circumfrences	4-6 sec.	NM	•Age •Gender
Sin *et al.* (2009)	USA & Korea	Koreans: 102 M & 192 F aged between 65 to 88 yrs (75 ± 6.48) Koreans Imigration: 49 M & 38 F aged between 65 to 84 yrs (73 ± 4.77)	Mean of two trials	J00105 Jamar hydraulic hand dynamometer	NM	NM	NM	NM	•Height, •Weight, •Mid-upper arm and Mid-calf circumference •Skinfold thickness	NM	NM	•Age, •Gender, •BMI, •Muscle areas of he mid-upper arm •Mid-calf •Hand grip strength •Korean imigrations vs koreans,
Mat Jais *et al.* (2018)	Singapor	99 M & 134F from 60 yrs over 85 yrs	One trial for each hand (both reported)	A Custom-Made Multifunctional Hand Strength Measurement Device	NM	•Sitting	Both hands	No	NM	60 sec	10 sec	•Age •Gender •Hand
Wang *et al.* (2018)	USA	6783 M and 6893 F aged between 6 to +80 yrs	Max of three trials	The Takei digital dynamometer, (Model T.K.K.5401)	Adjusted	•Standing	Both hands	No	NM	60 sec	NM	•Age •Gender •Hand

**NM: Non-mentioned*

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

Source	Location	Sample type	Measure used	Dynamometer	Grip span	Posture	Measured Hand	Support	Anthropometric measures taken	Rest time	Squeeze time	Factor
Shahida *et al.* (2015)	Malaysia	56 M (aged 60-79 yrs) 56 F (aged 60-82 yrs)	Mean of 2 highest trials	Jamar Hand Dynamometer (Sammons Preston) range; 0-90 kg and graduation of 1 kg	NM	•Sitting on a chair without armrest	Dominant hand	No	•36 dimensions were taken; •Weight •Stature •Hand length •Shoulder height •Elbow height •Forearm circumference, so on	NM	NM	•Age, •Gender •18 anthropometric dimensions (the variables which have correlation cofficent more than 0.5)
Maranhao Neto *et al.* (2017)	Brazil	123 M (aged 60–87 yrs) 140 F (aged 60–90 yrs)	Max of two	Lafayette dynamometer (Model 78010 Lafayette, IN, USA)	NM	NM	Both hands	NM	•Weight, •Height •Waist circumference	NM	NM	•Age, •Gender •Physical activity level, •Height •Body mass •Fat-free mass
Mathiowetz *et al.* (1985)	USA	310 M with mean:49.03 328 Female with mean: 49.75 (Range 20-94 yr.)	Mean of three	Jamar dynamometer	Fixed with 2nd setting (4.76cm)	•Sitting	Both hands	Yes	NM	NM	NM	•Age •Gender •Hand
Ribom *et al.* (2011)	Sweden	999 M aged from 70-80 yrs	Max of two	Jamar1 Hydraulic Hand Dynamometer (5030J1, Jackson, MI, USA)	Each five spans	•Sitting	Both hands	No	•Height •Weight	NM	NM	•Age

**NM: Non-mentioned*

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

Source	Location	Sample type	Measure used	Dynamometer	Grip span	Posture	Measured Hand	Support	Anthropometric measures taken	Rest time	Squeeze time	Factor
Porto *et al.* (2019)	Brazil	150 Subjects M & F (68.78 ± 5.23yrs)	Mean of three	Jamar Dynamometer (Sammons Preston, Illinois)	NM	•Sitting on a chair without armrests.	Dominant hand	No	•Height •Weight	NM	NM	•Gender •Age •Weight •Height •Body Mass index (BMI) •Physical activity level
Samuel and Rowe's (2012)	United Kingdom	42 M and 40 F, age from 60 to 88 yrs (73.2 ± 7.3 yrs)	Max of three	Jamar Dynamometer (Biometrics Ltd., UK.)	NM	•Sitting	Both hands	No	•Height •Weight	30 sec	NM	•Age •Gender •Knee and Hip joint
Neves *et al.* (2018)	Brazil	141 M mean age: 71 range (65-93) 246 F mean age 71 range (65-90)	Max of three	Manual Hydraulic Dynamometer (Model SH5001, Saehan Corp., Masan, Korea)	NM	•Sitting on a chair without armrests.	NM	NM	•Height •Weight •Arm circumference •Neck circumference •Calf circumference •Thigh circumference	15sec	NM	•Age •Gender •The muscle strength of the lower limbs

**NM: Non-mentioned*

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

Source	Location	Sample type	Measure used	Dynamometer	Grip span	Posture	Measured Hand	Support	Anthropometric measures taken	Rest time	Squeeze time	Factor
Almeida Silva *et al.* (2013)	Brazil	283 F & 133 M 60-69 yrs 138 F & 64 M 70-79 yrs 93 F & 42 M 80+yrs 52 F & 27	NM	A Manual Hydraulic Dynamometer (Takei Kiki Kogyo Dynamometer ® TK 1201 – Japan)	Adjusted	NM	NM	NM	•Height, •Weight, •Arm muscle circumference •Corrected arm muscle area	NM	NM	•Gender •Age •Flexibility •Arm muscle circumference •Corrected arm muscle area •Body mass index
Schlüssel *et al.* (2008)	Brazil	1122 M & 1928 F 20-29 yrs 295 M 431 F 30-39 yrs 244 M 397 F 40-49 yrs 220 M 403 F 50-59 yrs 166 M 327 F 60-69 yrs 121M 198 F 70+ yrs 76 M 172 F	Max of three	Jamar Mechanical Dynamometers (Sammons Preston e Korea)	Adjusted	•Standing	Both hands	NM	•Height •Weight	60 sec	NM	•Gender •Age •Body Mass index
Peebles and Norris (2003)	UK	65 M (from 2 to 80 yrs) 88 F (from 2 to 86 yrs)	Max of two	Hand Dynamometer (MKIIIa) (made by the Medical Physics Department) (based on a bridge of strain gauges)	Adjusted	•Standing with free posture	Dominant hand	NM	NM	2 min	5 sec	•Gender •Age

**NM: Non-mentioned*

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

Source	Location	Sample type	Measure used	Dynamometer	Grip span	Posture	Measured Hand	Support	Anthropometric measures taken	Rest time	Squeeze time	Factor
Gunasekarana *et al*. (2016)	India	60–65 yrs; 330 M & 185 F 66–70 yrs; 95 M & 34 F + 70 yrs; 69 M & 10 F	Max of six (regardless of hand)	Hand Held Dynamometer	NM	•Sitting with arm support chair	Both hands	NM	•Height •Weight	NM	NM	•Gender •Age •Body Mass index
Bohannon *et al*. (2006)	USA	1477 M 1840 F	Max of three	Jamar Dynamometer	NM	NM	Both hands	NM	NM	NM	NM	•Age •Gender •Hand
Xiao *et al*. (2005)	China	147 M 47 F	Mean of two	Jackson Evaluation System (Model 32628DL*C)	Fixed with 2.5cm	•Sitting and the gripdynamometer was held with the palm facing up	Both hands	No	•Height •Weight •Acromial •Height •Iliac Height •Knuckle Height •Knee Height •Chest Depth •Abdominal Depth	NM	3 sec	•Age •Gender •Anthropomethric •Variables •Industrial Worker •College Student •Office Clerk

**NM: Non-mentioned*

Table 2.2. Results of reviewed studies.

Source	Location	Sample type	Dominant (Right)	Non-Dominant (Left)
Liao *et al*. (2014)	Taiwan	M: 136 65–69 yrs; n = 17 70–74 yrs; n = 46 75–79 yrs; n = 42 80–84 yrs; n = 18 85+ yrs; n = 13	Overall; 31.6 ± 6.8 65–69 yrs; 34.3 ± 5.1 70–74 yrs; 32.9 ± 7.4 75–79 yrs; 31.6 ± 6.0 80–84 yrs; 29.0 ± 7.1 85+ yrs; 26.8 ± 6.0	NM
		F: 113 65–69 yrs; n = 20 70–74 yrs; n = 50 75–79 yrs; n = 29 80–84 yrs; n = 12 85+ yrs;(n = 2	Overall; 21.5 ± 5.3 65–69 yrs; 22.9 ± 4.8 70–74 yrs; 22. ± 5.5 75–79 yrs; 22.0 ± 4.3 80–84 yrs; 17.4 ± 5.2 85+ yrs; 12.0 ± 2.8	NM
Desrosiers *et al.* (1995)	Canada	M:180	60 - 69 yrs: (45.6 ± 8.6) / Min-Max (31-70) kg 70 - 79 yrs: (42.4 ± 9.1) /Min-Max (24 - 69) kg 80 +- yrs: (34.5 ± 7.2) / Min-Max (16.5 - 48) kg	60 - 69 yrs: (43.6 ± 8.7) /Min-Max (30-72)kg 70 - 79 yrs: (40.5 ± 8.5) / Min-Max (26-62)kg 80 + yrs: (32.1 ± 7.0) / Min- Max (18-47)kg
		W:180	60 - 69 yrs: (25.3 ± 4.8) Min-Max (18-41) kg 70 - 79 yrs: (23.7 ±5.1) Min-Max (11 - 36) kg 80 + yrs: (20.0 ±4.3) Min-Max (12 - 32) kg	60 - 69 yrs: (23.6 ± 4.7) Min-Max 12-36 kg 70 - 79 yrs: (22.0 ±4.7) Min-Max 10-30 kg 80 + yrs (18.5 ± 4.4) Min-Max 10-30 kg
Koopman *et al.* (2014)	Africa	480 M aged from 58 to76;	31.3 ± 8.7 kgf	NM
		443 F aged from 56 to 70	23.6 ± 5.9 kgf	
Demura *et al.* (2011)	Japan	15 M (age mean 65.6 ysr)	36.7 ± 4.9kg	NM
		15 F (age mean 65.0 yrs)	22.5 ± 3.1kg	
Bohannon and Magasi (2015)	USA	390 Subjects (from 60–85 yrs) 70–74 yrs; n=42 M 75–79 yrs; n=26 M 80–85 yrs; n=46 M	70–74 yrs = 76.4 ± 22.0 Pound 75–79 yrs = 75.1 ± 22.9 Pound 80–85 yrs = 62.8 ± 20.9 Pound	NM
		390 Subjects (from 60–85 yrs) 70–74 yrs; n=46 F 75–79 yrs; n=54 F 80–85 yrs; n=21 F	70–74 yrs = 48.2 ± 11.9 Pound 75–79 yrs = 44.3 ± 13.8 Pound 80–85 yrs = 45.3 ± 8.9 Pound	NM

**NM: Non-mentioned*

Table 2.2. Results of reviewed studies (cont.).

Source	Location	Sample type	Dominant (Right)	Non-Dominant (Left)
Aoki and Demura (2011)	Japan	15 young F (21.5 ± 1.4 yrs) 15 elderly F (65.0 ± 2.6 yrs)	NM	NM
Martin *et al*. (2015)	UK	60 F (50 ± 21 yrs) and (range 18–86 yrs) 57 M (48 ± 18 yrs) and (range 20–93 yrs)	NM	NM
Kaur (2009)	India	600 Jat F (rural=300, urban=300) (from 40 to 70 yrs)	NM	NM
Ramlagan *et al*. (2014)	South Africa	All 3840 Subjets (both male and female) aged 61.6 yrs	34.3 ± 6.5kg	NM
		3840 Subjets 44.1% Male; aged 61.1 yrs	Overall Male: 37.9 ± 19.6kg 70-79 years: 35.0 ± 19.2kg 80 + years: 31.1 ± 16.8kg	NM
		3840 Subjets 55.9% Femal; aged 62.0 yrs	Overall Female: 31.5 ± 17.8kg 70-79 years: 28.7 ± 16.5kg; 80 + years: 25.2 ± 14.2kg	NM
Sternang *et al*. (2015)	Sweden	849 M with aged between 50-88 years	Male; 72- 96 yrs; 35.33 kgf	NM
		345 F with aged between 50-88 years	Female; 67- 97 yrs; 23.18 kgf	NM
Hu *et al*. (2007)	China	50 M aged between 65-85 yrs;	39 ± 11kg	NM
		58 F aged between 65-81 yrs	21 ± 5.2kg	NM
Sin *et al*. (2009)	USA & Korea	Koreans: 102 M Koreans Imigration: 49 M from 65 to 88 yrs	Korean Immigrations: 31.6 ± 5.6kg Korean: 31.9 ± 8.2kg	NM
		Koreans: 192 F Koreans Imigration: 38 F from 65 to 88 yrs	Korean Immigrations: 19.6 ± 4.1kg Korean: 19.5 ± 5.4kg	NM

**NM: Non-mentioned*

Table 2.2. Results of reviewed studies (cont.).

Source	Location	Sample type	Dominant (Right)	Non-Dominant (Left)
Mat Jais *et al*. (2018)	Singapor	99 M (60 yrs over 85 yrs) 60-64 yrs: 6 65-69 yrs: 24 70-74 yrs: 24 75-79 yrs: 19 80-84 yrs: 15 85 + yrs: 11	60-64 yrs: 24.2 ± 6.3kg 65-69 yrs: 29.9 ± 8.7kg 70-74 yrs: 23.9 ± 6.8kg 75-79 yrs: 24.7 ± 8.1kg 80-84 yrs: 18.1 ± 6.7kg 85 + yrs: 20.3 ± 9.4kg	60-64 yrs: 22.4 ± 7.8kg 65-69 yrs: 26.1 ± 7.6kg 70-74 yrs: 21.3 ± 7.7kg 75-79 yrs: 22.1 ± 7.7kg 80-84 yrs: 16.7 ± 5.4kg 85 + yrs: 18.0 ± 5.7kg
		134 F (from 60 yrs over 85 yrs) 60-64 yrs: 11 65-69 yrs: 35 70-74 yrs: 33 75-79 yrs: 21 80-84 yrs: 18 85 + yrs: 16	60-64 yrs: 17.0 ± 3.4kg 65-69 yrs: 17.7 ± 5.4kg 70-74 yrs: 15.7 ± 6.2kg 75-79 yrs: 12.6 ±5.7kg 80-84 yrs: 10.5 ± 4.5kg 85 + yrs: 14.4 ± 4.1kg	60-64 yrs: 14.5 ± 3.7kg 65-69 yrs: 15.0 ± 4.6kg 70-74 yrs: 13.1 ± 4.9kg 75-79 yrs: 11.0 ± 4.8kg 80-84 yrs: 10.5 ± 4.8kg 85 + yrs: 11.5 ± 3.4kg
Wang *et al*. (2018)	USA	6783 M aged between 6 to +80 yrs 70-74 yrs: 226 75-79 yrs: 161 80+ yrs: 243	70-74 yrs: 38.8 ± 7.4 kgf 75-79 yrs: 35.3 ± 7.2 kgf 80 + yrs: 31.4 ± 6.9 kgf	70-74 yrs: 36.7 ± 0.4 kgf 75-79 yrs: 35.7 ± 0.5 kgf 80 yrs: 30.1 ± 0.4 kgf
		6893 F aged between 6 to +80 yrs 70-74 yrs: 282 75-79 yrs: 153 80-84 yrs: 248	70-74 yrs: 24 ± 4.7 kgf 75-79 yrs: 23.1 ± 4.6 kgf 80 + yrs: 19.5 ± 4.5 kgf	70-74 yrs: 22.6 ± 0.4 kgf 75-79 yrs: 21.7 ± 0.5 kgf 80+ yrs: 18.3 ± 0.5 kgf
Wu *et al*. (2009)	Taiwan	244 M aged from 20 to 80+ yrs	70–74 yrs: Mean 24.7kg (19.8–29.6) 75 + yrs: Mean 22.5kg (16.9–28.1)	NM
		238 F aged from 20 to 80+ yrs	70-74 yrs: Mean 16.5kg (14.1–18.9) 75+ yrs: Mean 13.4kg (11.0–15.9)	NM
Shahida *et al*. (2015)	Malaysians	56 M (aged 60-79 yrs)	271.64 ± 69.01 N	NM
		56 F (aged 60-82 yrs)	159.30 ± 58.03 N	NM
Maranhao Neto *et al*. (2017)	Brazil	123 M (aged 60–87 yrs)	35.3 ± 7.3kg	NM
		140 F (aged 60–90 yrs)	21.2 ± 5.6kg	NM

**NM: Non-mentioned*

Table 2.2. Results of reviewed studies (cont.).

Source	Location	Sample type	Dominant (Right)	Non-Dominant (Left)
Mathiowetz *et al*. (1985)	USA	310 M age mean: 49.03 yrs (Range 20-94 yrs) 70-74; 26 M 75+; 25 M	70-74 yrs: 75.3 ± 21.5 N 75+ yrs: 65.7 ± 21 N	70-74 yrs:64.8 ± 18.1 75+ yrs: 55.0 ± 17.0
		328 Female age mean: 49.75yrs (Range 20-94 yrs) 70-74; 29 F 75+; 26 F	70-74 yrs: 49.6 ± 11.7 N 75+ yrs: 42.6 ± 11 N	70-74 yrs: 41.7 ± 10.2 N 75+ yrs: 37.6 ± 8.9 N
Ribom *et al*. (2011)	Sweden	999 M aged from 70-80 yrs	41 ± 8 kg	40 ± 8 kg
Porto *et al*. (2019)	Brazil	150 Subjects M & F (68.78 ± 5.23yrs) (Composed)	25.51 ± 8.07 (kgf)	NM
Samuel and Rowe's (2012)	United Kingdom	42 M and 40 F, age from 60 to 88 yrs (73.2 ± 7.3 yrs)	NM	NM
Neves *et al*. (2018)	Brazil	141 M mean age: 71 range (65-93)	30.1 ± 11.1 kgf	NM
		246 F mean age 71 range (65-90)	17.1 ± 6.2 kgf	
Almeida Silva *et al*. (2013)	Brazil	133 M 60-69 yrs; 64 M 70-79 yrs; 42 M 80+yrs; 27 M	Overall= mean 31 ± 8.8 kgf 60-69 = mean 32.9 ± 8.7 kgf 70-79 = mean 32.7 ± 7.7 kgf 80+ = mean 23.7 ± 6.7 kgf	NM
		283 F 60-69 yrs; 38 F 70-79 yrs; 93 F 80+yrs; 52 F	Overall= mean 19.1 ± 6.1 kgf 60-69 = mean 21.7 ± 5.5 kgf 70-79 = mean 18.2 ± 5.3 kgf 80+ = mean 13.9 ± 5.3 kgf	NM

**NM: Non-mentioned*

Table 2.2. Results of reviewed studies (cont.).

Source	Location	Sample type	Dominant (Right)	Non-Dominant (Left)
Schlüssel *et al*. (2008)	Brazil	1122 M aged from 20 to 70+ yrs 70+ yrs; 76 M	31.8 ± 0.79 kgf	29.4 ± 0.75 kgf
		1928 F aged from 20 to 70+ yrs 70+ yrs 172 F	17.2 ± 0.41 kgf	16.4 ± 0.41 kgf
Peebles and Norris (2003)	UK	65 M (from 2 to 80 yrs) 71-80 yrs; 8 M	71-80 yrs; 373.3 ± 30.3 N	NM
		88 F (from 2 to 86 yrs) 71-80 yrs; 12 F 81-90 yrs; 6 F	71-80 yrs; 225.4 ± 48.5 N 81-90 yrs; 160.1 ± 29.3 N	NM
Gunasekarana *et al*. (2016)	India	60–65 yrs; 330 M 66–70 yrs; 95 M + 70 yrs; 69 M	60–65 yrs: 27.31 ± 10.45 kgf 66–70 yrs: 22.49 ± 9.89 kgf 70 + yrs: 21.23 ± 8.27 kgf	NM
		60–65 yrs; 185 F 66–70 yrs; 34 F + 70 yrs; 10 F	60–65 yrs: 12.12 ± 5.60 kgf 66–70 yrs: 11.3 8± 7.78 kgf 70+ yrs:10.40 ± 4.93 kgf	NM
Bohannon *et al*. (2006)	USA	1477 M (Total Subject) 70-74 yrs; 120 M 75+ yrs; 217 M	70-74 years: mean 84.3 N 75+ years: mean 61.7 N	70-74 years: mean 79.9 N 75+ years: mean 65.6 N
		1840 F (Total Subjects) 70-74 yrs; 166 F 75+ yrs; 361 F	70-74: mean 53.4 N 75+: mean 39.6 N	70-74: mean 49.5 N 75+: mean 36.1 N
Xiao *et al*. (2005)	China	147 M	43.92 ± 7.14 kgf	42.07 ± 7.2 kgf
		47 F	23.26 ± 5.47 kgf	21.29 ± 5.09 kgf
Desrosiers *et al*. (1995)	Canada	49 M (71.1 ± 7.9 yrs) aged between 60 to 84 yrs	Flexed to 90° (averag value) = 42. 31 ± 9.6 kgf Extended (average value) = 41.74 ± 9.8 kgf Flexed to 90° (maximum value) =43.94 ± 9.6 kgf Extended (maximum value) = 43.10 ± 10.0 kgf	Flexed to 90° (averag value) =44.68 ± 9.9 kgf Extended (average value) = 39.80 ± 9.4 kgf Flexed to 90° (maximum value) = 42.43 ± 9.9 kgf Extended (maximum value) = 41.22 ± 9.4 kgf

**NM: Non-mentioned*

3. RATIONALE AND OBJECTIVES OF THE STUDY

3.1. Rationale of the Study

Aging causes many changes in humanbody and reduced muscle strength is one of those changes. Since grip strength is reduced with the age, it significantly and adversely affects daily activities of the elderly people (Hu *et al.*, 2007). This is true especially when they interact products requiring grip strength. Hence, to make the lives of elderly people easier and more comfortable, the designers of products, work and technology needs the strength data of elderly.

There are many studies on the grip strength of various elderly populations of the world. However, there are differences among some of these populations as the literature review showed. So, it is a need to establish such database for the elderly population of Turkey. As far as we know from the literature, there is no such study for the elderly population of Turkey. Therefore, the main aim of this study is to establish a grip strength database of elderly people of Turkey. Furthermore, investigate the effects of some anthropometric and demographic factors on the grip strength of elderly.

3.2. The Objectives of the study

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

(i) Estimating the isometric grip strength values of elderly (over 70) people of Turkey;
(ii) Investigating the effects of gender, age, height, weight and occupation on grip strength; and
(iii) Comparing the strength data of elderly population of Turkey with the strength data of population of other countries.

4. METHODOLOGY

4.1. Sampling Approach

The main aim of the study is to obtain maximum voluntary grip strength data for elderly population of Turkey. To meet the requirements of the study, the sample was chosen randomly by visiting senior centers around İstanbul city and finding elderly people in other areas of the city. The subjects had to not have any body limitations for the study. Such limitations could be a defect on the body dimensions, deficiency in hand, a burned body part etc. Thus, in order to choose the right subjects for the test, selected questions were asked to each candidate under the supervision the of senior centers administration. Only the elderly people who did not have any body defects were allowed for the test.

Since the study focused the age group over 70 years, some type of diseases were ignored which are common among many elderly people and have not directly an effect on grip strength for the focused age group. The subjects who suffered from the diseases such an Alzheimer, arm pain and musculoskeletal disorders were not accepted which would have lead to experimental errors. The subjects who had serious health problems were excluded from the experiments and the experimentation period was conducted only with the healthy subjects.

Subjects were recruited from a metropolitan city of Turkey (İstanbul) and its surrounding areas. According to the results of Turkish Statistical Institute (TÜİK) in 2014, 78.3 % of people who lives in Istanbul city are registered in other provinces of Turkey. Thus, it can be said that population of İstanbul reflects the general population of Turkey because of its demographic feature. The sample also included a few foreign people who live in Turkey.

With regard to TÜİK reports which were published in 2018, the distribution of population of Turkey is shown in Table 4.1. The number of people in terms of province regions, and the distribution percentages are also shown in Figure 4.1.

Table 4.1. Distribution of population of Turkey based on family origin (TÜİK, 2018).

Region	**Population**
Mediterranean	10.461.409
Aegean	10.514.200
Eastern Anatolia	6.058.499
Central Anatolia	13.114.013
Marmara	25.034.570
Black Sea	7.973.211
Southeastern Anatolia	8.847.980
Total	82.003.882

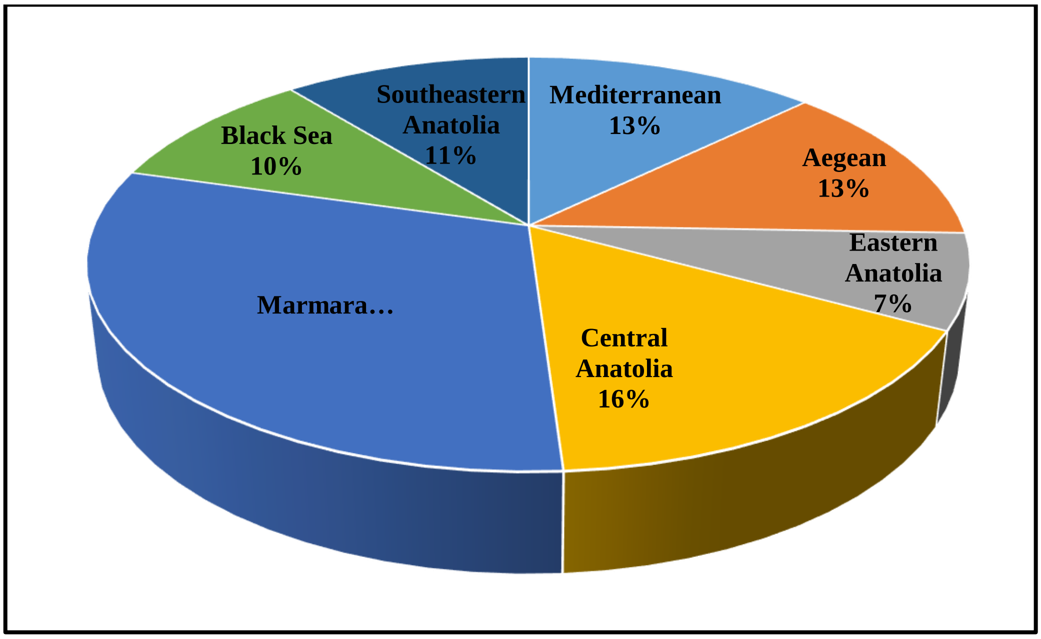

Figure 4.1. Distribution of family origin region of population of Turkey with respect to seven regions (TÜİK, 2018).

In order to form the study, represent the whole age groups of elderly male and female population of Turkey, the stratified sampling method was used. In that circumstance, the subjects were selected randomly between ages of 70-97 years from 7 regions of Turkey.

As stated in Turkish Statistical Institute’s (2018) data of age distribution, there are 4.573.997 elderly people who are 70+ years of age in the population of Turkey. The age distribution of Turkey’s population and the percentage in the age groups are shown in Figure 4.2. In this study, the subjects were stratified into four age groups as following: (70-74), (75-79), (80-84), (85 +). In that context, the number of the elderly people in Turkey’s population who are in the same age groups are shown in Table 4.2. According to (TÜİK, 2018) the percentage of the age group (80-84) is the 0.8% and (90+) is the 0.2% of total population. Since there are not adequate amount of people with that age groups, (80-84) and (90+) were merged as 85+ for the study.

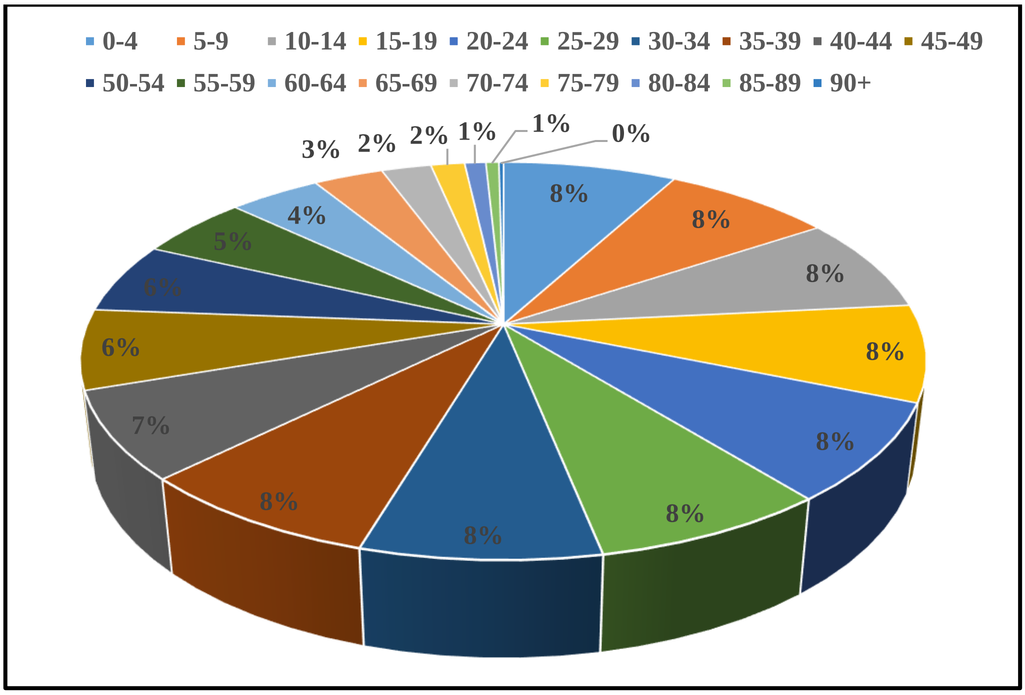

Figure 4.2. Age distribution of population of Turkey (TÜİK, 2018).

Table 4.2. Distribution of total population of Turkey with male & female population statistics of the age groups between 70 and 85+ years and their percentages (TÜİK, 2018).

Age-groups (in years)	**Total Population**	**Male**	**Female**	**Percentage of Population**
70-74	1.856.922	835.353	1.021.569	2.3%
75-79	1.262.550	539.825	722.725	1.5%
80-84	793.736	318.882	474.854	1.0%
85 +	660.789	230.093	430.696	0.8%
Total	4.573.997	1.924.153	2.649.844	5.6%

In addition to regional distribution and age groups for both genders, the subjects were grouped based on their occupation before their retirement. In literature, there are many studies, which take manual and non-manual workers as two occupational groups. In order to examine the job-group effect on the elderly male & female population of Turkey, the subjects were divided into two job groups; manual workers and non-manual workers according to jobs' power demand levels (ISCO-08; Crawley *et al.*, 2012). This categorization was partly made by the help of the outcomes of ISCO-08 (2012).

4.1.1. Pilot Study

Before performing the main experiment, 28 male and 28 female (7 subjects from each age group) subjects were selected randomly for a pilot study.

The pilot study was conducted for the reasons below;

(i) to get familiar with the equipment and procedures of the study.

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

4.1.2. Sample Size Determination

Sample size calculation is a fundamental part of the statistical analysis in order to draw a conclusion on the population. Determining the sample size is required for designing the data needed to obtain sufficient statistical power. It must be large enough to receive reliable results and on the other hand it must be small enough to complete the study in a feasible time.

ISO standards for generating anthropometric databases give sample size calculation formula for normative data studies as the following (ISO 15535:2012):

$$N = \left(\frac{1.96 \times CV}{a}\right)^2 \times 1.534^2 \tag{4.1}$$

where, 1.96 is the critical Z value from a standard normal distribution for a 95% confidence interval, CV is the coefficient of variation, a is the percentage of relative accuracy desired (CI is to be no larger than ± some percentage of the mean) (Montogomery, 2003).

CV is defined as the following:

$$CV = \frac{SD}{\bar{x}} \times 100 \tag{4.2}$$

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

Based on the results of the pilot study, mean and standard deviation were calculated for maximum voluntary grip strength values of 56 subjects. Relative accuracy (α) is decided to be at least 5%. Mean and standard deviation values in the pilot study are utilized for calculation of CV values which are required for determination of minimum sample size calculation of grip strength. The following equations demonstrate the calculation steps of sample size for dominant hand grip strength response of males (Montogomery, 2003).

$$CV = \frac{49.96}{300.29} \times 100 = 16.64 \tag{4.3}$$

$$N = \left(\frac{1.96 \times 16.64}{5}\right)^2 \times 1.534^2 = 100 \tag{4.4}$$

In the study there were two responses for each subject which are dominant hand and non- dominant hand grip strength values. Since CV values of maximum voluntary grip strength vary for each hand and gender, the calculation of required minimum sample sizes vary accordingly. Table 4.3 shows sample statistics of pilot study for both gender and each hand.

Table 4.3. Sample Statistics of Pilot Study

Gender	**Grip Strength Responses (N)**	$\bar{x}$	**SD**	**CV**
Male	**Dominant Grip Str.**	300.29	49.96	16.64
	Non-Dominant Grip Str.	286.53	44.58	15.56
Female	**Dominant Grip Str.**	186.33	33.3	17.87
	Non-Dominant Grip Str.	173.02	30.99	17.91

The largest of the calculated sample size, which is related to non-dominant hand grip strength of female test combination is taken as the minimum required sample size. This is at least 117 subjects are needed for conducting a reliable statistical analysis.

Calculations and results of sample size values can be seen in Table 4.4. Although 117 female and 101 male subjects were sufficient for the study, in order to assure the levels of relative accuracy and confidence for all the variables, 251 subjects (126 Males & 125 Females) were used for the study.

Table 4.4. Minimum sample size for 95 % confidence and 5 % relative accuracy

Gender	Grip Strength Responses	Sample Size Calculations (N)
Male	**Dominant Hand**	$N = \left(\frac{1.96\times16.64}{5}\right)^2 \times 1.534^2 = 100.1 = 101$
	Non-Dominant Hand	$N = \left(\frac{1.96\times15.56}{5}\right)^2 \times 1.534^2 = 87.5 = 88$
Female	**Dominant Hand**	$N = \left(\frac{1.96\times17.87}{5}\right)^2 \times 1.534^2 = 115.5 = 116$
	Non-Dominant Hand	$N = \left(\frac{1.96\times17.91}{5}\right)^2 \times 1.534^2 = 116.0 = 117$

4.1.3. Distribution of Subjects

In the study, 251 subjects were selected which are distributed equally between males and females. 125 females & 126 males were distributed homogenously according to their family origins to estimate the maximum voluntary grip strength of elderly population of Turkey. To this respect, subjects were sized almost equally from 7 regions of Turkey. The subjects were grouped based on their fathers' official provinces. They were asked about their birthplace, city of family origin, father and mother's birthplace. The regional distribution of family origins of the subjects is summarized in Table 4.5 and Figure 4.3.

Table 4.5. Distribution of family origin regions of the subjects

Region	Subjects
Mediterranean	31
Aegean	33
Eastern Anatolia	34
Central Anatolia	34
Marmara	47
Black Sea	37
Southeastern Anatolia	30
Other	5
Total	**251**

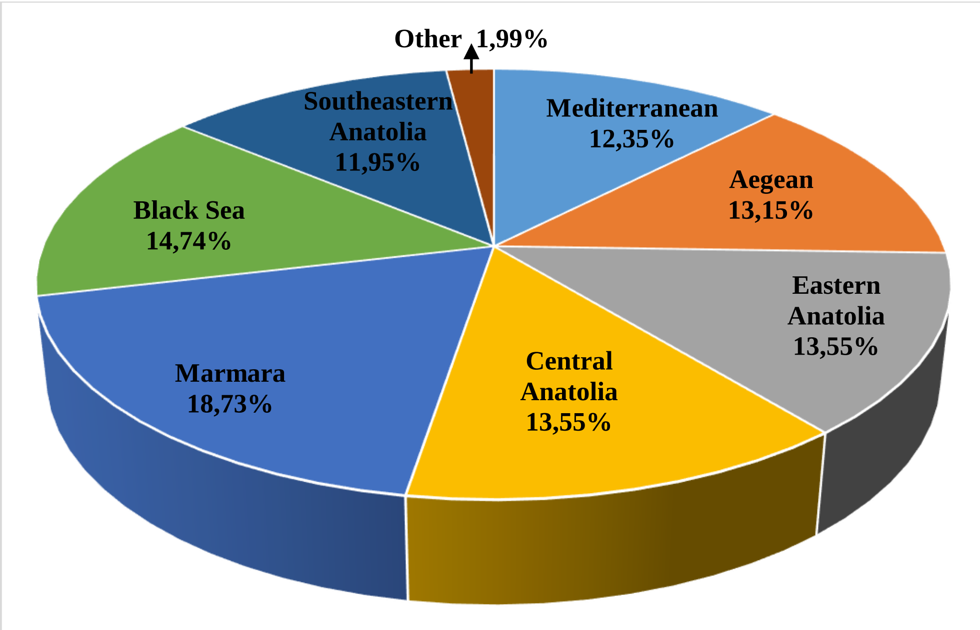

Figure 4.3. Distribution of family origin regions of the subjects

In addition to regional distribution, the study is planned to stratify the subjects into four groups equally in terms of their age: *(70-74), (75-79), (80-84)* and *(85+)*. In the literature, there are many studies, which take manual and non-manual workers as two occupational groups. In order to examine the job-group effect on the elderly male & female population of Turkey, the subjects were divided into two job groups; manual workers and non-manual workers according to jobs' power demand levels (ISCO-08; Crawley *et al.*, 2012). This categorization was partly made by the help of the outcomes of ISCO-08 (2012). Table 4.6 describes the number of male and female subjects by age and occupation groups.

Table 4.6. Number of subjects by gender, age and occupational groups

Occupation	Age Group (yrs)	Number		
		Man	Woman	All
Manual	70-74	16	14	30
	75-79	14	15	29
	80-84	16	14	30
	85+	18	23	41
	All	**64**	**66**	**130**
Non-Manual	70-74	17	17	34
	75-79	18	12	30
	80-84	12	17	29
	85+	15	13	28
	All	**62**	**59**	**121**
Total	**70-98**	**126**	**125**	**251**

Considering the BMI effect on maximum grip strength response, the subjects were categorized into three groups according to their BMI values. 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 mass divided by the square of their height (kg/m^2) (Wikipedia, 2018). Individuals with BMI <18.5 are considered as underweight; those between 18.5 and 25 are considered as having normal weight; and those at 25 or greater are considered as overweight. Equation 4.5 shows the formula for calculating Body mass index (BMI). The categorization of BMI is shown in Table 4.7.

$$\text{BMI } (kg / m^2) = \text{Weight } (kg) / \text{Height}^2 \ (m^2) \qquad (4.5)$$

Table 4.7. BMI categories and number of subjects in terms of their BMI values.

Category	BMI Range (kg/m^2)	Subjects
Underweight	< 18.5	1
Normal	$18.5 \leq x < 25$	65
Overweight	$25 \geq$	185
Total		251

Figure 4.4 shows the distribution of BMI groups for the subjects. Since there is only one female subject which falls into the underweight category, it is excluded from the statistical analysis.

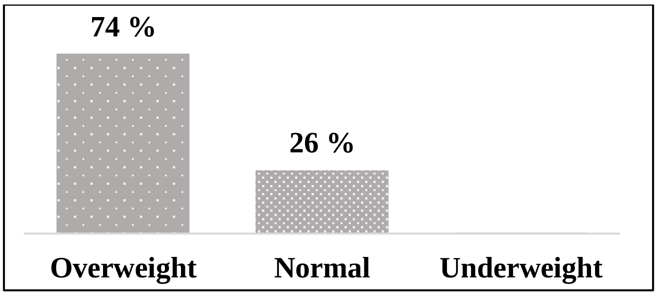

Figure 4.4. Distribution of BMI groups

The groups of subjects were summarized in Table 4.8 in terms of their age, occupation groups and BMI categories. Table 4.9 shows the detailed occupation classification of subjects for males and females for each group (manual & non- manual).

Table 4.8. The number of subjects categorized by age, job groups, gender and BMI.

Occupation		BMI Category	Age Group (yrs)				All
			70-74	75-79	80-84	85+	
Male	Manual	Underweight	0	0	0	0	**0**
		Normal	7	5	6	5	**23**
		Overweight	9	9	10	13	**41**
		All	**16**	**14**	**16**	**18**	**64**
	NonManual	Underweight	0	0	0	0	**0**
		Normal	1	9	6	4	**20**
		Overweight	16	9	6	11	**42**
		All	**17**	**18**	**12**	**15**	**62**
	Total		**33**	**32**	**28**	**33**	**126**
Female	Manual	Underweight	0	0	0	0	**0**
		Normal	1	1	0	8	**10**
		Overweight	13	14	14	15	**56**
		All	**14**	**15**	**14**	**23**	**66**
	NonManual	Underweight	0	0	1	0	**1**
		Normal	4	1	4	3	**12**
		Overweight	13	11	12	10	**46**
		All	**17**	**12**	**17**	**13**	**59**
	Total		**31**	**27**	**31**	**36**	**125**

Table 4.9 Occupation Classification

Female (125)		Male (126)	
Manual (65)	**Non Manual (60)**	**Manual (64)**	**Non Manual (62)**
Cook (1)	Architect (2)	Baker (1)	Agricultural Engineer (1)
Domestic Cleaner (1)	Artist (1)	Boxer (2)	Bank Teller (3)
Factory Labourer (3)	Bank Teller (5)	Building Caretaker (1)	Barber (1)
Farmer (10)	Bookkeeper (2)	Carpenter (1)	Bookkeeper (2)
Food Processing Labourer (1)	Chemical Engineer (1)	Construction Labourer (2)	Cabinetmaker (1)
Housekeeper (1)	Doctor (2)	Cook (1)	Chemical Engineer (1)
Housewife (32)	Hairdresser (2)	Driver (7)	Civil Engineer (1)
Machine Operator (1)	Journalist (1)	Dry Cleaner (1)	Doctor (1)
Patient Care (1)	Laborant (1)	Electrician (1)	Engineer (2)
Shoe Factory Labourer (2)	Lawyer (4)	Electrician (Braker) (1)	Football Player (1)
Spinning Factory Labourer (2)	Midwife (1)	Factory Labourer (5)	Health Officer (2)
Street Vendor (1)	Needlecraft Teacher (1)	Farmer (14)	Journalist (2)
Tailor (7)	Notary Puplic (1)	Fisher (1)	Lawyer (1)
Textile Factory Labourer (1)	Nurse (6)	Gardener (1)	Manager (7)
Tobacco Factory Labourer (1)	Office Clerk (2)	Horseshoer (1)	Mechanical Engineer (3)
	Painter (3)	Housepainter (1)	Medical Assistant (1)
	Pharmaceutist (2)	Ironworker (1)	Mining Engineer (1)
	Post Office Clerk (2)	Lathe Operator (2)	Office Clerk (8)
	Secretary (4)	Livestock Farming (1)	Owner of Company (1)
	Sporter (1)	Machine Operator (2)	Police (1)
	Teacher (12)	Mechanic (2)	Police Commissioner (1)
	Translator (1)	Metal Factory Labourer (3)	Post Office Clerk (1)
	Typist (1)	Metal Labourer (1)	Sales Clerk (1)
	Writer (2)	Oil Factory Labourer (1)	Self Employment (2)
		Operator (1)	Sergeant (1)
		Panel Beater (1)	Tax Officer (1)
		Petrol Attendant (1)	Teacher (5)
		Plumber (1)	Tradesman (8)
		Porter (1)	Typographer (1)
		Shoemaker (1)	
		Street Vendor (1)	
		Textile Factory Labourer (2)	
		Tobacco Factory Labourer (1)	

*All subjects were evaluated in accordance with the years of working in the past. In addition, housewives were accepted as manual workers

4.2. Equipment

The main aim of the study is to find out the effects of maximum voluntary grip strength of the elderly population. For that reason, not only experimental variables but also some anthropometric dimensions were taken into consideration. Thus, before starting hand grip strength test these anthropometric dimensions were also measured.

In this section, the information about the tools used for both hand grip strength, and some anthropometric dimensions (height, weight, hand length, wrist circumference, etc.) measurements are given.

4.2.1. The Measuring Tapes

Two types of tape measures were used in this study. The large and long tape is constructed from a stiff metallic material strip was used to measure height of subjects. The plastic and flexible tape was used for dimensions including waist and forearm circumferences.

4.2.2. Weighing Scale

Weighting scale is a measuring instrument for determining the weight or mass of an object. It is used in the study to determine the weights of the subjects which had been checked for accuracy with given weights before the tests.

4.2.3. Sliding Caliper

Calipers are used to measure the distance between two opposing sides of the subjects such as length and breadth measurement. The edges of the caliper need to be adjusted to fit across the points to be measured. Then, the caliper is removed, and the distance through the scales on the caliper is recorded. In this study, caliper was used to measure hand length and hand breadth of subjects. The result on this equipment is read with a high degree of accuracy and repeatability.

4.2.4. Jamar Plus^{+} Digital Hand Dynamometer

In many studies, Jamar hydraulic hand dynamometer was used for the measurement of hand grip strength. In this study, Jamar Plus Hand Dynamometer (Sammons Preston) was used (Figure 4.5). The dynamometer accommodates various size hands because its handle adjusts to five grip positions: 3.5 cm, 4.8 cm, 6.1 cm, 7.3 cm and 8.6 cm.

The equipment was calibrated before starting the experiments. The calibration of the equipment was performed in the Ergonomics Laboratory (ErgoLab) of Boğaziçi University. Firstly, two Hydrolic Hand Dynamometers and Digital hand dynamometer of laboratory were selected. All of dynamometers’ scaling method were adjusted as lbs. After determined weights were measured for both dynamometers, the results were read from the scale and compared with the determined actual weights of the objects being held. The weights that were used in calibration started from 10 lbs and were increased by 10 lbs until 150 lbs. The readings from the scale were the same as the actual weights of the objects for the digital dynamometer while they were not same for the hydraulic dynamometer. Therefore, the equipment was accurate and needed no further calibration.

Figure 4.5. Jamar Plus Hand Dynamometer (Sammons Preston).

4.3. Testing Procedure

Prior to tests, a brief description of the objectives and requirements of the study was communicated to each subject. Since the study is aimed for elderly people, many senior centers that are located around İstanbul, were visited. The tests were conducted under the supervision of an authority assigned by the administration of senior centers. The subjects who had serious health problems such as Alzheimer, arm pain and musculoskeletal disorders were excluded from the experiments. The ones that did not have any bodily defects were accepted to take part 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 the study. For the illiterate subjects, consent form was read in control of senior centers’ management. Only the subjects who confirmed the procedure, were selected for the study. In the personal consent form, it was also reported that all information obtained during the study would be held in strict confidence. The “Personal Consent Form” was prepared both in English and Turkish (Appendix A). However, Turkish version was used for all subjects.

In the last step before starting the tests, “Personal Data Form” (Appendix A) was filled out on behalf of the subjects by the investigator for the purposes of not to tire elderly subjects out. The form has the questions including birthdate, birthplace, occupation, dominant hand, family origin, and mother and father’s birthplace. If the birthplace of a participant’s mother and father differ from each other, the city of the father’s was taken into consideration.

4.3.1. Anthropometric measurements

The following anthropometric measurements were taken.

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

Body height was measured while the subject stood fully erect with heels together with shoes-off and head oriented in the Frankfurt plane (ISO 7250).

Weight was measured by a mechanical scale. 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.

A flexible tape was used to measure circumferences of wrists and forearms of the subjects. Circumference of forearm was measured while the elbow was flexed at 90 degree and wrist in neutral posture. To be able to measure the widest part of forearm, the subject was asked to squeeze his/her fist moderately and then the measurement was performed by a tape measure. To measure circumferences of wrists, subjects hold their forearm horizontal with outstretched, fingers extended.

To measure length and breadth of hands of the participants a sliding caliper was used. For hand length, which is the distance from the crease of the wrist to the tip of the middle finger with the hand held straight and stiff; and subject held the forearm horizontal with hand stretched out flat, palm up. While measuring hand breadth; subject held his/her forearm horizontal with hand stretched out flat, palm up.

All anthropometric measurements were performed for the both dominant and non-dominant hand of the subjects. Almost all anthropometric measurements were measured according to ISO 7250-1, 2008: Basic human body measurements for technological design. All this anthropometric data was recorded in “Personal Data Form” by the investigator after appropriate measurements.

4.3.2. Grip Strength Measurement

4.3.2.1. Preparation for the test. Following the measurement of hand dimensions of the subjects, they were familiarized with the equipment and procedures for collecting maximum voluntary contraction (MVC) data. Before the actual tests, first the subjects moved and shook their hands and fingers to speed up their blood circulation, as a warm-up period. Participants were prepared mentally and physically to the test to be performed as much as possible. Most especially the subjects over the age of 80 were motivated more than the remaining subjects. The cooperation between particapants and the experimenter were improved in order to collect reliable data.

4.3.2.2. Determination of preferred grip span. The common population grip strength norms have been established, in general, by using the 2nd setting for females and the 3rd setting for males. However, some females had larger hands and some males had smaller hand.

Therefore "preferred span" is the better choice to obtain the actual strength capacity of population (Ekşioğlu, 2016). Hence, in this study, maximum voluntary grip strength measurements with Jamar Plus hand grip dynamometer were performed using the preferred span. The preferred grip spans of the subjects were determined according to the procedure described in Ekşioğlu (2016). This approach mainly involves a trial-and error approach with different span settings. Then, the subject decides on his /her preferred span.

Consequently, in this study, 85% (107 of 126) of men and 5% (6 of 125) of women preferred the 3rd setting while %15 of men and 95% of women preferred the 2rd setting which is a narrower span.

4.3.2.3. Grip Strength Measurement. After setting the dynamometer to the preferred span, each subject's MVC was collected according to Caldwell Protocol (1974).

The grip strength tests were performed in neutral sitting posture for both dominant and non-dominant hands. Maximal grip strengths were recorded while the dynamometer was supported by the experimenter. Subjects were seated comfortably on a chair without armrests, shoulder in neutral posture, elbow flexed at 90° and wrist in neutral posture following the standards of American Society of Hand Therapists (Fess & Moran, 1981; Fess, 1992). In this posture, the test was done for both dominant and non-dominant hand. The experimenter supported the dynamometer from top and bottom of it, to minimize the weight effect of the dynamometer on the strength value. The tests were performed in that posture at least twice for each hand. Measurement of grip strength is shown in Figure 4.6.

According to Caldwell Protocol, after ensuring that the subject was "ready" for the test, the experimenter instructed each subject in the same tone of voice, 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 for both dominant and non-dominant hand. Whenever the strength variation was more than 10 per cent between two trials, the subject was asked to repeat the test once more. Therefore, the maximum of the two trials, within 10 per cent of each other, was recorded on the "Data Collection Form" as the subject's MVC for that test combination. The data collection form also includes descriptive and anthropometric data of the subjects. This form can be seen in Appendix A. To eliminate fatigue effect on grip strength, the subjects were allowed to rest about two minutes between trials. The tests were performed sequentially with dominant and non-dominant hands by supporting the dynamometer. During the testing, the experimenter did not provide any feedback about the strength values to the subjects. Verbal encouragements, rewards, goal setting, competition and noises were also avoided.

Figure 4.6. Measurement of grip strength

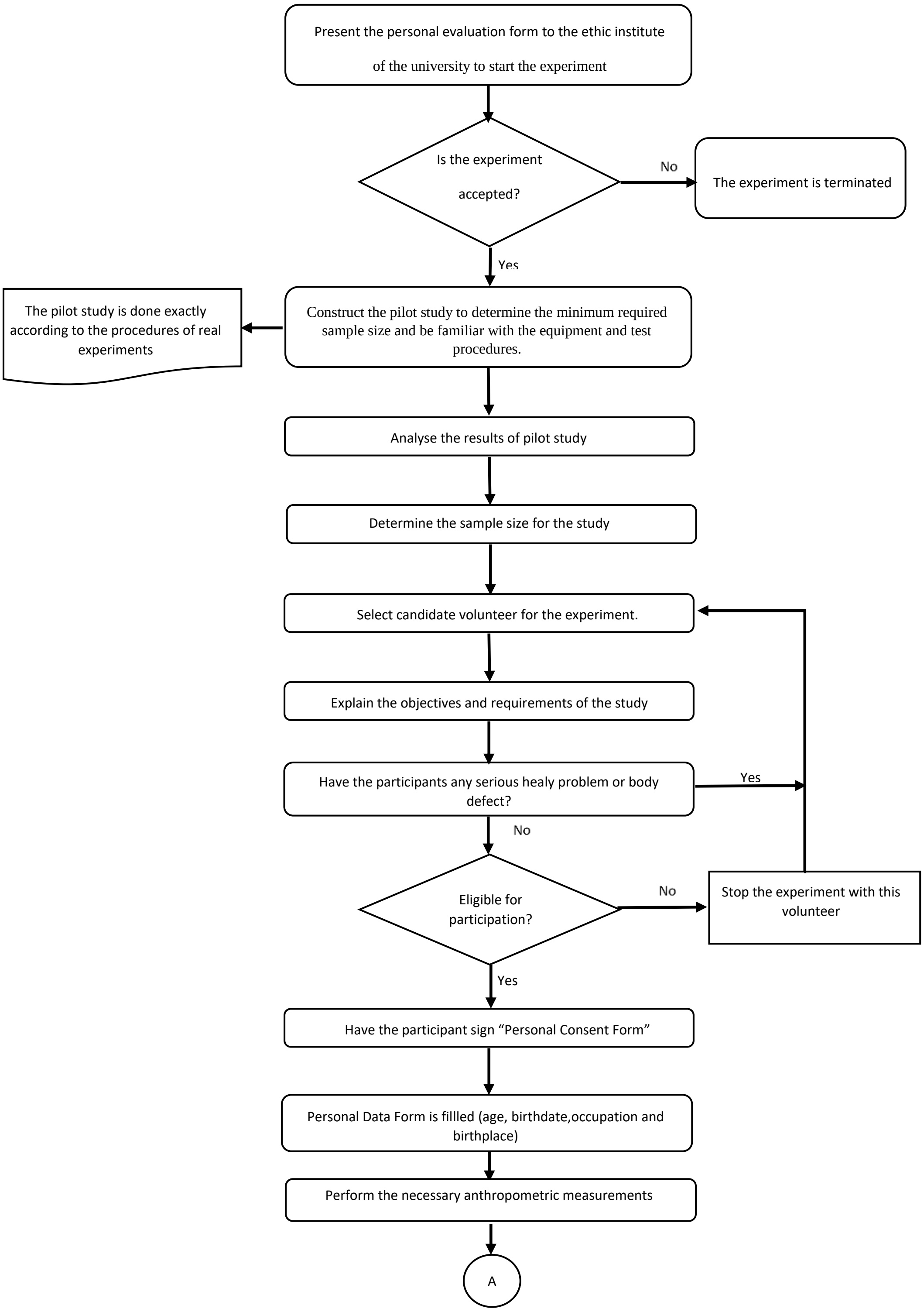

Figure 4.7. Flow chart of the experimental procedure.

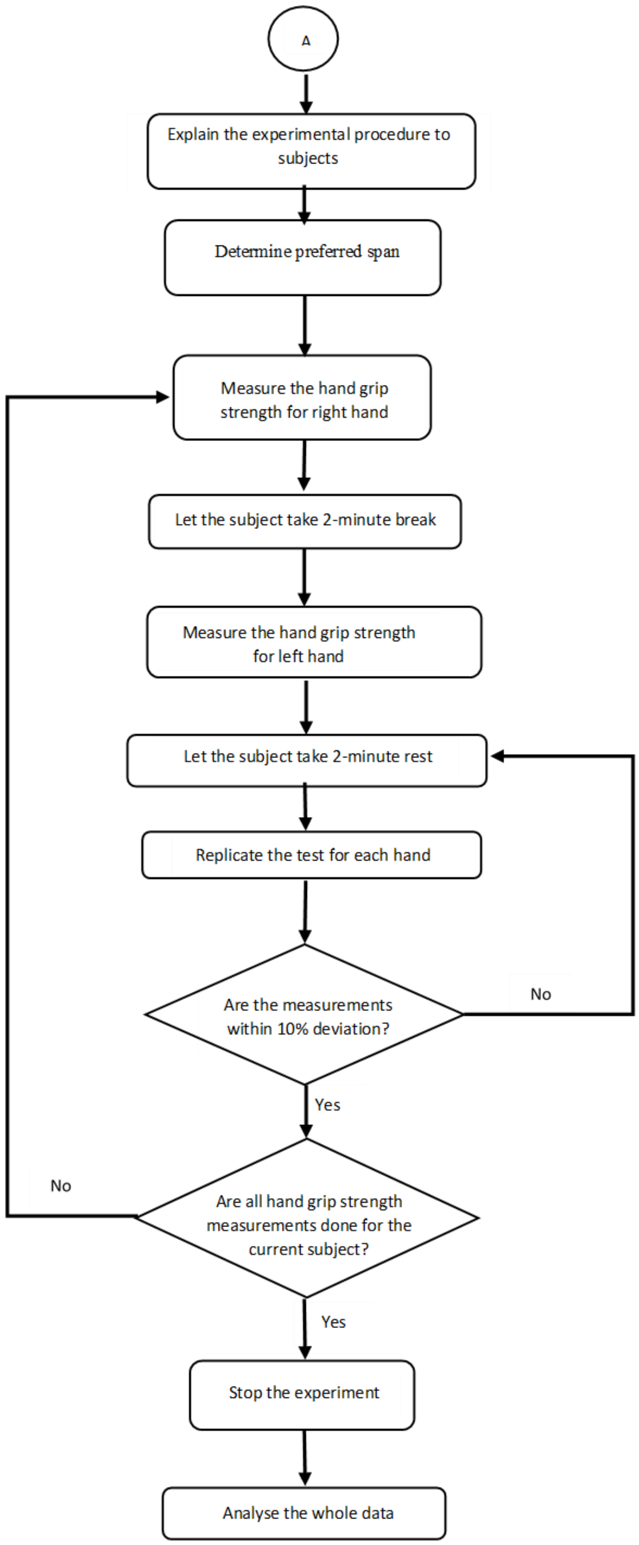

Figure 4.7. Flow chart of the experimental procedure (cont.).

4.4. Study Design

4.4.1. Classification Variables

One of the objectives of this study is to investigate the effects of independent variables on hand grip strength for elderly people. Maximum voluntary hand grip strength is the response variable (dependent variable) of the design which is dependent on the independent variables (design factors) such as age group, occupation group and BMI group for the study. Classification factors and levels of that factors for both males and females can be seen in Table 4.10.

Table 4.10. Classification factors and their levels

Classification Factors	Number of Levels	Levels
Occupation Group	2	(1) Manual Worker (2) Non-Manual Worker
BMI Group	3	(1) Underweight (2) Normal (3) Overweight
Age Group	4	(1) 70-74 yrs (2) 75-79 yrs (3) 80-84 yrs (4) 85 + yrs

4.4.2. Experimental Conditions

In that study, dominant hand's maximum voluntary grip strength is the response variable. However, dominant and non-dominant hand responses were also compared. For this reason, each subject performed grip strength test for both dominant and non-dominant hand, also each test was performed at least two times. Therefore, the number of recorded hand grip strength data points (test runs) was at least (126 + 125) * 2 * 2 = 1004 (Table 4.11). But, since the dominant hand's maximum grip strength value is considered as a response variable in the analysis, the number of strength data for the statistical analysis is 126 and 125 for males and females respectively. The orders and response data for each condition were recorded in "Experimental Form" that can be seen in Appendix B.

Table 4.11. Experimental Conditions

Subject	**Sitting**			
	Supported			
	Right		**Left**	
	Trials		**Trials**	
	1	**2**	**1**	**2**
1	1	2	3	4
2	5	6	7	8
3	9	10	11	12
. . .	. . .	. . .	. . .	. . .
250	997	998	999	1000
251	1001	1002	1003	1004

4.4.3. Statistical Model

Completely Randomized Design (CRD) has been applied in this study since there are only classification factors. To investigate the effects of factors (age group, occupation group and BMI group) on grip strength, analysis of variance (ANOVA) was conducted.

Each participant performed the tests in a predetermined random sequence of the hands. The minimum number of tests that were performed by each subject is 2 hands* 2 trials = 4.

4.5. Statistical Analysis

Minitab version 18.1. was used for performing statistical analysis. P-values $0.05 \leq p \leq 0.1$ were accepted as marginal and p-values ≤ 0.05 were accepted as significant.

4.5.1. Descriptive Statistics

After all measurements were taken, descriptive statistics such as mean, standard deviation, range and percentiles (5th, 50th and 95th) of grip strength were calculated for Age-Group, Job-Group and BMI-Group.

4.5.2. Inferential Statistics

Inferential statistics used in this study are as following:

4.5.2.1. Correlation analysis. In order to investigate the strength of linear relationship between variables and hand grip strength, Pearson's correlation coefficient was used for both genders. Moreover, it was calculated to understand relationship between hand breadth, hand length, wrist and forearm circumferences, height and weight.

4.5.2.2. Analysis of Variance and t-tests. Analysis of variance (ANOVA) was utilized for investigating the effects of age-group, occupation-group and BMI-group on dominant hand grip strength. Gender effect and hand effect were investigated by t-test. Following three assumptions were checked before using ANOVA:

- Normality assumption: The error terms (residuals) of the model must distribute normally, zero being the center of the distribution (~ NID (0, σ^2)) (Montgomery, 2012).
- Independence assumption: Error terms must be uncorrelated (correlation of each value and the value before it) and correlation between error terms and independent variables (autocorrelation between residuals) (Montgomery, 2012).
- Homogeneity of variance assumption: The variances of response variables for each treatment must not be different from each other (Montgomery, 2012).

Anderson-Darling normality test and normal probability plot of residuals were used to verify the assumption that the residuals are normally distributed. The plot should look like a sample from a normal distribution centered at zero. If the p-value for the Anderson Darling test is lower than significance level (0.05), it is concluded that the data do not follow the normal distribution. According to plot of residuals and Anderson-Darling test, for both males and female the residuals follow normal distribution (Montgomery, 2005).

$$\begin{aligned} &H_0 : \text{The data follow normal distribution} \\ &H_1 : \text{The data do not follow normal distribution} \end{aligned} \qquad (4.6)$$

The residuals versus order plot was used to verify the assumption that the residuals are uncorrelated with each other. Pearson's correlation coefficients between residuals and independent variables were calculated, in order to check autocorrelations and results showed that they were independent from each other. Variance inflation factor (VIF) was also used for the purpose.

$$H_0 : \text{Group variances are equal} \qquad (4.7)$$
$$H_1 : \text{Group variances are not equal}$$

The residual plots were utilized to verify the assumption that the residuals have a constant variance. If the model is correct and if the assumptions are satisfied, the residuals should be structureless; particularly, they should be unrelated to any variable including the predicted response (Montgomery, 2005). Bartlett's test was also used to verify the result. Bartlett's test of the hypotheses:

$$H_{0:}\ \sigma_1^2 = \sigma_2^2 \ldots \sigma_n^2 \qquad (4.8)$$
$$H_{1:}\ \sigma_i^2 \neq \sigma_j^2\ for\ at\ least\ one\ pair\ (i, j)$$

where i and j stand for each treatment of grip strength for this study. H_0 hypothesis states the equality of variances of grip strength.

Three assumptions of parametric ANOVA were satisfied; therefore, it was suitable to investigate the independent variable effect on grip strength response by parametric ANOVA. The intent was testing the equality of the means of response variables at the combination of 4 age groups, 2 job groups and 2 BMI groups. In total there were 2x2x4 = 16 combinations.

The hypothesis in ANOVA state that the means of the groups are equal as given in Equation 4.6 (Montgomery, 2005):

$$H_0 = \mu_1 = \mu_2 = \ldots\ldots = \mu_{16} \qquad (4.9)$$
$$H_1 = \text{At least one } \mu \text{ is dif.}$$

The mathematical model which describes the relationship between response and treatment for ANOVA was given as following. Since there was no significant interaction effect, the interaction effects were excluded from the model (Montgomery, 2005):

$$y_{ijk} = \mu + a_i + b_j + c_k + \varepsilon_{ijk} \tag{4.10}$$

where,

y_{ijk} : ijk^{th} response (maximum grip strength)

μ : The overall mean

a_i : Effect of i^{th} level of age group factor (i= 1,2,3,4)

b_j : Effect of j^{th} level of body mass index (BMI) group factor (j= 1,2 underweight group was excluded since there was only one subject in this group)

c_k : Effect of k^{th} level of occupation group factor (k= 1,2)

ε_{ijk} : Random error component NID (0, σ^2)

<u>4.5.2.3. Post-hoc Analysis</u>. After ANOVA, a multiple comparison test was performed. Tukey’s test was used for post-hoc analysis. Because, while making pairwise comparisons, it is easy to compute, and reduce the probability of making a Type I error. It is also robust with respect to unequal group sample sizes (McHugh, 2011). Moreover, because of computational simplicity and its statistical features, Tukey’s test is recommended (Jaccard et. al, 1984). The hypothesis of this test is as the following (Montgomery, 2005):

$$H_0: \mu_i = \mu_j$$
$$H_1: \mu_i \neq \mu_j \text{ (for at least one pair)} \tag{4.11}$$

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

<u>4.5.2.4. T-test</u>. Two sample t-test was used to determine the gender effect on the grip strength. Additionally, it was utilized to compare the results of the current study with the results of the studies performed previously.

$$t_0 = \frac{\bar{y}_1 - \bar{y}_2}{\sqrt{{S^2}_1/\mathrm{n}_1 + {S^2}_2/\mathrm{n}_2}} \tag{4.12}$$

Where; y_1 and y_2 are means, $S^2{}_1$ and $S^2{}_2$ are sample variances, n_1 and n_2 are sample sizes of two samples.

4.5.2.5. Paired t-test. For comparison of hand, which have two factor levels with balanced data, paired t-test was used. It can be more powerful than a two samples t-test. Since, the paired observations are dependent, a paired t-test does not depend on the additional variation that arises from the independence of the observations. Furthermore, it does not require equal variance for both samples. Hence, in order to analyse the differences between two treatments given to the same subject, a paired t-test is useful to have more statistical power (Minitab Inc., 2018). The hypotheses of paired t-test are (Montgomery, 2005):

$$\begin{aligned} H_0&: \mu_d = 0 \\ H_1&: \mu_d \neq 0 \end{aligned} \tag{4.13}$$

Where; μ_d is the difference of the mean between two groups.

4.5.2.6. Regression Analysis. In order to develop prediction equations for grip strength responses of both male and female regression analysis was conducted.

The relationship between independent variables and dominant hand grip strength response was a point of interest in the study. After checking the assumptions, multiple linear regression approach was used for the purpose. The general form of the multiple linear regression equation, without interaction effect was found appropriate. The general form of the multiple linear regression equation is as follows (Montgomery, 2005):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \varepsilon \tag{4.14}$$

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

To determine whether the model is adequate, the assumptions of multiple linear regression were checked to obtain reliable models. The assumptions are (Minitab Inc., 2018);

- There should be a linear relationship between the dependent and independent variables. It can be checked by utilizing fitted line plots (Stevens, 2009).
- The residuals of the independent variables should be normally distributed. This assumption can be checked by looking at the normal probability plots of residuals.
- Multicollinearity means that predictor variables in the model are correlated with other predictor variables. It may increase the variance of the regression coefficients. Therefore, to examine the variance inflation factor (VIF) is the way of measuring multicollinearity. VIF is desired to be smaller than 10 (Keith, 2006).
- The variances must be equal within groups. In order to check homogeneity of variances, Bartlett's test and residual analysis can be used.
- Autocorrelation means that the errors of observations are correlated with each other. It may cause the underestimation of the coefficients and standard error for the regression. Durbin-Watson statistic is used to verify this assumption. It determines whether or not the correlation between error terms is zero.

After regression models were determined, a test for significance of regression was performed to check the consistency of model (Montgomery, 2005). The model utility test is performed for checking the significance of the model. The hypothesis of this test is:

$$H_0: \beta_1 = \beta_2 = \cdots = \beta_n = 0$$
$$H_1: \beta_j \neq 0 \; for \; at \; least \; one \; j \; (j = 1, \ldots, n) \tag{4.15}$$

If H_0 hypothesis above is rejected, 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).

Furthermore, R^2 and R_{adj}^2 statistics were investigated to see the goodness of fit of the regression model. R^2 is the square of the correlation between the actual and the predicted values of the dependent variable. R_{adj}^2 is used incorporates the model's degrees of freedom and could be interpreted as the proportion of total variance that is explained by the model. R_{adj}^2 statistic only increase as predictors are added if the increase in model fit is improved. (Grace Martin, 2012).

Stepwise and Best subsets approaches were adopted during the statistical analysis. The Best subsets approach was used to check the obtained models, it gives many different alternative sub models with Mallow's C_p statistics to compare them (Montgomery, 2012).

5. RESULTS

5.1. Overview

In this part of the study, the collected data from total (126 Male + 125 Female) 251 subjects were analysed. Descriptive statistics of test results, correlation analysis, analysis of variance results with multiple comparisons, and regression analysis can be found in this section.

5.2. Descriptive Statistics

5.2.1. Mean, Standard Deviation and Range of Variables

Descriptive statistics of demographic profile and anthropometric characteristics of the subjects are shown in Table 5.1. The means, standard deviations, minimum and maximum values of age, body-mass, height, BMI, hand length, hand breadth, wrist circumference and forearm circumference of dominant and non-dominant data for both genders are shown.

Table 5.1. Anthropometric dimensions of the subjects

Measurement Type	Male (n = 126)		Female (n = 125)	
	Mean ± SD	**Min-Max**	**Mean ± SD**	**Min-Max**
Age (yr)	79.4 ± 6.1	70.0 – 95.0	80.0 ± 7.1	70.0 – 98.0
Body-Mass (kg)	74.1 ± 12.4	49.6 – 110.0	70.0 ± 15.1	35.4 – 110.0
Height (cm)	166.1 ± 8.1	145.0 – 189.0	151.5 ± 7.5	133.0 – 171.0
BMI (kg/m²)	26.8 ± 4.1	18.9 – 40.0	30.5 ± 6.3	18.1 – 50.1
Right Hand				
Hand Length (cm)	18.0 ± 0.9	15.2 – 19.6	16.6 ± 0.8	14.7– 18.5
Hand Breadth (cm)	8.4 ± 0.4	7.1 – 9.4	7.6 ± 0.4	6.3 – 8.5
Wrist Circumference (cm)	18.6 ± 1.2	15.3 – 21.0	17.1 ± 1.3	13.6 – 22.5
Forearm circumference (cm)	26.1 ± 2.6	19.0 – 31.3	24.3 ± 2.6	17.1 – 32
Left Hand				
Hand Length (cm)	18.0 ± 0.9	15.2 – 19.8	16.6 ± 0.8	14.8 – 18.5
Hand Breadth (cm)	8.4 ± 0.4	7.1 – 9.5	7.5 ± 0.4	6.4 – 8.5
Wrist Circumference (cm)	18.5 ± 1.2	15.2 – 21.0	17.1 ± 1.4	13.6 – 23.5
Forearm circumference (cm)	26.1 ± 2.6	19.0 – 31.5	24.2 ± 2.6	17.1 – 32.0

The means, standard deviations, minimum and maximum values of grip strength for both dominant and non-dominant hand stratified by age-group, job-group and BMI-group were calculated for each gender.

Table 5.2, Table 5.3 and Table 5.4 show presents descriptive statistics (mean, standard deviation (SD) and range (min - max)) of the maximum voluntary grip strength (in N) by age, gender and occupation also by age, gender and BMI group, respectively for both dominant hand and non-dominant hand.

In BMI group, underweight people were excluded in calculations since there was only one underweight subject.

By examing the tables, we can make the following observations prior to statistical significance tests.

According the results of Table 5.1, the mean of dominant hand grip strength response are higher than non-dominant for both genders. And male subjects were found stronger than female subjects for each hand and each age group. It can be seen from Table 5.1, that the maximum grip strength value is highest for 70-74 year age group for both genders and significantly decreases for older groups. For both genders and each hand 85+ age group is the weakest.

Table 5.2 indicated that manual workers are stronger than non-manual workers for females, in contrast to non-manual workers are stronger for males. The measurements given in Table 5.3 show that overweight people are significantly stronger than than normal weight people for each hand and both genders.

Box plots of dominant hand grip strength of both genders stratified by age group are shown in Figure 5.1.

Table 5.2. Descriptive statistics of dominant hand and non-dominant hand grip strength (N) by age and gender

Groups		N	Dominant		Non-Dominant	
			Mean ± SD	Min-Max	Mean ± SD	Min-Max
All		251	236.5 ± 86.0	66.7 – 473.7	215.1 ± 83.9	67.7 – 459.0
Male	Male	126	289.3 ± 78.4	116.7– 473.7	266.6 ± 78.1	92.2 – 459.0
	70-74	33	329.9 ± 79.7	154.0– 473.7	305.1 ± 74.4	139.3– 459.0
	75-79	32	320.7 ± 71.5	142.2– 439.3	296.4 ± 71.4	136.3– 425.6
	80-84	28	276.4 ± 64.7	176.5– 408.9	256.2 ± 64.6	142.2– 359.9
	85-95	33	229.4 ± 51.5	116.7– 343.2	207.9 ± 61.5	92.2 – 324.6
Female	Female	125	183.3 ± 55.0	66.7 – 342.3	163.2 ± 51.5	67.7 – 324.6
	70-74	31	214.1 ± 58.1	112.8– 326.6	191.0 ± 52.0	106.9– 292.2
	75-79	27	211.5 ± 47.8	124.5– 342.3	187.9 ± 44.4	98.1 – 324.6
	80-84	31	176.7 ± 41.3	98.1 – 287.3	154.2 ± 42.4	85.3 – 261.8
	85-98	36	141.2 ± 36.7	66.7 – 223.6	128.7 ± 40.1	67.7 – 215.7

Table 5.3. Descriptive statistics of dominant hand and non-dominant hand grip strength (N) by age, occupation and gender

Groups		N	Dominant		Non-Dominant	
			Mean ± SD	Min-Max	Mean ± SD	Min-Max
All		251	236.5 ± 86.0	66.7 - 473.7	215.1 ± 83.9	67.7 - 459.0
Male	Manual	64	286.8 ± 75.1	126.5- 427.6	267.8 ± 74.7	130.4- 443.3
	70-74	16	334.8 ± 67.7	173.6- 412.9	310.6 ± 69.6	159.8- 443.3
	75-79	14	315.2 ± 76.4	142.2- 427.6	292.5 ± 78.8	136.3- 395.2
	80-84	16	278.3 ± 60.5	214.8- 370.7	260.3 ± 55.6	158.9- 359.9
	85-95	18	229.5 ± 52.8	126.5- 333.4	217.1 ± 62.8	130.4- 324.6
	Non-Manual	62	292.0 ± 82.2	116.7- 473.7	265.3 ± 82.1	92.2 - 459.0
	70-74	17	325.2 ± 91.5	154.0- 473.7	300.0 ± 80.5	139.3- 459.0
	75-79	18	325.0 ± 69.3	190.2- 439.3	299.5 ± 67.3	154.9- 425.6
	80-84	12	273.9 ± 72.6	176.5- 408.9	250.6 ± 77.2	142.2- 352.1
	85-95	15	229.2 ± 51.7	116.7- 343.2	196.8 ± 60.1	92.2 - 301.1
Female	Manual	66	185.8 ± 57.6	78.5 - 342.3	163.0 ± 55.5	76.5 - 324.6
	70-74	14	217.2 ± 61.6	127.5- 326.6	183.1 ± 54.1	106.9- 280.5
	75-79	15	214.1 ± 53.5	124.5- 342.3	195.9 ± 54.4	98.1 - 324.6
	80-84	14	190.9 ± 45.6	142.2- 287.3	159.7 ± 49.7	90.2 - 261.8
	85-98	23	145.1 ± 39.7	78.5 - 223.6	131.4 ± 44.6	76.5 - 215.7
	Non-Manual	59	180.5 ± 52.3	66.7 - 308.9	163.5 ± 47.0	67.7 - 292.2
	70-74	17	211.5 ± 56.8	112.8- 308.9	197.5 ± 50.9	113.8- 292.2
	75-79	12	208.3 ± 41.7	139.3- 278.5	177.8 ± 26.3	145.1- 218.7
	80-84	17	165.1 ± 34.5	98.1 - 236.3	149.6 ± 36.2	85.3 - 208.9
	85-98	13	134.4 ± 30.9	66.7 - 189.3	123.8 ± 31.8	67.7 - 182.4

Table 5.4. Descriptive statistics of dominant hand and non-dominant hand grip strength (N) by age, BMI group and gender

Groups		N	Dominant		Non-Dominant	
			Mean ± SD	Min-Max	Mean ± SD	Min-Max
All		251	236.5 ± 86.0	66.7– 473.7	215.1 ± 83.9	67.7– 459.0
Male	**Normal**	43	273.7 ± 75.1	116.7- 428.6	246.6 ± 74.2	120.6- 425.6
	70-74	8	325.5 ± 75.7	173.6- 401.1	297 ± 64.2	159.8- 354.0
	75-79	14	305.0 ± 69.6	190.2- 428.6	273.2 ± 76.4	146.1- 425.6
	80-84	12	251.7 ± 41.8	178.5- 319.7	228.2 ± 60.4	158.9- 337.3
	85-95	9	208.3 ± 66.6	116.7- 333.4	184.9 ± 47.1	120.6- 251.1
	Overweight	83	297.4 ± 79.3	142.2- 473.7	276.9 ± 78.5	92.2 - 459.0
	70-74	25	331.3 ± 82.4	154.0- 473.7	307.7 ± 78.5	139.3- 459.0
	75-79	18	332.9 ± 72.5	142.2- 439.3	314.5 ± 63.6	136.3- 408.9
	80-84	16	295.0 ± 73.5	176.5- 408.9	277.1 ± 61.1	142.2- 359.9
	85-95	24	237.2 ± 43.6	179.5- 343.2	216.5 ± 64.8	92.2 - 324.6
Female	**Normal**	22	172.4 ± 57.7	78.5 - 292.2	151.6 ± 56.9	67.7 - 267.7
	70-74	5	226.7 ± 76.5	112.8- 292.2	206.9 ± 59.6	134.4- 267.7
	75-79	2	188.8 ± 43.7	157.9- 219.7	172.6 ± 29.1	152.0- 193.2
	80-84	4	184.9 ± 39.3	152.0- 230.5	172.6 ± 42.9	110.8- 208.9
	85-98	11	140.1 ± 35.6	78.5 - 210.8	115.1 ± 38.4	67.7 - 205.9
	Overweight	102	185.9 ± 54.6	66.7 - 342.3	165.9 ± 50.4	70.6 - 324.6
	70-74	26	211.7 ± 55.4	127.5- 326.6	187.9 ± 51.2	106.9- 292.2
	75-79	25	213.4 ± 48.5	124.5- 342.3	189.1 ± 45.6	98.1 - 324.6
	80-84	26	176.0 ± 42.9	98.1 - 287.3	151.8 ± 43.2	85.3 - 261.8
	85-98	25	141.7 ± 37.9	66.7 - 223.6	134.6 ± 40.1	70.6 - 215.7

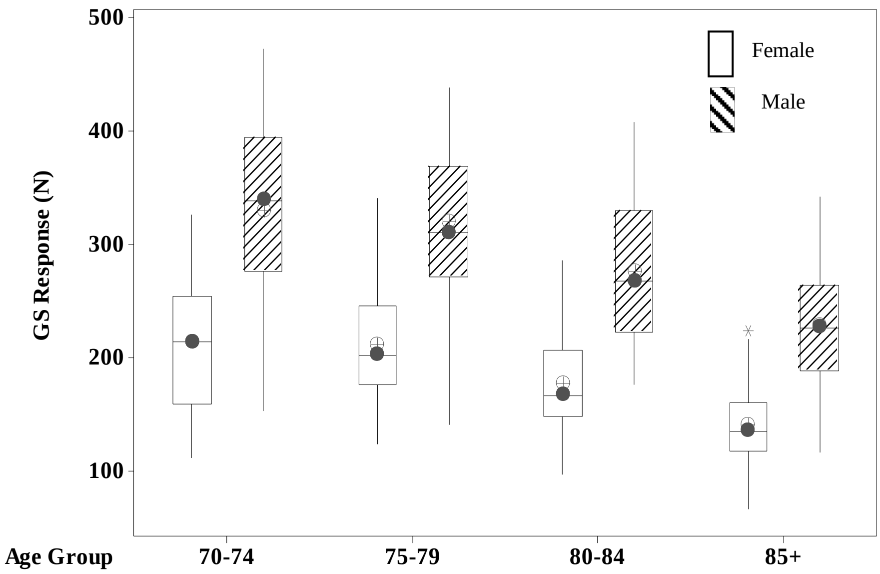

Figure 5.1. Box plots of dominant hand grip strength of both genders stratified by age group

5.2.2. Percentile Values

The percentiles of the hand grip strength values were calculated for each group. Equation 5.1 shows calculation of the value of a percentile (Montgomery, 2003);

$$\textit{The value of } p^{th} \textit{ percentile} = \bar{x} + (Z_p \times SD) \qquad (5.1)$$

As an example, the calculation of percentile value for the case of dominant hand grip strength response of male with $\bar{x}$ = 289.3 and SD = 78.4, is presented below:

$$\textit{the value of } 95^{th} \textit{ percentile} = 289.3 + (Z_{0.95} \times 78.4)$$
$$= 289.3 + (1.645 \times 78.4)$$
$$= 418.3 \text{ N}$$

which means that 95 % of dominant hand grip strength of males is below 418.3 N and only 5 % is above it.

5th, 50th, and 95th percentile values with standard deviation statistics for age group, job-group and BMI-group (in which underweight people were excluded since there were only 1 person in this group) were calculated as given in Table 5.5, Table 5.6 and Table 5.7.

Table 5.5. Hand grip strength percentiles for age groups in each gender

Groups		N	Dominant				Non-Dominant			
			5	50	95	SD	5	50	95	SD
All		251	95.1	236.5	378.0	86.0	77.0	215.1	353.2	83.9
Male	Male	126	160.3	289.3	418.3	78.4	138.0	266.6	395.1	78.1
	70-74	33	198.7	329.9	461.0	79.7	182.7	305.1	427.5	74.4
	75-79	32	203.1	320.7	438.3	71.5	179.0	296.4	413.9	71.4
	80-84	28	170.0	276.4	382.9	64.7	150.0	256.2	362.4	64.6
	85-95	33	144.7	229.4	314	51.5	106.8	207.9	309	61.5
Female	Female	125	92.9	183.3	273.7	55.0	78.6	163.2	247.9	51.5
	70-74	31	118.6	214.1	309.6	58.1	105.4	191.0	276.6	52.0
	75-79	27	132.9	211.5	290.2	47.8	114.9	187.9	260.8	44.4
	80-84	31	108.8	176.7	244.7	41.3	84.5	154.2	223.8	42.4
	85-98	36	80.9	141.2	201.6	36.7	62.7	128.7	194.7	40.1

Table 5.6. Hand grip strength percentiles stratified by occupation and age group for each gender

Groups		N	Dominant				Non-Dominant			
			5	50	95	SD	5	50	95	SD
All		251	95.1	236.5	378.0	86.0	77.0	215.1	353.2	83.9
Male	**Manual**	64	163.2	286.8	410.3	75.1	144.9	267.8	390.7	74.7
	70-74	16	223.5	334.8	446.2	67.7	196.1	310.6	425.1	69.6
	75-79	14	189.5	315.2	440.9	76.4	162.9	292.5	422.1	78.8
	80-84	16	178.7	278.3	377.9	60.5	168.8	260.3	351.8	55.6
	85-95	18	142.7	229.5	316.3	52.8	113.9	217.1	320.3	62.8
	Non-Manual	62	156.7	292.0	427.2	82.2	130.3	265.3	400.4	82.1
	70-74	17	174.7	325.2	475.7	91.5	167.6	300.0	432.4	80.5
	75-79	18	210.9	325.0	439.1	69.3	188.8	299.5	410.1	67.3
	80-84	12	154.5	273.9	393.3	72.6	123.7	250.6	377.6	77.2
	85-95	15	144.2	229.2	314.2	51.7	98.0	196.8	295.6	60.1
Female	**Manual**	66	91.1	185.8	280.5	57.6	71.7	163.0	254.3	55.5
	70-74	14	116.0	217.2	318.5	61.6	94.1	183.1	272.2	54.1
	75-79	15	126.1	214.1	302.2	53.5	106.4	195.9	285.3	54.4
	80-84	14	115.9	190.9	265.9	45.6	78.0	159.7	241.4	49.7
	85-98	23	79.8	145.1	210.5	39.7	58.1	131.4	204.7	44.6
	Non-Manual	59	94.5	180.5	266.5	52.3	86.1	163.5	240.8	47.0
	70-74	17	118.1	211.5	305.0	56.8	113.7	197.5	281.3	50.9
	75-79	12	139.8	208.3	276.9	41.7	134.5	177.8	221.1	26.3
	80-84	17	108.4	165.1	221.8	34.5	90.0	149.6	209.1	36.2
	85-98	13	83.6	134.4	185.1	30.9	71.5	123.8	176.1	31.8

Table 5.7. Hand grip strength percentiles stratified by BMI and age group in each gender

Groups		N	Dominant				NonDominant			
			5	50	95	SD	5	50	95	SD
All		251	95.1	236.5	378	86	77	215.1	353.2	83.9
Male	Normal	43	150.1	273.7	397.3	75.1	124.6	246.6	368.6	74.2
	70-74	8	200.9	325.5	450	75.7	191.4	297	402.6	64.2
	75-79	14	190.5	305	419.4	69.6	147.6	273.2	398.8	76.4
	80-84	12	183	251.7	320.4	41.8	128.8	228.2	327.7	60.4
	85+	9	98.7	208.3	317.9	66.6	107.4	184.9	262.4	47.1
	Overweight	83	167	297.4	427.9	79.3	147.7	276.9	406.1	78.5
	70-74	25	195.7	331.3	466.9	82.4	178.6	307.7	436.8	78.5
	75-79	18	213.7	332.9	452.2	72.5	209.9	314.5	419.1	63.6
	80-84	16	174.1	295	415.9	73.5	176.6	277.1	377.6	61.1
	85+	24	165.5	237.2	309	43.6	109.9	216.5	323.1	64.8
Female	Normal	22	77.4	172.4	267.3	57.7	58.1	151.6	245.2	56.9
	70-74	5	101	226.7	352.5	76.5	108.9	206.9	304.9	59.6
	75-79	2	116.9	188.8	260.6	43.7	124.7	172.6	220.5	29.1
	80-84	4	120.1	184.9	249.6	39.3	102	172.6	243.2	42.9
	85+	11	81.5	140.1	198.7	35.6	51.9	115.1	178.2	38.4
	Overweight	102	96	185.9	275.7	54.6	83.1	165.9	248.8	50.4
	70-74	26	120.5	211.7	302.8	55.4	103.8	187.9	272.1	51.2
	75-79	25	133.6	213.4	293.1	48.5	114.1	189.1	264	45.6
	80-84	26	105.4	176	246.6	42.9	80.8	151.8	222.9	43.2
	85+	25	79.4	141.7	204	37.9	68.6	134.6	200.7	40.1

5.2.3. Distribution of Anthropometric Measurements

Figure 5.2 shows distributions for some anthropometric measurements including body mass, stature, wrist circumference, sitting height, hand length and forearm circumference (cm). Some of them have skewed normal distributions.

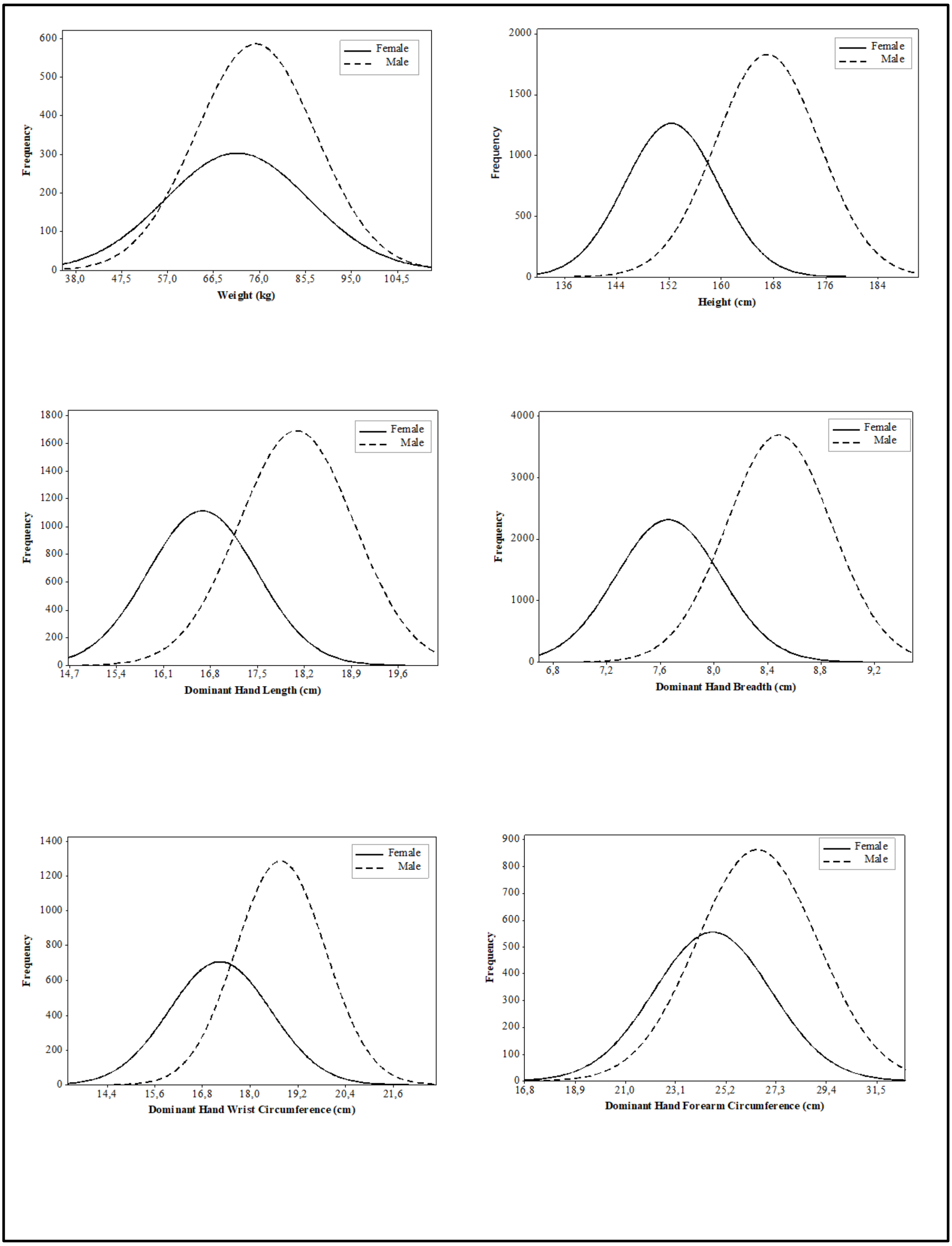

Figure 5.2. Distribution some of anthropometric data for males and females

5.3. Inferential Statistics

In this section, significance of difference between hands, genders and classification groups on strength response and linear correlations between anthropometric measurements were examined.

5.3.1. Correlation Analysis

Correlation analyses (Pearson) were performed to understand the strength of linear relationship between continuous independent variables and response (grip strength) variable for both gender seperately. Specifically, Pearson product moment correlation coefficients were calculated to examine the linear relationships between anthropometric measurements (height, body-mass, BMI, forearm, hand and wrist dimensions) and maximum grip strength response.

Table 5.8 and Table 5.9 depict Pearson correlations between dominant hand grip strength, age and dominant hand's anthropometric data with p-values for both genders.

Table 5.10 and Table 5.12 display Pearson product-moment correlation coefficients between dominant and non- dominant hand grip strengths with anthropometric measures of subject for males and females, respectively. Table 5.11 and Table 5.13 show Pearson correlations among anthropometric data.

With strong correlation coefficient value, age was found significantly and negatively correlated with grip strength response for both females and males.

There was significant and positive relationship between grip strength response with hand length and hand breadth for both genders.

While, height was found significantly correlated with grip strength response for both genders, weight was found significant for males only.

Table 5.8. Pearson correlations among dominant hand grip strength, age, height, weight and body mass index with p-values for both genders

		Grip Strength	Age	BMI	Weight
Age	**M**	-0.517 (p <0.001)			
	F	-0.591 (p <0.001)			
BMI	**M**	0.101 (p = 0.262)	-0.029 (p = 0.748)		
	F	0.09 (p = 0.32)	-0.206 (p = 0.021)		
Weight	**M**	0.347 (p <0.001)	-0.171 (p = 0.055)	0.814 (p <0.001)	
	F	0.25 (p = 0.005)	-0.437 (p <0.001)	0.888 (p <0.001)	
Height	**M**	0.433 (p <0.001)	-0.23 (p = 0.009)	-0.141 (p = 0.115)	0.455 (p <0.001)
	F	0.371 (p <0.001)	-0.541 (p <0.001)	-0.138 (p = 0.128)	0.322 (p <0.001)

Table 5.9. Pearson correlations among dominant hand grip strength value, hand length, hand breadth, wrist and forearm circumference with p-values for both genders

		Grip Strength	Hand Length	Hand Breadth	Wrist Circumference
Hand Length	**M**	0.479 (p <0.001)			
	F	0.368 (p <0.001)			
Hand Breadth	**M**	0.366 (p <0.001)	0.498 (p <0.001)		
	F	0.381 (p <0.001)	0.58 (p <0.001)		
Wrist Circumference	**M**	0.4 (p <0.001)	0.374 (p <0.001)	0.514 (p <0.001)	
	F	0.301 (p = 0.001)	0.449 (p <0.001)	0.456 (p <0.001)	
Forearm Circumference	**M**	0.469 (p <0.001)	0.286 (p = 0.001)	0.431 (p <0.001)	0.829 (p <0.001)
	F	0.36 (p <0.001)	0.318 (p <0.001)	0.27 (p = 0.002)	0.783 (p <0.001)

Table 5.10. Pearson Correlations between grip strengths and anthropometric data of Male

Correlations	**DGS (N)**	**NDGS (N)**
NDGS (N)	0.866 <0.001	
Age	-0.517 <0.001	-0.488 <0.001
BMI	0.101 0.262	0.135 0.131
Weight (kg)	0.347 <0.001	0.348 <0.001
Height (cm)	0.433 <0.001	0.394 <0.001
DHL (cm)	0.479 <0.001	0.394 <0.001
NDHL (cm)	0.416 <0.001	0.343 <0.001
DHB (cm)	0.366 <0.001	0.34 <0.001
NDHB (cm)	0.325 <0.001	0.353 <0.001
DHWC (cm)	0.4 <0.001	0.474 <0.001
NDHWC (cm)	0.363 <0.001	0.45 <0.001
DHFC (cm)	0.469 <0.001	0.488 <0.001
NDHFC (cm)	0.423 <0.001	0.46 <0.001

Almost all measurements significantly correlated with both dominant and non-dominant grip strength response.

There exists high positive correlation between dominant hand grip strength with non-dominant hand grip strength response for both genders.

Weight and Height were found also significantly correlated with all anthropometric measurements for female and males.

Table 5.11. Pearson Correlations between anthropometric data of Male

Correlations	**BMI**	**Age**	**Weight (kg)**	**Height (cm)**	**DHL (cm)**	**NDHL (cm)**	**DHB (cm)**	**NDHB (cm)**	**DHWC (cm)**	**NDHWC (cm)**	**DHFC (cm)**
Age	-0.029 0.748										
Weight (kg)	0.814 <0.001	-0.171 0.055									
Height (cm)	-0.141 0.115	-0.23 0.009	0.455 <0.001								
DHL (cm)	-0.083 0.358	-0.093 0.3	0.277 0.002	0.608 <0.001							
NDHL (cm)	-0.1 0.263	-0.083 0.356	0.255 0.004	0.595 <0.001	0.946 <0.001						
DHB (cm)	0.14 0.117	-0.153 0.088	0.365 <0.001	0.412 <0.001	0.498 <0.001	0.504 <0.001					
NDHB (cm)	0.159 0.076	-0.173 0.053	0.367 <0.001	0.39 <0.001	0.48 <0.001	0.501 <0.001	0.911 <0.001				
DHWC (cm)	0.483 <0.001	-0.209 0.019	0.654 <0.001	0.383 <0.001	0.374 <0.001	0.352 <0.001	0.514 <0.001	0.475 <0.001			
NDHWC (cm)	0.508 <0.001	-0.23 0.009	0.673 <0.001	0.376 <0.001	0.365 <0.001	0.345 <0.001	0.483 <0.001	0.495 <0.001	0.94 <0.001		
DHFC (cm)	0.569 <0.001	-0.312 <0.001	0.735 <0.001	0.384 <0.001	0.286 0.001	0.242 0.006	0.431 <0.001	0.384 <0.001	0.829 <0.001	0.816 <0.001	
NDHFC (cm)	0.605 <0.001	-0.309 <0.001	0.747 <0.001	0.344 <0.001	0.256 0.004	0.233 0.009	0.411 <0.001	0.393 <0.001	0.795 <0.001	0.816 <0.001	0.971 <0.001

Table 5.12. Pearson Correlations between grip strengths and anthropometric data of female

Correlations	**DGS (N)**	**NDGS (N)**
NDGS (N)	0.858 <0.001	
Age	-0.591 <0.001	-0.549 <0.001
BMI	0.09 0.32	0.144 0.11
Weight (kg)	0.25 0.005	0.27 0.002
Height (cm)	0.371 <0.001	0.31 <0.001
DHL (cm)	0.368 <0.001	0.314 <0.001
NDHL (cm)	0.351 <0.001	0.31 <0.001
DHB (cm)	0.381 <0.001	0.38 <0.001
NDHB (cm)	0.348 <0.001	0.336 <0.001
DHWC (cm)	0.301 0.001	0.314 <0.001
NDHWC (cm)	0.298 0.001	0.295 0.001
DHFC (cm)	0.36 <0.001	0.331 <0.001
NDHFC (cm)	0.362 <0.001	0.323 <0.001

Table 5.13. Pearson Correlations between anthropometric data of female

Correlations	BMI	Age	Weight (kg)	Height (cm)	DHL (cm)	NDHL (cm)	DHB (cm)	NDHB (cm)	DHWC (cm)	NDHWC (cm)	DHFC (cm)
Age	-0.206 0.021										
Weight (kg)	0.888 <0.001	-0.437 <0.001									
Height (cm)	-0.138 0.128	-0.541 <0.001	0.322 <0.001								
DHL (cm)	0.13 0.15	-0.359 <0.001	0.351 <0.001	0.477 <0.001							
NDHL (cm)	0.104 0.25	-0.341 <0.001	0.328 <0.001	0.481 <0.001	0.961 <0.001						
DHB (cm)	0.182 0.043	-0.218 0.015	0.357 <0.001	0.391 <0.001	0.58 <0.001	0.553 <0.001					
NDHB (cm)	0.148 0.101	-0.184 0.042	0.328 <0.001	0.398 <0.001	0.559 <0.001	0.56 <0.001	0.901 <0.001				
DHWC (cm)	0.38 <0.001	-0.4 <0.001	0.562 <0.001	0.405 <0.001	0.449 <0.001	0.399 <0.001	0.456 <0.001	0.398 <0.001			
NDHWC (cm)	0.38 <0.001	-0.371 <0.001	0.56 <0.001	0.392 <0.001	0.4 <0.001	0.353 <0.001	0.425 <0.001	0.359 <0.001	0.942 <0.001		
DHFC (cm)	0.442 <0.001	-0.449 <0.001	0.613 <0.001	0.385 <0.001	0.318 <0.001	0.299 0.001	0.27 0.002	0.205 0.023	0.783 <0.001	0.791 <0.001	
NDHFC (cm)	0.436 <0.001	-0.461 <0.001	0.602 <0.001	0.366 <0.001	0.304 0.001	0.292 0.001	0.276 0.002	0.219 0.015	0.772 <0.001	0.791 <0.001	0.975 <0.001

5.3.2. Paired T-Test Comparisons

For equal sample sizes with the same sample, paired t-tests were performed. Therefore, dominant hand and non-dominant hand grip strength have been tested by using paired t-test in order to check if mean differences of are significant.

$$H_0: \mu\_difference = 0$$
$$H_1: \mu\_difference \neq 0 \quad (5.2)$$

where = $\mu\_difference = \mu\_dominant\ hand - \mu\_nondominant\ hand$ is the difference of the mean between two groups (Minitab, 2018). Equations of paired t-test given in methods chapter were used for dominant and nondominant hand both male and female. This was shown in Table 5.14 and 5.15

Table 5.14. Paired t-test table for both hand and for both genders

Grip Strength Response (N)		**N**	**Mean**	**StDev**	**SE Mean**
Female	DGS Response (N)	124	183.46	55.17	4.95
	NGS Response (N)	124	163.41	51.64	4.64
Male	DGS Response (N)	126	289.34	78.42	6.99
	NGS Response (N)	126	266.56	78.13	6.96
All	DGS Response (N)	250	236.83	86.05	5.44
	NGS Response (N)	250	215.4	83.98	5.31

Table 5.14 indicates that the mean of dominant hand grip strength value is 289.34 N which is higher than non-dominant hand grip strength that is 266.56 N for male. Although the mean difference of female is less than difference of grip strength means of male, it had the same result.

Table 5.15. Paired t-test result table for hand and for both genders

Group	$\bar{x}_{diff}$	**StDev**$_{diff}$	**SE Mean**$_{diff}$	**95% CI for Mean *diff***	**T-Value**	**P-Value**	**Significance Status**
Female	20.06	28.63	2.57	(14.97; 25.15)	7.8	<0.001	Significant
Male	22.78	40.52	3.61	(15.64; 29.93)	6.31	<0.001	Significant
All	21.43	35.09	2.22	(17.06; 25.80)	9.66	<0.001	Significant

According to result table of paired t-test Table 5.15, since the p-values are lower than 0.05, for differences within hands for each gender are statistically significant and dominant hand is significantly higher than non-dominant hand for both genders. Figure 5.3 provides the boxplot of mean grip strength values for different hands for all subjects.

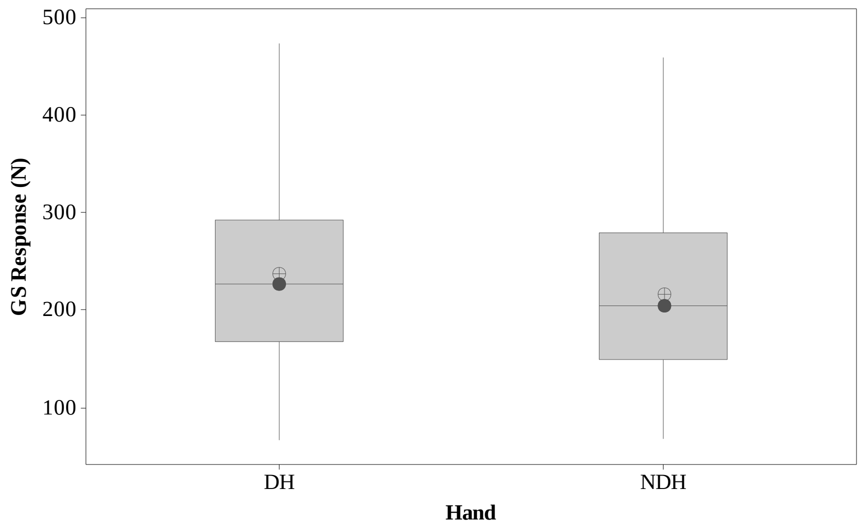

Figure 5.3. Box plots of grip strength for both hands for both genders combined.

5.3.3. Factor Effects: ANOVA and Post-hoc Analysis

In this study complete randomized design model were used for independent variables in order to determine the effects of age, occupation and BMI groups on hand grip strength for both male and female. ANOVA results are further investigated by post-hoc analysis using Tukey tests. All the ANOVA and Tukey's test were performed for dominant hand grip strength only, since both hands grips strength values are highly correlated.

Initially, assumptions of ANOVA (analysis of variance) were checked to ensure applicability of this method for male and female. Then the method is applied for checking if factors age-group, job group or BMI group affect grip strength response.

(i) *Normality Test:* To use ANOVA, residuals of grip strength values must fit to normal distribution. (Montgomery. 2005). This assumption was checked by making Anderson-Darling normality test (α 0.05) in Minitab 18.1. For the residuals of grip strength (N), the result of the test was a p-value of 0.891 for males and 0.143 for females. The null hypothesis, which states that data follows a normal distribution can be accepted, since p-value was greater than 0.05. Therefore, the residuals data for both males and females follow normal distribution.

Another procedure of determining normality is checking the distribution of residuals. In Figure 5.4 and Figure 5.5 normal probability plot of residuals were shown for males and females respectively. The residual plots almost resemble a linear pattern, and fit the normal probability line, which indicates that the distribution is a good model for the grip strength (N).

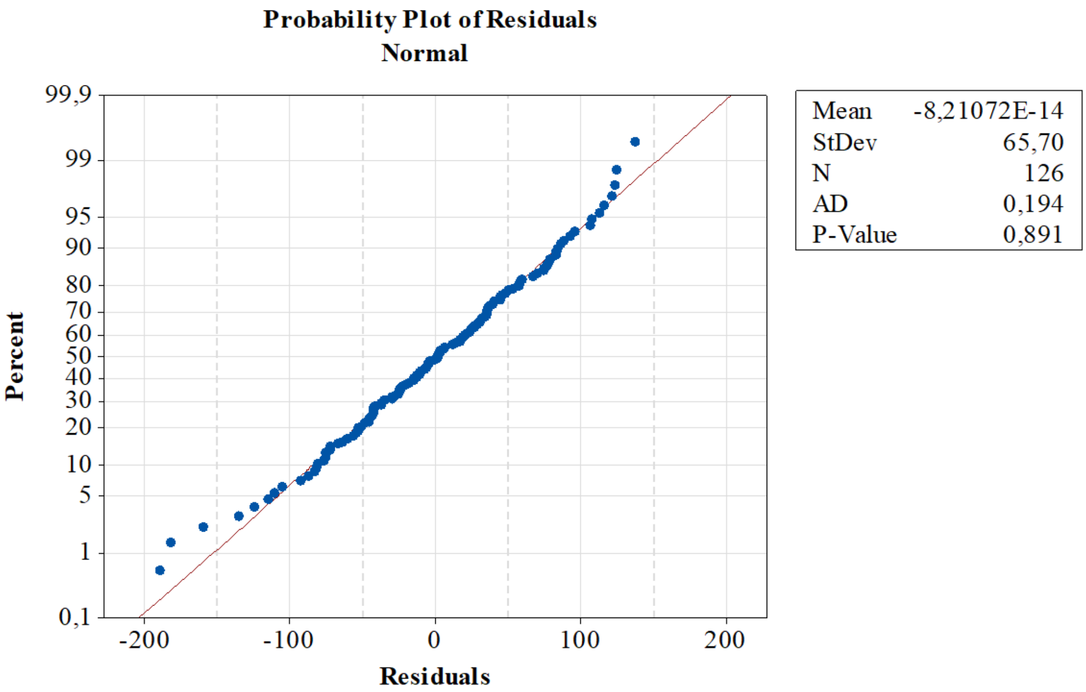

Figure 5.4. Normal probability plot of residuals of grip strength data for males.

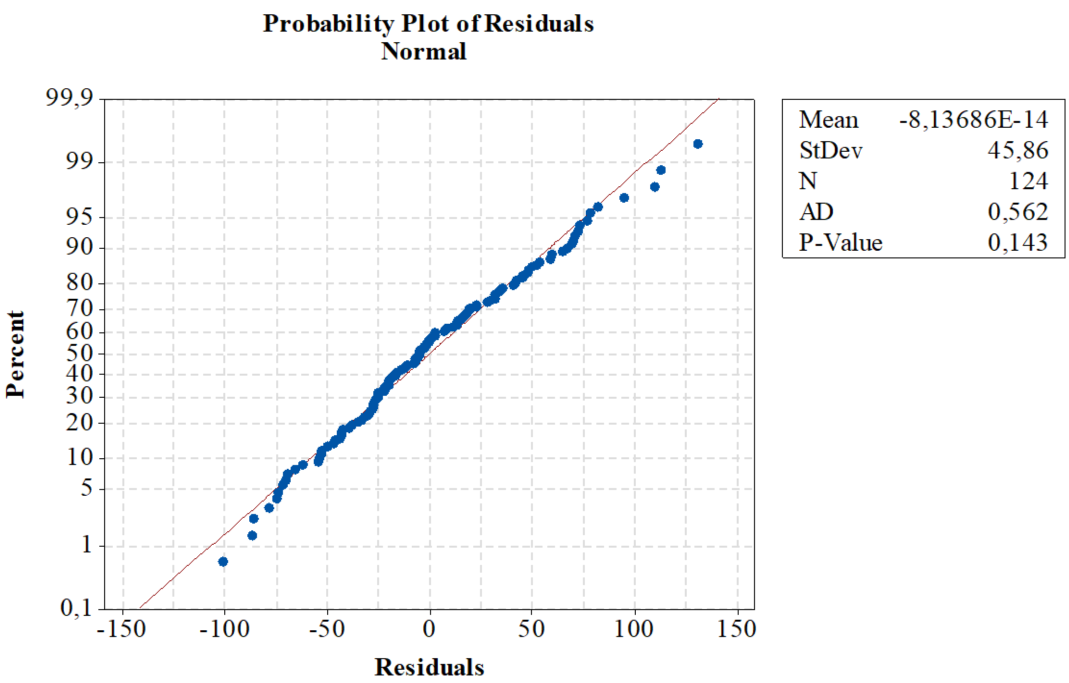

Figure 5.5. Normal probability plot of residuals of grip strength data for females.

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

The plot of the residuals versus observation order for males and females were shown in Figure 5.6 and Figure 5.7 respectively. The residuals seem to distribute around the 0 line. Since there is not serial correlation, independence assumption was satisfied.

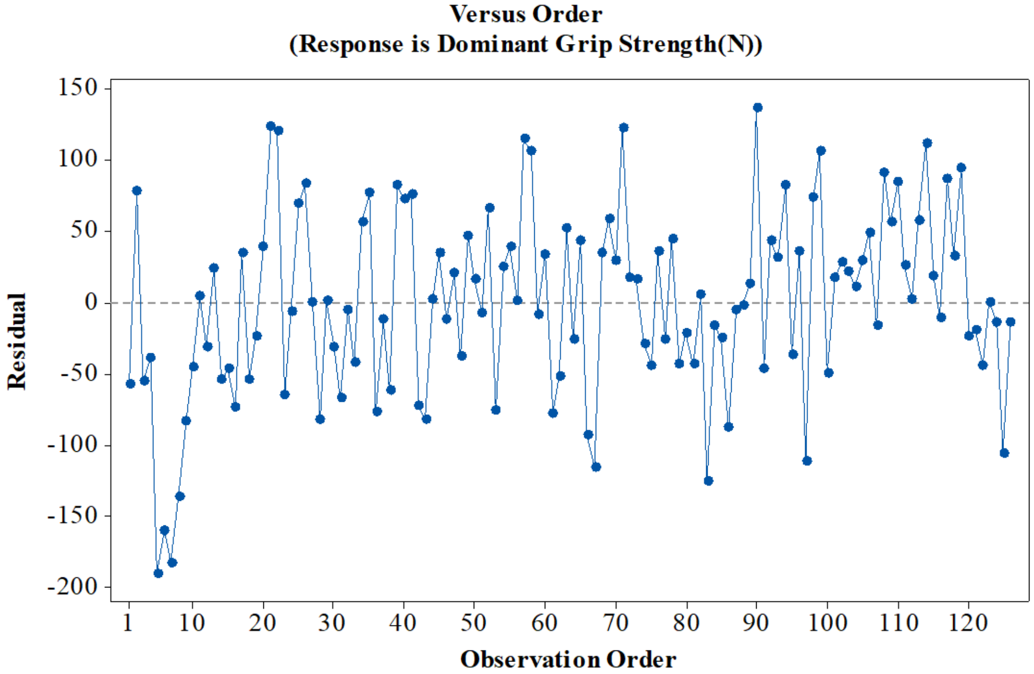

Figure 5.6. Plot of residuals versus observation order for males

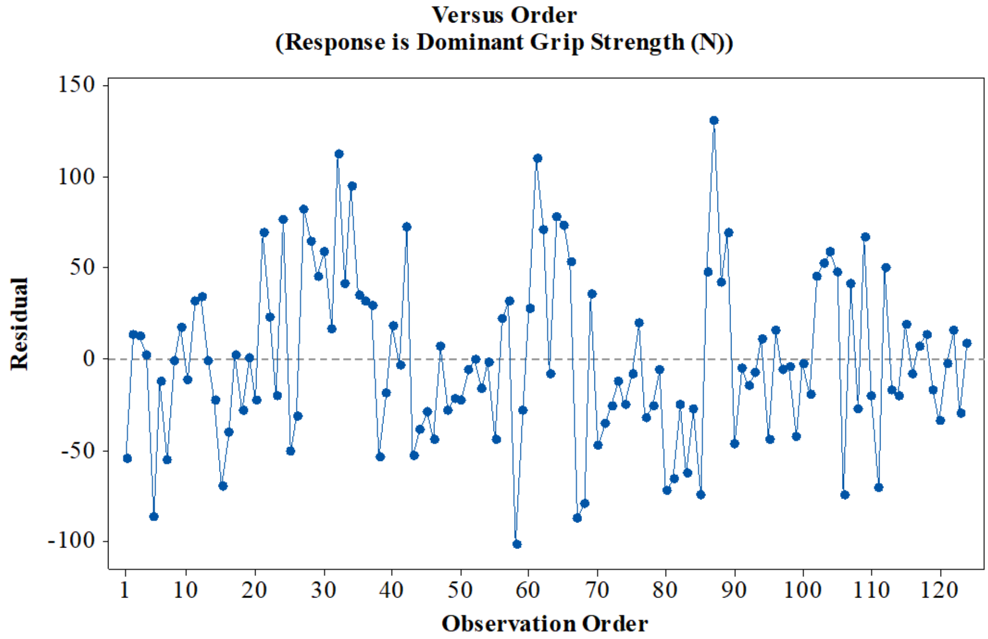

Figure 5.7. Plot of residuals versus observation order for females

In Table 5.16, Pearson’s correlation coefficients between independent variables and residuals for males and females are shown.

Table 5.16. Correlation coefficients between independent variables and residuals

Residuals	Age Group	BMI Group	Occupation Group
Residuals for Male	- 0.000	- 0.000	- 0.000
P Value	1.000	1.000	1.000
Residuals for female	0.000	0.000	0.000
P Value	1.000	1.000	1.000

(iii) *Variance Equality Test:* The third assumption about ANOVA is that variances of response variables for each treatment must not be different from each other (homogeneity assumption). A simple check is to plot the residuals versus the fitted values. This plot should not reveal any obvious pattern (Montgomery. 2005).

In Figure 5.8 and 5.9, plot of residuals versus fitted values for males and females can be seen respectively. In these figures, no unusual structure is apparent. Therefore, equality variance assumption was satisfied for both genders.

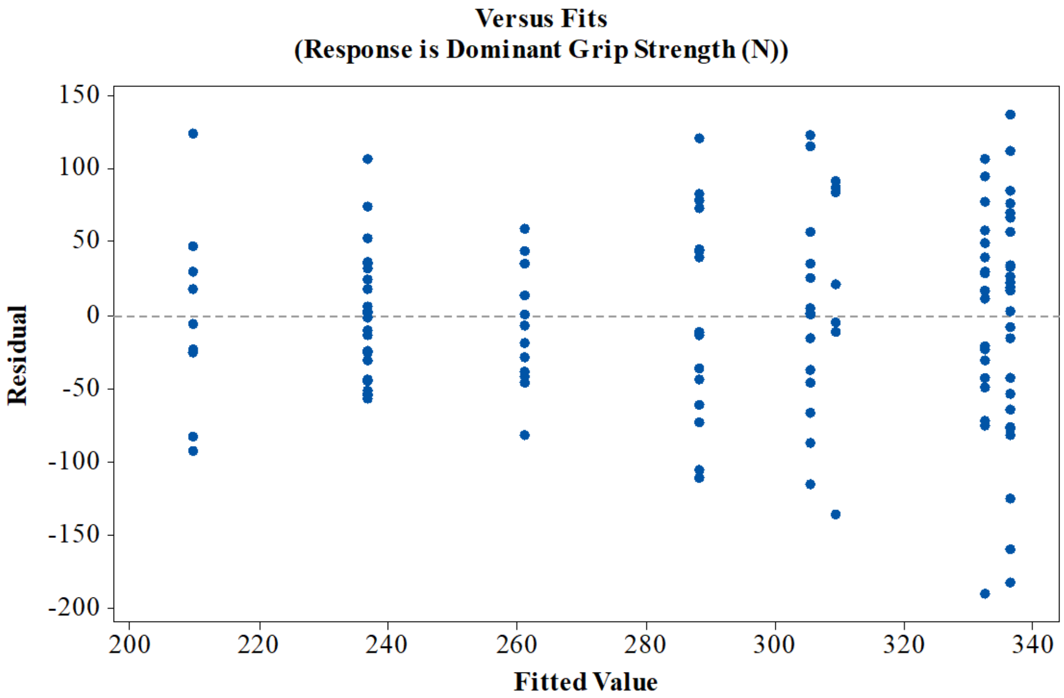

Figure 5.8. Plot of residuals versus fitted values for males

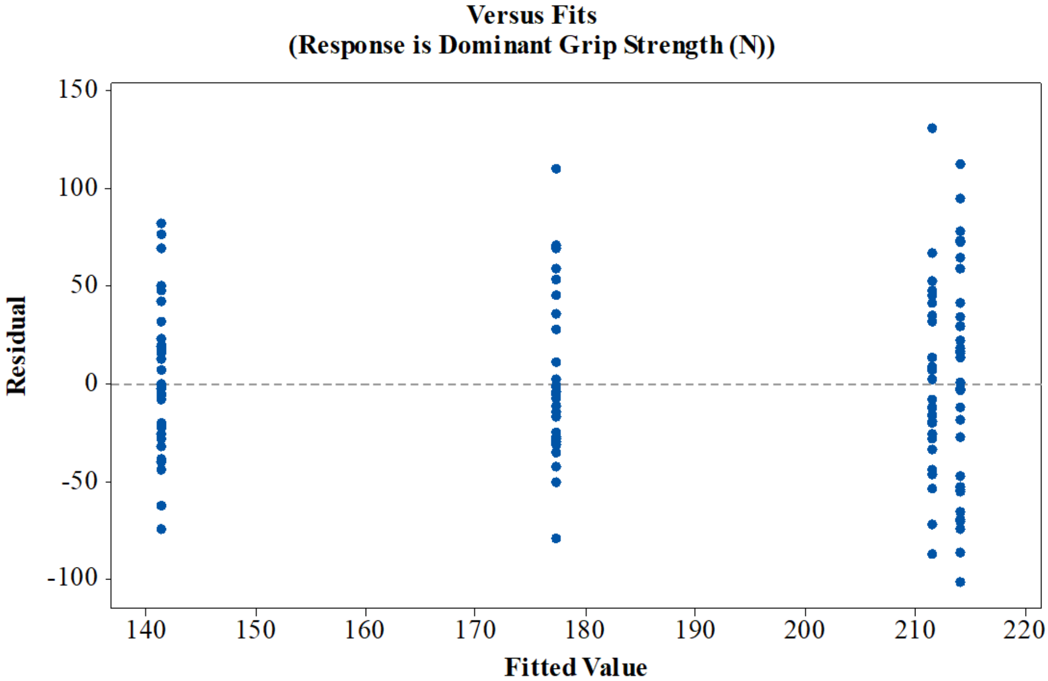

Figure 5.9. Plot of residuals versus fitted values for females

After checking the residual plot, another method for diagnosing the equality of variance could be applied when normality assumption is satisfied. (Montgomery, 2005) One method is Bartlett's test of the hypotheses:

$$H_{0:}\,\sigma_1^2 = \sigma_2^2 \ldots \sigma_n^2 \tag{5.3}$$

$$H_{1:}\,\sigma_i^2 \neq \sigma_j^2 \; for\ at\ least\ one\ pair\ (i,j)$$

where i and j stand for each treatment of grip strength for each gender in this study. H_0 hypothesis states the equality of variances of grip stregth. Table 5.17 the results of Bartlett's test for males and females can be seen. Since p values are higher than 0.05, the null hypothesis cannot be rejected. Therefore, both for males and females, variances are same for each treatment.

Table 5.17 The result of Bartlett's test for males and females

Grip Strength	Barlett's Test Results
Male	0.189
Female	0.467

Three assumptions of ANOVA were satisfied, therefore the effects of independent variables on maximum grip strength was investigated.

5.3.3.1. ANOVA Results. After running ANOVA, for both male's and female's interaction effects were found non-significant with high p-value. Hence, interaction effects between treatments were neglected and only main effects were taken into consideration in the model. The reduced ANOVA model for complete randomized design is as follows (Montgomery. 2005);

$$y_{ijk} = \mu + a_i + b_j + c_k + \varepsilon_{ijk} \tag{5.4}$$

where,

y_{ijk} : ijk^{th} response (maximum grip strength)

μ : The overall mean

a_i : Effect of i^{th} level of age group factor

b_j : Effect of j^{th} level of body mass index (BMI) group factor

c_k : Effect of k^{th} level of occupation group factor

ε_{ijk} : Random error component NID $(0,\sigma^2)$

for,

$i = 1, 2, 3,4$ (1: 70-74 years)

(2: 75-79 years)

(3: 80-84 years)

(4: 85+ years)

$j = 1, 2$ (1: Normal weight)

(2: Overweight)

(underweight group was excluded since there was only 1 female subject in this group)

$k = 1, 2$ (1: Manual worker)

(2: Non-manual worker)

ANOVA of completely randomized design for dominant hand grip strength response was summarized in table 5.18, 5.19 for males and 5.20, 5.21 for females. Since the interaction effects were neglected, 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.

(i) *ANOVA of Male Data*: Table 5.18 indicates that age group and BMI group have significant effect on hand grip strength response, while occupation group does not have any effect. ANOVA was rerun without occupation group that can be seen in Table 5.19.

The p-value of lack of fit is larger than the significance level for both tables which indicates the test does not detect any lack-of-fit. Moreover, the p-value of lack of fit is higher for the reduced model which can indicate the reduced model is more accurate. The model correctly specifies the relationship between the response and the predictors (Minitab Inc., 2018)

Table 5.18. Analysis of variance result of males for all three groups

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
Occupation Group	1	852	23	23.2	<0.001	0.944
BMI Group	1	15719	19814	19814.5	4.21	0.042
Age Group	3	212743	177142	59047.2	12.55	<0.001
Error	113	531812	531812	4706.3		
Lack-of-Fit	3	3128	3128	1042.6	0.22	0.884
Pure Error	110	528684	528684	4806.2		
Total	125	768703				

Table 5.19. Analysis of variance result of males for the two groups only

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
BMI Group	1	15980	20104	20103.9	4.51	0.036
Age Group	3	213184	213184	71061.3	15.94	<0.001
Error	121	539539	539539	4459		
Lack-of-Fit	11	10855	10855	986.8	0.21	0.997
Pure Error	110	528684	528684	4806.2		
Total	125	768703				

(ii) *ANOVA of Female Data*: Table 5.20 shows that, the p-values of BMI group and occupation group are higher than significance level (0.1), they do not have any effect on grip strength response for elderly females. Only the age group has significant effect on grip strength response for females. ANOVA was rerun without BMI and Occupation groups that can be seen in Table 5.21.

In Table 5.21 p-value of lack of fit was increased like previously, so it can be said that the model has been improved.

Table 5.20. Analysis of variance result of females for all three groups

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
BMI Group	1	3289	381	380.5	0.17	0.68
Age Group	3	112507	68253	22751.1	10.2	<0.001
Occupation Group	1	4544	3888	3888	1.74	0.189
Error	111	247517	247517	2229.9		
Lack-of-Fit	2	6223	6223	3111.7	1.41	0.25
Pure Error	109	241294	241294	2213.7		
Total	123	374373				

Table 5.21. Analysis of variance result of females (for age group only)

Source	DF	Seq SS	Adj SS	Adj MS	F-Value	P-Value
Age Group	3	115719	115719	38573	17.9	<0.001
Error	120	258654	258654	2155		
Lack-of-Fit	11	17360	17360	1578	0.71	0.724
Pure Error	109	241294	241294	2214		
Total	123	374373				

Only for significant factors indicated by ANOVA, Tukey's test was used in order to determine the differences of the factor levels. The results explained in the following.

5.3.3.2. Gender Effect. According to many studies, grip strength response has the largest difference between gender groups. Similar with previous studies, results indicated that the mean of grip strength response of female lower than those of males. This significant difference can be seen in Figure 5.10 Boxplot of mean grip strengths for males and females. Figure 5.11 shows distributions of dominant grip strength of males and females with the means which are 183.3 N for females and 289.3 N for males.

As it is seen in Table 5.22, there are statisticaly differences between the mean of grip strength of elderly male and elderly female population of Turkey.

Table 5.22. Result of t-test for males and females

Gender	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Male	126	289.3	78.4	7	105.9	12.33	<0.001	248
Female	124	183.4	55.2	5				

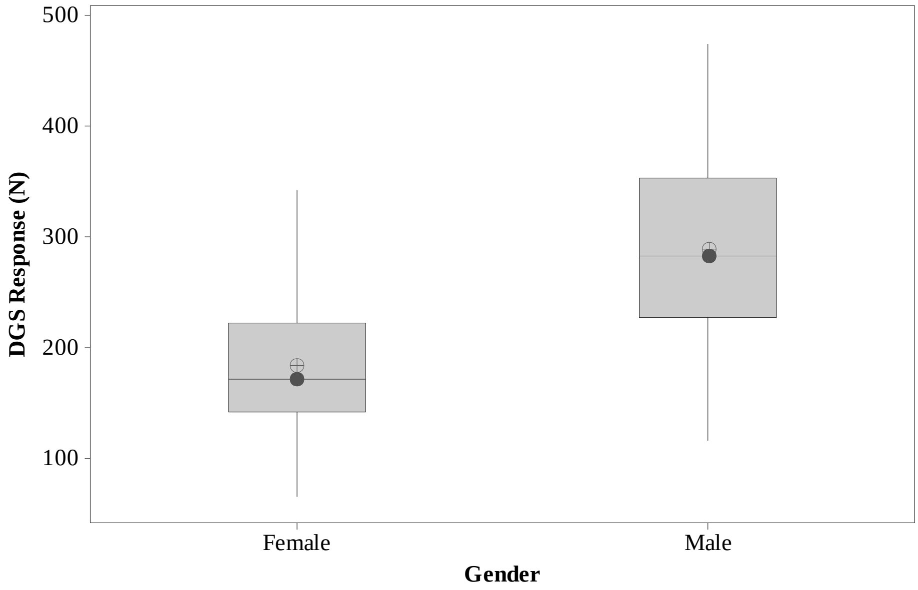

Figure 5.10. Box plots of mean dominant grip strength for males and females

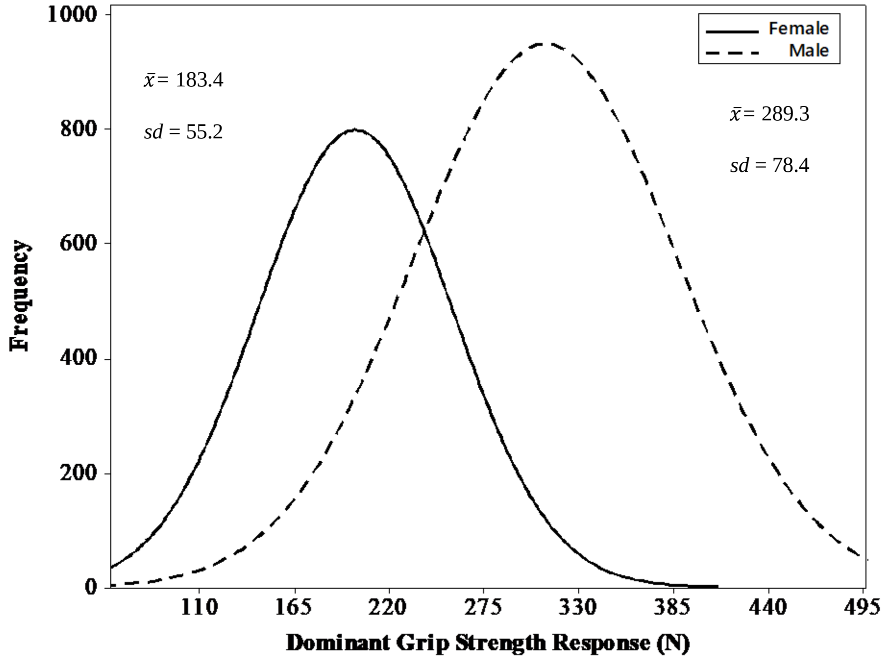

Figure 5.11. Frequency distributions of dominant grip strength of males and females

5.3.3.3. Age Effect. Age was found as a significant factor in the ANOVA analysis for both genders. The differences between age groups were examined in this section.

Figure 5.12 shows box plots of dominant hand grip strength of males for different age groups. In Table 5.23, results of Tukey's test can be seen for different age groups for males. For males, results show that first age group (70 - 74) is the strongest group, although there are small differences between first age group (70-74) and second group (75-79), they are not statistically significant. However, after age 80, the mean grip strength response starts to decrease significantly.

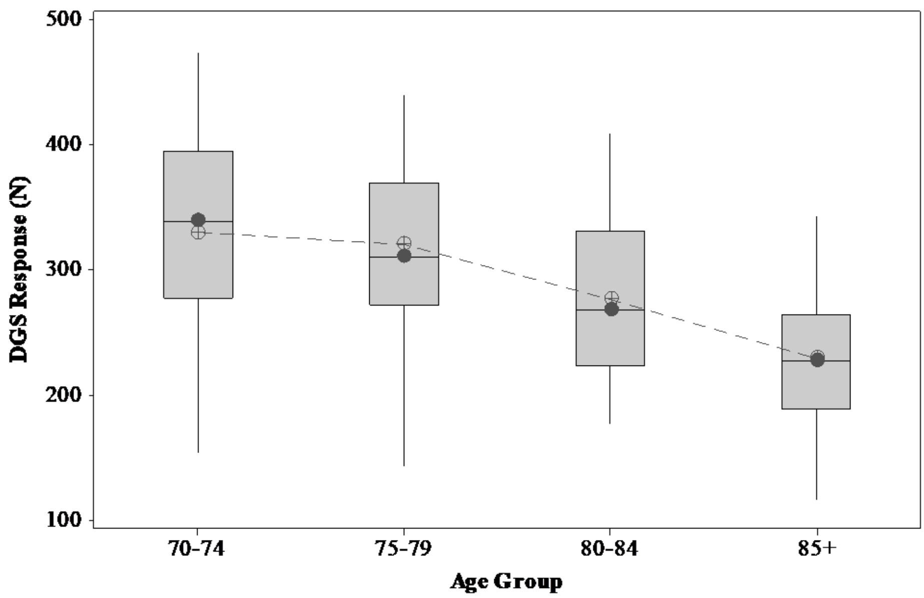

Figure 5.12. Box plots of dominant hand grip strength of males for age groups

Table 5.23. Results of Tukey's test for different age groups (for males)

Difference of Age Group Levels	Difference of Means	SE of Difference	T-Value	Adj P-Value
(75-79) - (70-74)	-3.9	16.8	-0.23	0.996
(80-84) - (70-74)	-48.4	17.3	-2.79	0.031
(85+) - (70-74)	-99.7	16.4	-6.06	<0.001
(80-84) - (75-79)	-44.5	17.3	-2.58	0.054
(85+) - (75-79)	-95.8	16.7	-5.74	<0.001
(85+) - (80-84)	-51.3	17.3	-2.97	0.019

Table 5.23 indicates that, there is huge difference between grip strength response of first age group (70-74) and fourth age group (85+). It is clear, the fourth age group (85+) is the weakest one for males. According to the grouping information, (75-79) and (80-84) are marginally different (Table 5.24).

Table 5.24. Grouping information of grip strength response for age groups using Tukey Method and 95% Confidence (for males).

Age Group	N	Mean	Grouping		
70-74	33	322.875	A		
75-79	32	319.013	A	B	
80-84	28	274.505		B	
85+	33	223.194			C

Means that do not share a letter are significantly different

Figure 5.13 provides box plots of dominant hand grip strength of females for different age groups. In Table 5.25, results of Tukey's test can be seen for different age groups for females. First age group (70-74) and second age group (75-79) share also same letter which is shown in Table 5.26. Therefore, it can be said there is not significantly difference between these two groups. Women whose ages are between 70 to 74 years are the strongest group while age group (85+) is the weakest one.

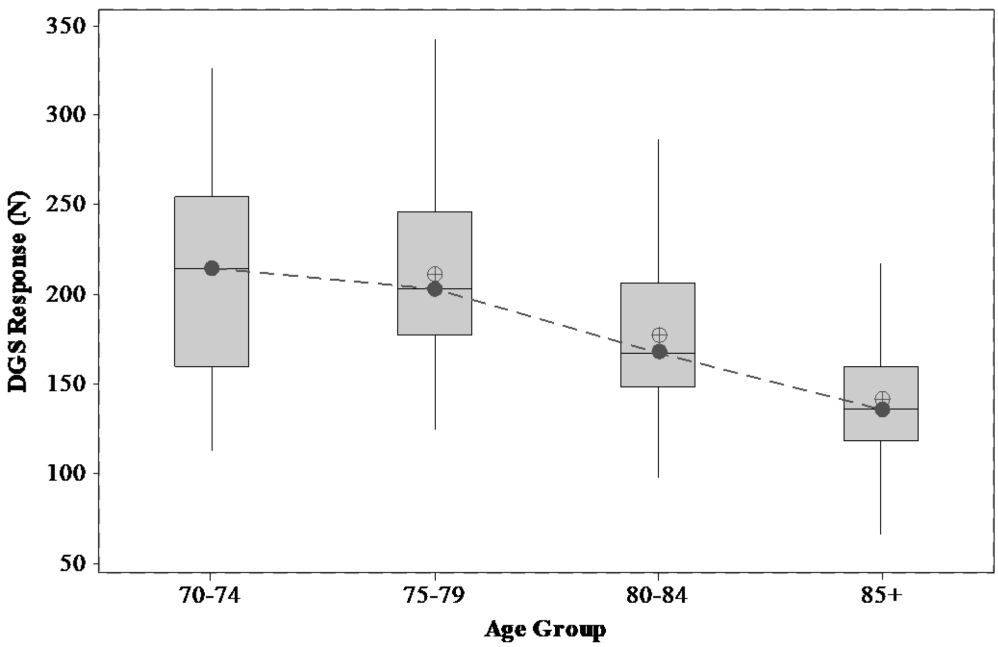

Figure 5.13. Box plots of dominant hand grip strength of females for age groups

On the other hand, similar with males, after age group (75-79) the mean grip strength starts to decrease dramatically for females as well. Except difference between first age group and second age group, the differences within groups were significant for females.

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

Difference of Age Group Levels	**Difference of Means**	**SE of Difference**	**T-Value**	**Adj P-Value**
(75-79) - (70-74)	-2.6	12.2	-0.21	0.997
(80-84) - (70-74)	-36.9	11.9	-3.1	0.013
(85+) - (70-74)	-72.9	11.4	-6.4	<0.001
(80-84) - (75-79)	-34.3	12.3	-2.79	0.031
(85+) - (75-79)	-70.3	11.8	-5.95	<0.001
(85+) - (80-84)	-36	11.5	-3.13	0.012

Individual confidence level = 98.96%

Table 5.26. Grouping information of grip strength response for age groups using Tukey Method and 95% Confidence (for females).

Age Group	**N**	**Mean**	**Grouping**		
70-74	31	214.101	A		
75-79	27	211.533	A		
80-84	30	177.206		B	
85+	36	141.243			C

5.3.3.4. BMI Effect. As result of ANOVA, BMI group was found significant only for males. Therefore, Tukey's test was done only for males in order to determine significantly differences between BMI group groups. Figure 5.14 and Figure 5.15 show box plots of grip strength for different BMI groups of males and females, respectively. Since males did not have any underweight subjects and females had only one subject, this group was excluded. It is seen that overweight group is significantly stronger than normal group for males, whereas the difference between the groups is not significant for females. Even it is not significant, in Figure 5.15 shows that overweight group is stronger than normal group with little difference for females.

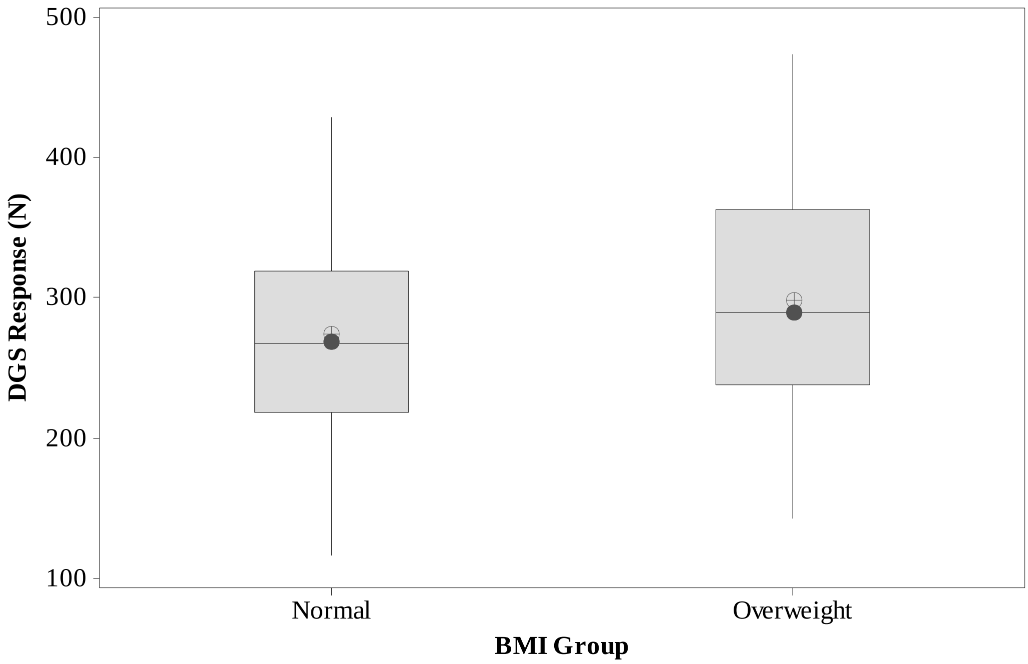

Figure 5.14. Box plots of dominant hand grip strength of males for BMI groups

Table 5.27. Results of Tukey's test for different BMI groups (for males)

Difference of BMI Group Levels	Difference of Means	SE of Difference	T-Value	Adj P-Value
Overweight - Normal	27.1	12.8	2.12	0.036

Individual confidence level = 95.00%

Table 5.28. Grouping information of grip strength response for BMI groups using Tukey Method and 95% Confidence. (for males)

BMI Group	N	Mean	Grouping	
Overweight	83	298.456	A	
Normal	43	271.338		B

Means that do not share a letter are significantly different.

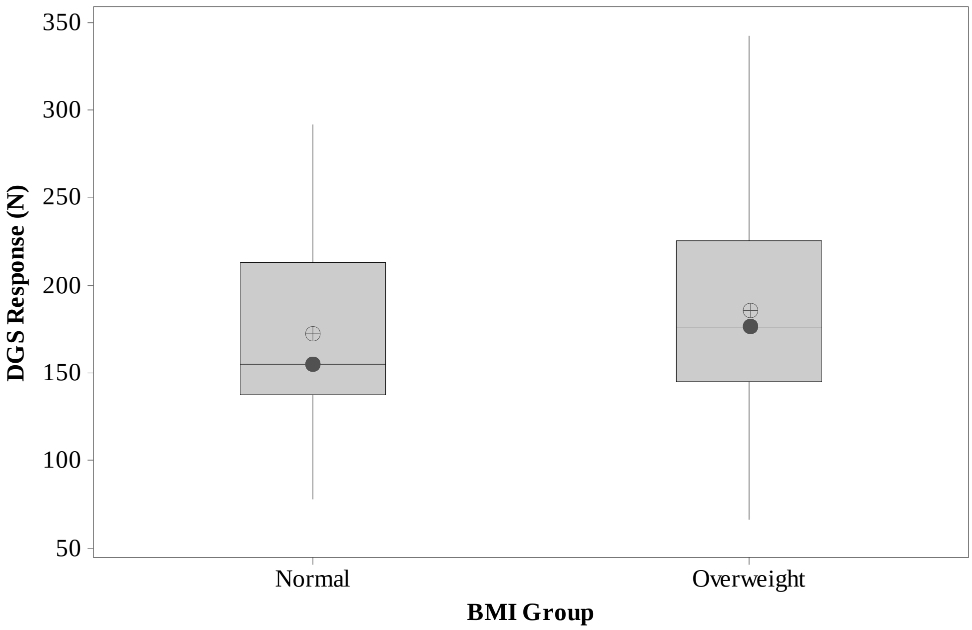

Figure 5.15. Box plots of dominant hand grip strength of females for BMI groups

5.3.3.5. Occupation Effect. For elderly people, the occupation group was not found significant for both genders. In Figure 5.16 and 5.17 show box plots of dominant hand grip strength for different occupation groups of males and females. As it was concluded from ANOVA, there is not statistically significant difference between occupation groups.

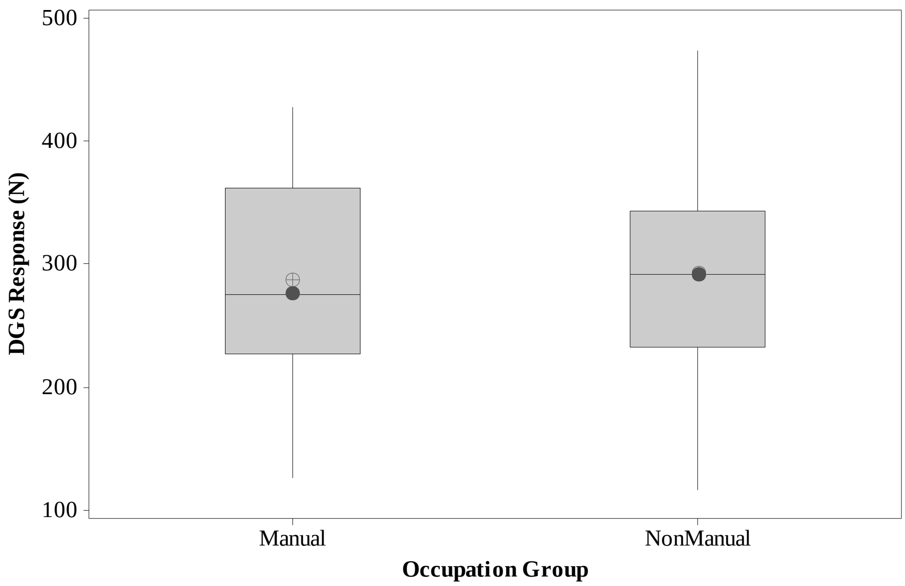

Figure 5.16. Box plots of dominant hand grip strength of males for occupation groups

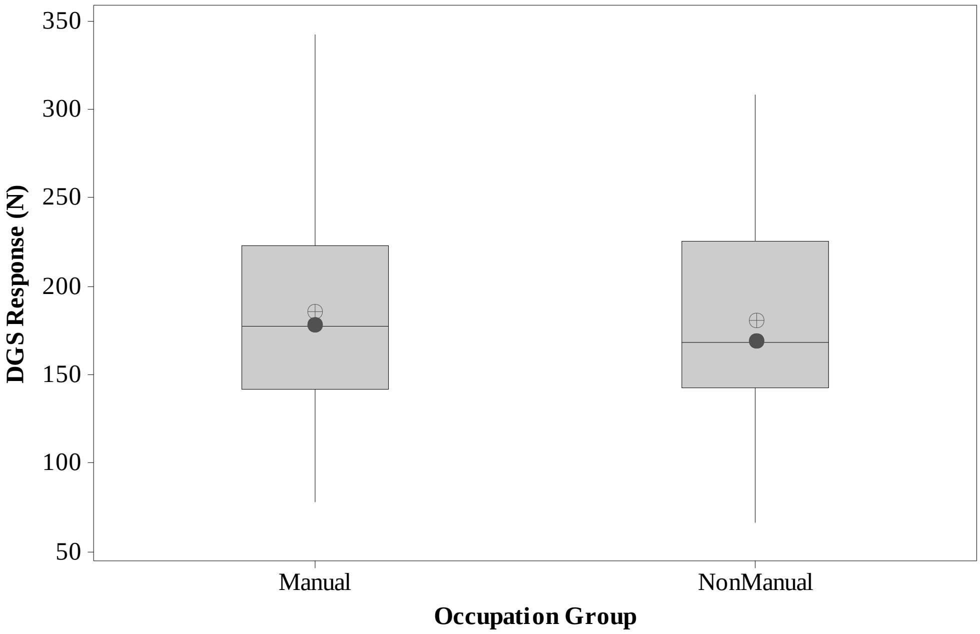

Figure 5.17. Box plots of dominant hand grip strength of females for occupation groups

5.3.4. Regression Analysis of Maximum Grip Strength

In this section, prediction equations for grip strength of males and females were established for significant independent variables which were found both by ANOVA and by correlation analysis. As investigated in the previous section, interaction effects were neglected and only the significant main effects were taken into consideration while determining the multiple linear regression model. After the diagnostics analysis, a no-interaction multiple linear regression model was determined as a suitable model for both male and female grip strength capacity.

A matrix plot is made use of to investigate whether to take into consideration any quadratic term in the model. Figure 5.18 and 5.19 are matrix plots of males and females, respectively. As theresult of matrix plot, quadratic effect of age is also investigated for both male and female.

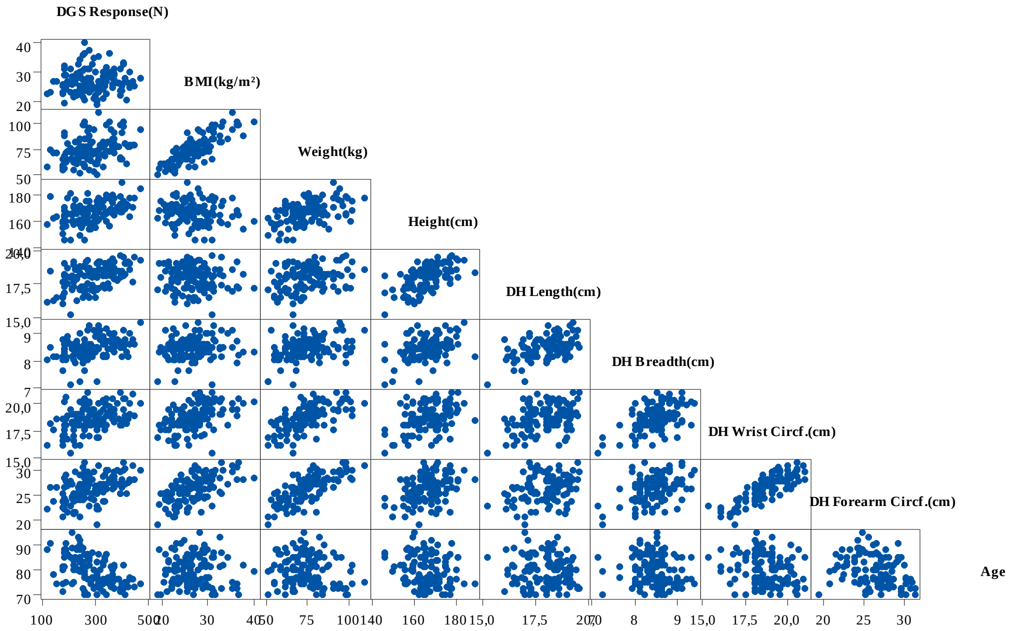

Figure 5.18. Matrix plots of Age, Height, Weight, BMI, DHL, DHWC, DHFC and DGS of Male

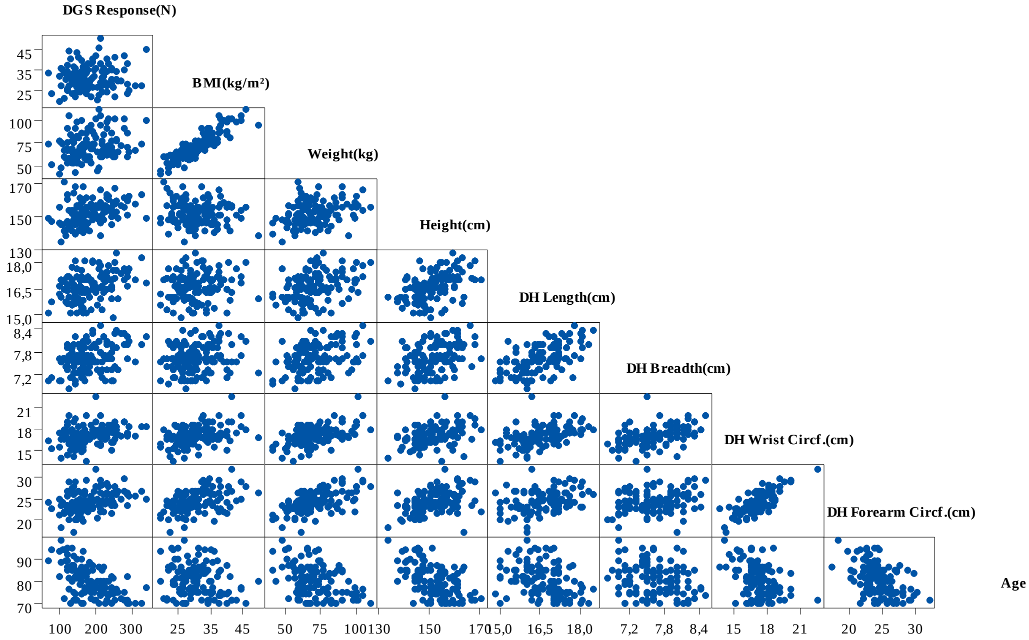

Figure 5.19. Matrix plots of Age, Height, Weight, BMI, DHL, DHWC, DHFC and DGS of Female

In addition to main effects, quadratic term of age and anthropometric variables were also added to regression model to predict maximum grip strength responses for both males and females.

Since occupation group was found insignificant effect on grip strength as a result of ANOVA, it was eliminated in the regression analysis. Additon to occupation group, p value of BMI was also found greater than the significance level of 0.05 by ANOVA analysis for female. However, the effect of BMI was taken into consideration as a continues variable. Therefore, it was not neglected for the regression analysis of female.

Before adding BMI-group into the model as a predictor for male, it was checked If it violates best subsets results and R^2_{adj} values. Since BMI is calculated by using measurement of weight and height, it would have an effect and would result in lower R^2_{adj}. But the alternative models and R^2_{adj} were generated from the best subset technique were not significantly differentiated for both options with the including BMI and without it. To evaluate all the alternatives, BMI and these two measurements were used as a predictor in the model.

Stepwise Regression Analysis technique and Best Subsets Regression analysis method was used to verify the results. By Stepwise regression, all independent variables in the model are checked each step until the variables not in the model have p-values that are greater than the specified alpha-to-enter value and when all variables in the model have p-values that are less than or equal to the specified alpha-to-remove value (0.05 was selected for the level of significance.) (Montgomery, 2012).

Best subsets regression investigates all models and identifies the models with the highest R^2_{adj} value and Mallows' C_p. It is an efficient way to identify models that adequately fit with as few predictors as possible (Minitab Inc, 2018).

The Best subsets approach was used to check the obtained models, it gives many different alternative sub models with Mallow's C_p statistics to compare them. The model with too many predictors can be slightly questionable whereas a model with too few predictors can produce biased estimates (Minitab Inc, 2018).

The model with the Mallows' C_p value that is close to or less than the number of predictors and with high R^2_{adj} was selected to determine most appropriate model.

Variance inflation factor (VIF) was utilized in order to decrease multicollinearity between independent variables. The amount of inflation of the variance of the estimated regression coefficients is measured with Variance Inflation factors (VIF) as compared to when the predictor variables are not linearly correlated. The case of VIF = 1 means that predictors are not correlated. If $1 < VIF < 5$, it means that predictors are moderately correlated. If $5<VIF<10$, predictors are highly correlated. VIF values greater than 10 may indicate serious multicollinearity (O'Brien, 2007). In order to prevent multicollinearity, only VIF values less than 5 were taken into consideration in this study (Montgomery, 2012).

5.3.4.1. Regression Equation of Grip Strength for Males. The general form of the male grip strength regression model is found as follows (Montgomery, 2005);

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1^2 + \varepsilon \qquad (5.5)$$

Where,

y: Response Variable (Max Dominant Grip Strength)

β_0: constant

β_1: Regression coefficient of age

β_2: Regression coefficient of height

β_3: Regression coefficient of weight

β_4: Regression coefficient of BMI

β_5: Regression coefficient of quadratic terms of age

ε : Error term

x_1: Regressor variable of age

x_2: Regressor variable of height

x_3: Regressor variable of weight

x_4: Regressor variable of BMI

10 different model alternatives are represented in Table 5.29 for grip strength (N) of males. For all the models, regression equations are listed in Appendix B.

Table 5.29. Different regression model alternatives of Grip Strength Response of Male

Regression Model	**S**	**R-Sq**	**R-Sq (adj)**	**Mallows C_p**
Model 1	58.401	45.4	44.5	7.9
Model 2	56.118	50	48.8	2.8
Model 3	56.416	50.3	48.2	2.5
Model 4	56.584	50.4	47.9	4.2
Model 5	56.594	50.4	47.9	4.2
Model 6	56.778	50.5	47.6	6
Model 7	56.822	50.4	47.5	6.2
Model 8	57.02	50.5	47.1	8
Model 9	57.064	50.4	47	8.2
Model 10	57.264	50.5	46.7	10

Model 1: Age, DHL

Model 2: Age, DHL, DHFC

Model 3: Age, age^2, height, DHL, DHFC

Model 4: Age, age^2, height, DHL, DHWC, DHFC

Model 5: Age, age^2, DHL, DHB, DHWC, DHFC

Model 6: Age, age^2, height, DHL, DHB, DHWC, DHFC,

Model 7: Age, age^2, weight, DHL, DHWC, DHFC, BMI

Model 8: Age, age^2, height, DHL, DHWC, DHFC, BMI

Model 9: Age, age^2, weight, height, DHL, DHWC, DHFC, BMI

Model 10: Age, age^2, weight, height, DHL, DHWC, DHFC, DHB, BMI

When examined all the alternatives, model 3,4, 5 and 6 were considered due to their high R^2_{adj} with C_p which is close to number of predictors, but Model 2 has minimum Mallow C_p and maximum R^2_{adj} in comparison with other models.

Multicollinearity between weight, height and BMI was found considerable high in model 7,8,9 and model 10 by stepwise regression. Model 2 was choosen as best model with lowest C_p value and highest R^2_{adj}.

Therefore, all the models were checked with Stepwise Regression and Best Subset Regression Analysis. The models had insignificant predictors with high p-values were eliminated and Model 2 was determined as most appropriate model to predict grip strength with the equation that has R^2_{adj} value 48.8 and Standard Deviation 56.118. Table 5.30 presents ANOVA table of regression model (model 2). The ANOVA tests the following hypothesis:

$$H_0: \beta_1 = \beta_2 = \beta_3 = \cdots = \beta_n = 0 \quad (5.6)$$
$$H_1: \beta_j \neq 0 \; for \; at \; least \; j \; (j = 1,2,..,n)$$

If H_0 hypothesis above is rejected, at least one of the regressor variables contributes significantly to the model.

Table 5.31 shows regression analysis of that model. Since p value < 0.05 it is clear that at least one of the regressor variables contributes significantly to the model.

Table 5.30. Analysis of variance table of regression model

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	3	384499	128166	40.7	<0.001
Error	122	384204	3149		
Total	125	768703			

Table 5.31. Regression analysis results of grip strength for males

Predictor	**Coef**	**SE Coef.**	**T**	**P**	**VIF**
Constant	-67	134	-0.5	0.619	
Age	-5.262	0.867	-6.07	<0.001	1.11
DH Length	32.75	5.85	5.59	<0.001	1.09
DH Forearm Circumference	7.09	2.12	3.35	0.001	1.2

(i) *Best Model*: Therefore, the best regression equation for male grip strength for the considered variables is:

Dominant Hand Grip Strength Response = – 67 – 5.262*Age + 32.75*DH Length + 7,09*DH Forearm Circumference

(S = 56.1178, R^2 = 50.2%, R^2_{adj} = 48.79 %)

Where, age is in years, hand length is in cm, hand forearm Circumference is in cm, hand grip strength is in N.

(ii) *Age Only Model:* To develop another model with only age for elderly people provide to estimate their grip strength response when all other variables are unknown apart from age. Table 5.32 shows ANOVA of regression model and it can be sad that age is significant factor in that model. Table 5.33 indicate the regression coefficient of grip strength only with age for male.

Table 5.32. Analysis of variance table of regression model with age only

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	1	205319	205319	45.19	<0.001
Error	124	563384	4543		
Total	125	768703			

Table 5.33. Regression analysis results of grip strength for males with age only

Predictor	**Coef**	**SE Coef.**	**T**	**P**	**VIF**
Constant	817.4	78.8	10.38	<0.001	
Age	-6.652	0.990	-6.72	<0.001	1.0

Therefore, the age only regression equation for male grip strength as follows:

Dominant Hand Grip Strength Response = 817.4 – 6.652*Age

(S = 67.4049, R^2 = 26.71 %, R^2_{adj} = 26.12 %)

Where, age is in years and hand grip strength is in N.

5.4.3.2. Regression Equation of Grip Strength for Females.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1^2 + \varepsilon \quad (5.7)$$

Where,

y: Response Variable (Max Dominant Grip Strength)

β_0: constant

β_1: Regression coefficient of age

β_2: Regression coefficient of height

β_3: Regression coefficient of weight

β_4: Regression coefficient of BMI

β_5: Regression coefficient of quadratic terms of age

ε : Error term

x_1: Regressor variable of age

x_2: Regressor variable of height

x_3: Regressor variable of weight

x_4: Regressor variable of BMI

10 different model alternatives are represented Table 5.34 for grip strength (N) of females. For all the models, regression equations are listed in Appendix B.

Table 5.34. Different regression model alternatives of Grip Strength Response of Females

Regression Model	**S**	**R-Sq**	**R-Sq (adj)**	**Mallows C_p**
Model 1	42.498	41.6	40.7	2.3
Model 2	42.376	42.4	41	5.6
Model 3	42.492	42.1	40.7	6.3
Model 4	42.066	43.8	41.2	4.9
Model 5	42.226	43.3	41.4	5.8
Model 6	42.063	44.2	41.9	5.8
Model 7	41.934	45.5	42.2	7.1
Model 8	42.017	45.8	42	8.6
Model 9	42.084	45.6	41.8	9
Model 10	42.092	46	41.8	10

Model 1: Age, DHB

Model 2: Age, weight, DHB

Model 3: Age, DHB, BMI

Model 4: Age, weight, DHB, DHFC

Model 5: Age, DHB, DHFC, DHWC

Model 6: Age, DHB, DHFC, DHWC, BMI

Model 7: Age, age^2, weight, DHB, DHFC, DHWC, BMI

Model 8: Age, age^2, height, DHB, DHFC, DHWC, DHL, BMI

Model 9: Age, weight, height, DHB, DHFC, DHWC, DHL, BMI

Model 10: Age, age^2, weight, height, DHB, DHFC, DHWC, DHL, BMI

In the table of females, it may be seen that all Models are similar R^2_{adj}, relatively small S values and valid $C_{p.}$ Although Model 6 and Model 7 have the highest R^2_{adj}, they have rather high C_p values. Since, Model 1 has relatively high R^2_{adj} and lowest C_p was considered as a most appropriate model. After some trials were done to find regression equation by using Stepwise Regression and Best Subset Regression Analysis. Model 1 was selected regression equation for females in order to estimate grip strength response with R^2 adj value 40.7 and Mallow C_p 2.3.

Table 5.35 indicates that the p-value of regression model is less than 0.05. So, it can be said that at least one of the regressor variables contributes significantly to the model. In Table 5.36, the regression coefficients for female grip strengths can be seen.

Table 5.35. Analysis of variance table of regression model

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	2	155839	77919	43.14	<0.001
Error	121	218535	1806		
Total	123	374373			

Table 5.36. Regression analysis results of grip strength for females

Predictor	**Coef**	**SE Coef.**	**T**	**P**	**VIF**
Constant	227.2	97.2	2.34	0.021	
DH Breadth	37.8	10.2	3.72	<0.001	1.05
Age	-4.143	0.553	-7.5	<0.001	1.05

(i) *Best Model*: Thus, the best regression equation for female grip strength is:

Dominant Grip Strength = 227.2 + 37.8 DH Breadth – 4.143*Age

(S = 42.498, R^2 = 41.6 %, R^2_{adj} = 40.7 %, Mallows' C_p = 2.3)

Where, age is in years, hand breadth is in cm, hand grip strength is in N.

(ii) *Age Only Model:* Another model with age only was developed for elderly female people provide to estimate their grip strength response when all other variables are unknown apart from age. Table 5.37 shows ANOVA of regression model and it can be sad that age is significant factor in that model. In table 5.38 can be seen the regression coefficient of grip strength only with age for female.

Table 5.37. Analysis of variance table of regression model with age only

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	1	130812	130812	65.52	<0.001
Error	122	243561	1996		
Total	123	374373			

Table 5.38. Regression analysis results of grip strength for females with age only

Predictor	**Coef**	**SE Coef.**	**T**	**P**	**VIF**
Constant	551.0	45.6	12.09	<0.001	
Age	-4.592	0.567	-8.09	<0.001	1.0

The regression equation of grip strength for female with age only as follows:

Dominant Hand Grip Strength Response = 551.0 – 4.592*Age

(S = 44.6811, R^2 = 34.94 %, R^2_{adj} = 34.41 %)

Where, age is in years and hand grip strength is in N.

6. DISCUSSION

6.1. Discussion on the Results of Current Study

This study provided consistent results with the number of studies in the literature. As expected, age, hand and gender were found the most significant factors of hand grip strength for elderly people which are significant factors not only for elderly but also for young adult people. Height, hand dominance and hand anthropometry were significant factors for both females and males, while weight was found significant only for males.

Results indicate that the mean grip strength of males is significantly higher than that of females. Neves *et al*. (2018) reported that physical perfomance which is an indicator of muscle strength is significantly correlated both with muscle strength and grip strength which depends on muscle cross section area (Ekşioğlu, 2016). Since males generally have larger muscle group than females, they are stronger than females. Not only elderly studies but also young adults' studies reported grip strength differences among genders. While Demura *et al*. (2011) investigated gender differences for elderly people, Schlüssel *et al*. (2008), Peebles and Norris (2003), Bohannon *et al*. (2006) and Ekşioğlu (2016) reported gender differences for relatively young people. All these studies found that males, on average are stronger than females both elderly and young people.

Many studies in the literature (e.g., Schlüssel *et al*., 2008; Desrosiers *et al*., 1995; Xiao *et al.*, 2005; Wang *et al*., 2018; Ekşioğlu, 2016) reported that the dominant hand is significantly higher than non-dominant hand regardless of gender. These results could be explained with the daily usage level of upper limbs, the dominant hand may be used more often to exert maximum strength than non-dominant hand in daily life (Desrosiers *et al*., 1995; Ekşioğlu, 2016). On the other hand, Mat Jais *et al*. (2018) and Mathiowetz *et al.* (1985) reported that even there is not significance difference between hands for specific age groups, these are exceptions. In contrary to the current study, the study of Mat Jais *et al.* (2018) reported that hand difference was not significant for the age group between 70 – 85 years. Regardless of age group, dominant hand is stronger than non-dominant in this study. For that reason, all analyses were conducted with grips strength response of dominant hand for both males and females.

In the current study, occupation group did not affect grip strength responses for elderly people. The previous jobs of the subjects were recorded as their occupations (all the elderly people of this study were retired). Xiao *et al.* (2005) and Ekşioğlu (2016) investigated occupational effect on grip strength. However, their study did not focus on only old people. Therefore, they reported grip strength differences between occupations and that manual workers are stronger than non-manual workers. When it comes to elderly people, the studies (Desrosiers *et al.,* 1995; Ramlagan *et al.*, 2014; Sternang *et al.*, 2015; Maranhao Neto *et al*., 2017; Porto *et al.,* 2019) investigated the effect of physical activities which is not mentioned in the current study. While Porto *et al*. (2019) concluded physical activities of people above 70 years was significantly correlated with grip strength, according to Ramlagan *et al*. (2014) it did have not any significant effect on grip strength response. In a similar manner, Sin *et al.* (2009) reported that grip strength was significantly related to quantity and quality of exercise together with physical function. So, the reported results are conflicting.

BMI effects on grip strength on elderly population was also investigated in the current study. As mentioned before, weight and height were significantly correlated with grip strength for males while only height was significant for females. It was also verified with the ANOVA analysis that BMI was found as a significant factor only for males. Schlüssel *et al*. (2008) and Ramlagan *et al*. (2014) have similarly reported that there was a high tendency of increasing grip strength with increasing BMI only for males. Ramlagan *et al*. (2014) reported that underweight males had lower grip strength than underweight females, while overweight males had higher grip strength than overweight females which is verified that BMI was not significant for females. Moreover, Almeida Silva *et al*. (2013) has also reported excess weight verified by BMI is not an indicator for muscular strength in the elderly people. It may be explained by higher fat deposition may result from muscle disuse, which result in muscular strength reduced. On the other hand, Kaur (2009) presented that BMI has a positive association with right and left hand grip strength for females, but the regarding study investigated age groups up to 70 years old which is not comparable for elderly people.

Other factors examined in that study are anthropometric dimensions and their relationship with grip strength. As mentioned above BMI is one of the variables. However, body height, weight, hand length and width, circumferences of wrist and forearm were other variables that are investigated. As result of the study, height is significantly correlated with grip strength for both genders. A number of studies in the literature (Desrosiers *et al*., 1995; Koopman *et al*., 2014; Ramlagan *et al.*, 2014; Shahida *et al.*, 2015; Maranhao Neto *et al.*, 2017; Ribom *et al*., 2011) have reported height as a significant factor of grip strength not only for young but also for elderly people. In these studies, hand circumference, palm length, forearm muscle circumferences were high and positively correlated with hand grip strength for both males and females. In the current study, hand length and breadth, wrist and forearm circumferences are highly correlated with GS, additionally hand length and forearm circumferences for male, hand breadth for females were predictors of regression equations similar with the studies of Almedia Silvia *et al*. (2013) and Wu *et al*. (2009).

Age is found most significant factor on grip strength response in agreement with many studies in literature (Desrosiers *et al*., 1995; Koopman *et al.*, 2014; Demura *et al*., 2011; Bohannon and Magasi, 2015; Aoki and Demura, 2011; Martin *et al*., 2015; Sternang *et al*., 2015; Hu *et al*., 2007; Mat Jais *et al*., 2018; Wang *et al*., 2018; Wu *et al*., 2009; Ekşioğlu, 2016.) Aging process eventuated in body alterations with loss of muscle mass which caused decreasing muscle strength (Ramlagan *et al*., 2014 and Almeida Silva *et al.*, 2013). Moreover, the reduction in muscle size has been associated with decreased handgrip strength (Ekşioğlu, 2016; Wang *et al*., 2018). In the present study, grip strength significantly reduced with increasing age especially after 80 years old regardless of gender in agreement with other studies (Liao *et al*., 2014; Desrosiers *et al.*, 1995; Ramlagan *et al*., 2014; Wang *et al*., 2018; Almeida Silva *et al*., 2013). On the other hand, Bohannon and Magasi (2015), reported that over 85 years old females had slightly higher grip strength than mid-eighties, similarly Mat Jais *et al*. (2018) that increasing for both genders.

6.2. Comparison with Other Studies

In order to determine the place of the grip strength data of elderly population of Turkey in the literature, the results of the study are compared with the similar studies. A similar study has not been performed in Turkey for elderly population previously. So, this study will be a base for further researches. The studies in the literature vary in sample size, sample type, measure used, experimental procedure, experimental posture, age range, methods and handles used. The direct comparisons of the current study with the related studies in the literature are not so feasible since there are some differences either in experimental conditions or focused age groups. The results are compared within the same age groups in general, since overall mean may include less than 70 years old subjects which are not included in the current study.

Therefore, to perform some comparisons, it was aimed to find the most similar experimental conditions with the same age group. Therefore, the following studies are considered for the comparisons.

For grip strength, the most similar studies for comparisons:

- Desrosiers *et al*. (1995)
- Bohannon and Magasi (2015)
- Mat Jais *et al.* (2018)
- Wang *et al.* (2018)
- Ribom *et al*. (2011)
- Peebles and Norris (2003)
- Wu *et al*. (2011)
- Almeida Silva *et al*. (2013)
- Neves *et al.* (2018)
- Hu *et al*. (2018)

Even though, all of the studies mentioned above were explained in detail in the literature review part, some specific information about them are given once more and while comparing the results, same age groups were taken into consideration.

6.2.1. Current study vs. Desrosiers *et al.* (1995) for grip strength

Desrosiers *et al.* (1995) conducted a study in Canada to investigate the relationship between age and gender on grip strength together with some athropometric variables such as; body weight, body height, hand length, hand circumference. Work characteristics, subjective health conditions and current activity level were also used in the study. They focused on the age group which ranged from 60 to 94 years (180 M and 180 F M). The subjects were meausered by using both the Jamar dynamometer and the Martin Vigorimeter while sitting and their elbows flexed 90◦, and their forearms in neutral with fixed second handle span while sitting position. Experiment was similar with the current study, except the dynamometer was not supported, rest time was 30 sec and span was fixed at second handle position. Results indicated that there are statistical differences between the current study and Desrosiers *et al*. (1995) for each age groups (70-79 and 80-94 years) and each hand for males and females. The difference might be resulted from experimental conditions (grip span or rest time) or anthropometric measurements since the average height of Canadian population is higher than elderly population of Turkey which are 169.5 ± 5.8 and 156.4 ± 6.8 for Canadians, 166.1 ± 8.1 and 151.5 ± 7.5 for current study's population, respectively for males and females.

Table 6.1. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Male, age range: 70-79, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al*. (1995)	60	415.8	89.2	12	90.4	6.14	<0.001	123
Current Study	65	325.35	75.3	9.3				

Table 6.2. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Male, age range: 80+, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al*. (1995)	60	338.33	70.6	9.1	87.4	7.23	<0.001	119
Current Study	61	250.96	62.1	8				

Table 6.3. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Male, age range: 70-79, non-dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al.* (1995)	60	397.17	83.36	11	96.3	6.91	<0.001	123
Current Study	65	300.84	72.51	9				

Table 6.4. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Male, age range: 80+, non-dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al.* (1995)	60	314.79	68.65	8.9	84.8	6.88	<0.001	119
Current Study	61	230.04	66.92	8.6				

Table 6.5. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Female, age range: 70-79, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al.* (1995)	60	232.42	50.01	6.5	19.46	2.03	0.044	116
Current Study	58	212.96	53.9	7.1				

Table 6.6. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Female, age range: 80+, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al.* (1995)	60	196.13	42.17	5.4	38.54	5.08	<0.001	124
Current Study	66	157.59	42.83	5.3				

Table 6.7. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Female, age range: 70-79, non-dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Desrosiers *et al.* (1995)	60	215.75	46.1	6	26.21	3.02	0.003	116
Current Study	58	189.54	48.22	6.3				

Table 6.8. Comparison of results for GS of current study with Desrosiers *et al.*'s study (Female, age range: 80+, non-dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Desrosiers *et al.* (1995)	60	181.42	43.14	5.6	40.98	5.33	<0.001	124
Current Study	66	140.44	43.14	5.3				

6.2.2. Current study vs. Bohannon and Magasi (2015) for grip strength

Bohannon and Magasi (2015) conducted the study in the USA in order to determine grip strength of two groups that are 178 males and 212 females with age ranges of 60–85 years, 152 males and 406 females aged between 20 and 40 years. The participants were measured for each hand by using a Jamar dynamometer in its second handle position, while they were seated with their arms by their sides and elbows flexed 90°. (Recommendations of ASHT). The independent t-tests were done for relative age groups for both genders to compare results. As can be seen in Table 6.9, there are statistical differences between the current study and Bohannon and Magasi (2015) study for males with the age group of 70-74 years, while for the older age groups which are 75-79 and 80-85 years in same gender there are no statistical differences. It can be seen at Table 6.10 and 6.11.

Table 6.9. Comparison of results for GS of current study with Bohannon and Magasi (2015) study (Male, age range: 70-74, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Bohannon and Magasi (2015)	42	399.84	99.86	15	69.9	3.28	0.002	73
Current Study	33	329.9	79.7	14				

Table 6.10. Comparison of results for GS of current study with Bohannon and Magasi (2015) study (Male, age range: 75-79, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Bohannon and Magasi (2015)	26	334.06	101.86	20	13.4	0.59	0.56	56
Current Study	32	320.7	71.5	13				

Table 6.11. Comparison of results for GS of current study with Bohannon and Magasi (2015) study (Male, age range: 80-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Bohannon and Magasi (2015)	46	279.34	92.97	14	2.9	0.15	0.884	72
Current Study	28	276.4	64.7	12				

However, in contrary to males, in females there are no statistical differences between the current study and Bohannon and Magasi (2015) in 70-74 and 75-80 age groups, while there are no statistical differences for the females belong to 80- 85 years age group. Table 6.12, 6.13 and 6.14 shows the comparison of females in the current study with Bohannon and Magasi (2015). The difference between that age group 80-85 for female and 70-74 for males might be anthropometric measurements of subjects since that were not mentioned in the study.

Table 6.12. Comparison of results for GS of current study with Bohannon and Magasi (2015) study (Female, age range: 70-74, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Bohannon and Magasi (2015)	46	214.4	52.93	7.8	0.3	0.002	0.981	75
Current Study	31	214.1	58.1	10				

Table 6.13. Comparison of results for GS of current study with Bohannon and Magasi (2015) study (Female, age range: 75-79, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Bohannon and Magasi (2015)	54	197.05	83.63	11	-14.4	-0.083	0.409	79
Current Study	27	211.5	47.8	92				

Table 6.14. Comparison of results for GS of current study with Bohannon and Magasi (2015) study (Female, age range: 80-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Bohannon and Magasi (2015)	21	201.5	39.59	8.6	24.8	2.16	0.036	50
Current Study	31	176.7	41.3	7.4				

6.2.3. Current study vs. Mat Jais *et al.* (2018) for grip strength

Mat Jais *et al.* (2018) conducted a study to obtain normative grip strength data of elderly population of Singapore. They aimed to investigate changes in grip strength against resistive torque force. 99 male and 134 female healthy Singaporean subjects aged 60 years and older were measured for this study. A Custom-Made multifunctional hand strength measurement device was used. It is validated with the gold standard Jamar dynamometer. Participants were measured while sitting posture upright on a chair with feet planted flat on the ground, shoulders adducted with hands in neutral rotation and flexion, and elbows flexed at 90, with the forearm in neutral position for each hand. It is expected to maintain their grip at maximum strength for up to 10 seconds which is 4 seconds in the current study. Three age groups of the study were compared according to the dominant hand strengths which is similar with the current study. Results showed in Tables below, there are statistical differences between the current study and Mat Jais *et al.* (2018) with almost every age group but over 85 years old female is completely same with the current study. The differences between studies might be explained by experimental conditions.

Table 6.15. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Male, age range: 70-74, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Mat Jais *et al*. (2018)	24	234.38	66.69	14	-95.5	-4.78	<0.001	55
Current Study	33	329.9	79.7	14				

Table 6.16. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Male, age range: 75-79, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Mat Jais *et al*. (2018)	19	242.22	79.43	18	-78.5	-3.64	0.001	49
Current Study	32	320.7	71.5	13				

Table 6.17. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Male, age range: 80-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Mat Jais *et al*. (2018)	15	177.5	65.7	17	-98.9	-4.75	<0.001	41
Current Study	28	276.4	64.7	12				

Table 6.18. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Male, age range: 85+, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Mat Jais *et al*. (2018)	11	199.08	92.18	28	-30.3	-1.37	0.178	42
Current Study	33	229.4	51.5	9				

Table 6.19. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Female, age range: 70-74, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Mat Jais *et al*. (2018)	33	153.96	60.8	11	-60.1	-4.04	<0.001	62
Current Study	31	214.1	58.1	10				

Table 6.20. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Female, age range: 75-79, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Mat Jais *et al*. (2018)	21	123.6	55.9	12	-87.9	-5.87	<0.001	46
Current Study	27	211.5	47.8	9.2				

Table 6.21. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Female, age range: 80-85, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Mat Jais *et al*. (2018)	18	102.97	44.13	10	-73.7	-5.88	<0.001	47
Current Study	31	176.7	41.3	7.4				

Table 6.22. Comparison of results for GS of current study with Mat Jais *et al.* (2018) study (Female, age range: 85+, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Mat Jais *et al*. (2018)	16	141.2	40.2	10	0	0	1	50
Current Study	36	141.2	36.7	6.1				

6.2.4. Current study vs. Wang *et al.* (2018) for grip strength

Wang *et al.* (2018) conducted the study in the USA with the aim of verifying the grip strength results obtained in 2011- 2012 and 2013-2014. 6783 M and 6893 F subjects aged from 6 to over 80 years old were measured by using The Takei digital dynamometer. The subjects were in standing position with elbow extended, and wrist in neutral position. Both dominant and non-dominant hands were tested 3 times with 60 sec. rest time and maximum of trials were recorded. Three age groups (70-74), (75-79) and (80-85) were compared for both genders. There are not any statistical differences in 75-79 years old males and 80-85 years old females between the current study and Wang *et al.* (2018). On the other hand, there are differences in the age groups (70-74), (80-85) years of male and (75-79), (80-85) years of female subjects between the studies. Results of t-test are shown in Table 6.23, Table 6.24, Table 6.25 for males and in Table 6.26, Table 6.27, Table 6.28 for females.

Table 6.23. Comparison of results for GS of current study with Wang *et al.* (2018) study (Male, age range: 70-74, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Wang *et al.* (2018)	226	380.5	72.56	4.8	50.6	3.68	<0.001	257
Current Study	33	329.9	79.7	14				

Table 6.24. Comparison of results for GS of current study with Wang *et al.* (2018) study (Male, age range: 75-79, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Wang *et al.* (2018)	161	346.18	70.6	5.6	25.5	1.86	0.064	191
Current Study	32	320.7	71.5	13				

Table 6.25. Comparison of results for GS of current study with Wang *et al.* (2018) study (Male, age range: 80-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Wang *et al.* (2018)	243	307.93	67.67	4.3	31.5	2.34	0.02	269
Current Study	28	276.4	64.7	12				

Table 6.26. Comparison of results for GS of current study with Wang *et al.* (2018) study (Female, age range: 70-74, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Wang *et al.* (2018)	282	235.36	46.09	2.7	21.26	2.37	0.018	311
Current Study	31	214.1	58.1	10				

Table 6.27. Comparison of results for GS of current study with Wang *et al.* (2018) study (Female, age range: 75-79, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Wang *et al.* (2018)	153	226.53	45.11	3.6	15.03	1.58	0.115	178
Current Study	27	211.5	47.8	9.2				

Table 6.28. Comparison of results for GS of current study with Wang *et al.* (2018) study (Female, age range: 80-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Wang *et al.* (2018)	248	191.23	44.13	2.8	14.53	1.74	0.083	277
Current Study	31	176.7	41.3	7.4				

6.2.5. Current study vs. Ribom *et al.* (2011) for grip strength

Ribom *et al.* (2011) conducted a study in Sweden with 999 male subjects aged between 70-80 years. Hand grip strength together with functional muscle strength were measured for each subject. A Jamar hydraulic hand dynamometer was used for grip strength test. They were asked to sit in a standard chair without support and performed two trials for each hand with each five spans. Rest time and squeeze time were not mentioned in the study. Overall strength mean was compared with the grip strength response that belongs to same age group in the current study. As it is seen in Table 6.29, there are statistical differences between the current study and Ribom *et al*. (2011). It might be explained with rest time and squeeze time which were not mentioned, or it might be the result of body dimension differences between two populations. Average height of Sweden elderly male is 174.4 ± 7.2 cm, whereas it is 166.1 ± 8.1cm for male subjects included in the current study.

Table 6.29. Comparison of results for GS of current study with Ribom *et al.* (2011) study (Male, age range: 70-80, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Ribom *et al*. (2011)	999	402.1	78.45	2.5	76.8	7.66	<0.001	1062
Current Study	65	325.35	75.33	9.3				

6.2.6. Current study vs. Peebles and Norris (2003) for grip strength

Peebles and Norris (2003) conducted a comprehensive study in the UK which consists of 150 subjects aged from 2 to 86 years. The participants consist of 65 males aged between 2 to 80 years and 88 females aged between 2 to 86. They were measured using a hand grip dynamometer with preferred handle separation between 30, 50 and 70 mm for five seconds with their dominant hand. They were standing and adopting a free posture. When it is compared with the current study with similar age groups for each gender, there are no statistical differences between the current study and Peebles and Norris (2003) for both genders. The result of t-test can be seen in Table 6.30 and Table 6.31 for males and females respectively.

Table 6.30. Comparison of results for GS of current study with Peebles and Norris (2003) study (Male, age range: 71-80, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Peebles and Norris (2003)	8	373.3	30.3	11	47.9	1.77	0.08	71
Current Study	65	325.35	75.33	9.3				

Table 6.31. Comparison of results for GS of current study with Peebles and Norris (2003) study (Female, age range: 71-80, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Peebles and Norris (2003)	12	225.4	48.5	14	12.5	0.75	0.45	68
Current Study	58	212.91	53.08	7				

6.3.7. Current study vs. Almeida Silva *et al.* (2013) for grip strength

Another study in Brazil was conducted by Almeida Silva *et al.* (2013). They investigated the influence of anthropometric variables and age on grip strength. 283 female and 133 male elderly subjects were measured by using Takei Kiki Kogyo Dynamometer which can be adjusted according to hand size. Position of subjects, rest time and squeeze time were not mentioned in the study. It is compared with the current study with similar age group for each gender, there are no statistical differences between the current study and Almeida Silva *et al*. (2013) for similar age groups of males as it is shown in Table 6.32 and Table 6.33. On the other hand, results of t-test for females is different. As it seen in Table

6.34 and 6.35 there are statistical differences between the current study and Almeida Silva *et al.* (2013) for same age groups (70-79) and (80-104) for females. The differences of females might be explained by different body dimensions between these two populations.

Table 6.32. Comparison of results for GS of current study with Almeida Silva *et al.* (2013) study (Male, age range: 70-79, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Almeida Silva *et al*. (2013)	42	320.68	75.51	12	19.8	1.36	0.177	105
Current Study	65	300.84	72.51	9				

Table 6.33. Comparison of results for GS of current study with Almeida Silva *et al.* (2013) study (Male, age range: 80-104, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Almeida Silva *et al*. (2013)	27	232.42	65.7	13	-18.6	-1.27	0.208	86
Current Study	61	250.97	62.09	7.9				

Table 6.34. Comparison of results for GS of current study with Almeida Silva *et al.* (2013) study (Female, age range: 70-79, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Almeida Silva *et al.* (2013)	93	178.48	51.96	5.4	-34.48	-3.91	<0.001	149
Current Study	58	212.96	53.9	7.1				

Table 6.35. Comparison of results for GS of current study with Almeida Silva *et al.* (2013) study (Female, age range: 80-104, dominant hand).

Studies	Sample Size	Mean	SD	SE of Mean	Difference	T- value	p- value	DoF
Almeida Silva *et al.* (2013)	52	136.31	51.98	7.2	-21.28	-2.44	0.016	116
Current Study	66	157.59	42.83	5.3				

6.2.8. Current study vs. Neves *et al.* (2018) for grip strength

Neves *et al.* (2018), investigated the relationship between grip strength with skeletal muscle mass for elderly people. The study was conducted in Brazil with 141 male subjects with average age 71 (65 to 91) and 246 female subjects with average age 71 (65 to 90). The subjects were measured by using a manual hydraulic dynamometer while sitting on an armless chair, with elbow flexed at a 90° angle, forearm in neutral position, three times for dominant hand. Rest time was 15 seconds in the study while it is 2 minutes in the current study. Handle size was adjustable however posture of the subjects was not mentioned in the study. Results of t-test can be seen in Table 6.36 and 6.37 for males and females respectively. The comparison was done with overall age group (70-94) for the subjects for each gender. As it is seen in Table 6.36, there are not statistical differences between the current study with Neves *et al.* (2019) for males. On the other hand, Table 6.37 shows that there are statistical differences between the females subjects of the current study with the Neves *et al.* (2019) elderly female subjects. The discrepancy may be explained by the difrerences between the sample size and daily lifestyle of the female population in Brazil and in Turkey.

Table 6.36. Comparison of results for GS of current study with Neves *et al.* (2019) study (Male, age range: 65-93, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Neves *et al*. (2018)	141	295.18	108.85	9.2	5.9	0.5	0.617	265
Current Study	126	289.3	78.4	7				

Table 6.37. Comparison of results for GS of current study with Neves *et al.* (2019) study (Female, age range: 65-93, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Neves *et al*. (2018)	246	167.7	60.8	3.9	-15.6	-2.41	0.016	369
Current Study	125	183.3	55	4.9				

6.2.9. Current study vs. Hu *et al.* (2007) for grip strength

Hu *et al.* (2007) conducted a study to investigate the relationship between maximum grip strength, age and anthropometric dimensions for Chinese population. The subjects were aged between 65.2–85.1 and 65.0–80.7 for males and females respectively. They were measured by using Smedley’s handgrip dynamometer which has two parallel bars and can be adjusted according to hand size for dominant hand. Rest time was 4-6 seconds between trials and posture of the subjects were not mentioned in the study. In contrary to comparisons with Almeida Silva *et al.* and Neves *et al.* (2019), there are statistical differences between the male subjects of the current study with Hu *et al.* (2007), while not in female. Results of t-test can be seen in Table 6.38 and 6.39 for males and females respectively. As it seen in Table 6.39, there not statistical differences between the female subjects of the current study with Hu *et al.* (2007). It might be explained by differences between sample size among male and female groups.

Table 6.38. Comparison of results for GS of current study with Hu *et al.* (2007) study (Male, age range: 65-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Hu *et al*. (2007)	50	382.46	107.87	15	71.8	4.65	<0.001	141
Current Study	93	310.63	75.4	7.8				

Table 6.39. Comparison of results for GS of current study with Hu *et al.* (2007) study (Female, age range: 65-85, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Difference**	**T- value**	**p- value**	**DoF**
Hu *et al*. (2007)	58	205.94	51	6.7	-6.96	-0.72	0.473	114
Current Study	58	212.9	53.08	7				

6.2.10. Current study vs. Wu *et al*. (2009) for grip strength

Wu *et al.* (2009) investigated the grip strength factors among age groups from 20 to over 80 years in Taiwan. They used same standard procedure by the American Society of Hand Therapists (ASHT). 244 males and 238 females subject were measured by using Jamar dynamometer with the four different positions of forearm; (1) pronated, (2) neutral, (3) supinated, and also (4) with elbow extended downwards by the side while the forearm in neutral position and for each position by using five different spans. They were seated for all combinations with shoulder adducted and neutrally rotated, elbow flexed to 90 degrees. According to study, grip span had significant relation with forearm position, palm length gender and age. The comparison between the regarding study and the current one, it was not feasible since SD of the results were not mentioned. But the study reported min and max results of grip strength for each age group.

Therefore, it might be interpreted according to mean and min-max values of results among related age groups for each gender. As it can be seen in Table 6.40, the mean of grip strength of Tawian population is lower than current study within each age group for both genders. Wu *et al*. (2009) compared the results between consolidates norms of Bohannon *et al*. (2006), and it was reported that the mean Taiwan grip strength was about 25.4% lower in males and 27.4% lower in females than Bohannon *et al*. When it is compared with the current study for the related age groups which are (70-74) and (75-80), it might be concluded that the mean of grip strengths of elderly male population of Taiwan are 26.6%, 31.2% lower than male population of Turkish for the age groups (70-74), (75-80) respectively. Similarly, elderly female population of Taiwan 24.4%, 37.9% are weaker than female of population of Turkey within (70-74), (75-80) age groups respectively. These gaps might be explained by differences in measuring procedures or physical differences in in height and weight.

Table 6.40. Comparison of results for GS of current study with Wu *et al.* (2009) study (Male & Female, age range: 70-80, dominant hand).

Studies	**Sample Size**	**Mean**	**SD**	**Min - Max**	**Subjects**
Wu *et al*. (2009)	18	242.22	n/a	194.17- 290.27	Male (70-74) yrs
Current Study	33	329.9	79.7	154 - 473.7	
Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Subjects**
Wu *et al*. (2009)	24	220.65	n/a	165.73 275.56	Male (75-80) yrs
Current Study	32	320.7	71.5	142.2 - 439.3	
Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Subjects**
Wu *et al*. (2009)	17	161.81	n/a	138.27 185.35	Female (70-74) yrs
Current Study	31	214.1	58.1	112.8 - 326.6	
Studies	**Sample Size**	**Mean**	**SD**	**SE of Mean**	**Subjects**
Wu *et al*. (2009)	23	131.41	n/a	107.87 155.93	Female (75-80) yrs
Current Study	27	211.5	47.8	124.5 - 342.3	

Table 6.41. Summary results of previous studies.

Population of Turkey vs.	**Country**	**Gender**	**Age range**	**Sample size**	**D/ND**	**GS (N)**
Desrosiers *et al*. (1995)	Canada	M	70-79	60	D	415.8±89.2
Desrosiers *et al*. (1995)	Canada	M	80+	60	D	338.3±70.6
Desrosiers *et al*. (1995)	Canada	M	70-79	60	ND	397.2±83.4
Desrosiers *et al*. (1995)	Canada	M	80+	60	ND	314.79±68.6
Desrosiers *et al*. (1995)	Canada	F	70-79	60	ND	232.42±50.01
Desrosiers *et al*. (1995)	Canada	F	80+	60	ND	168.13±42.17
Desrosiers *et al*. (1995)	Canada	F	70-79	60	ND	215.75±46.1
Desrosiers *et al*. (1995)	Canada	F	80+	60	ND	181.42.75±43.14
Bohannon and Magasi (2015)	USA	M	70-74	42	D	399.84.75±99.86
Bohannon and Magasi (2015)	USA	M	75-79	26	D	334.06.75±101.86
Bohannon and Magasi (2015)	USA	M	80-65	46	D	279.34.75±92.97
Bohannon and Magasi (2015)	USA	F	70-74	46	D	214.4.75±52.93
Bohannon and Magasi (2015)	USA	F	75-79	54	D	197.05±83.63
Bohannon and Magasi (2015)	USA	F	80-85	21	D	201.5±39.59
Mat Jais *et al*. (2018)	Singapor	M	70-74	24	D	234.38±66.69

Table 6.41. Summary results of previous studies (cont.).

Population of Turkey vs.	**Country**	**Gender**	**Age range**	**Sample size**	**D/ND**	**GS (N)**
Mat Jais *et al*. (2018)	Singapor	M	75-79	19	D	242.22±79.43
Mat Jais *et al*. (2018)	Singapor	M	80-85	15	D	177.5±65.7
Mat Jais *et al*. (2018)	Singapor	M	85+	11	D	199.08±92.18
Mat Jais *et al*. (2018)	Singapor	F	70-74	33	D	153.96±60.8
Mat Jais *et al*. (2018)	Singapor	F	75-79	21	D	123.6±55.9
Mat Jais *et al*. (2018)	Singapor	F	80-95	18	D	102.97±44.13
Mat Jais *et al*. (2018)	Singapor	F	85+	16	D	141.2±40.2
Wang *et al*. (2018)	USA	M	70-74	226	D	380.5±72.56
Wang *et al*. (2018)	USA	M	75-79	161	D	346.18±70.6
Wang *et al*. (2018)	USA	M	80-85	243	D	307.93±67.67
Wang *et al*. (2018)	USA	F	70-74	282	D	235.36±46.09
Wang *et al*. (2018)	USA	F	75-79	153	D	226.53±45.11
Wang *et al*. (2018)	USA	F	80-85	248	D	191.23±44.13
Ribom *et al*. (2011)	Sweden	M	70-80	999	D	402.1 ±78.45

Table 6.41. Summary results of previous studies (cont.).

Population of Turkey vs.	**Country**	**Gender**	**Age range**	**Sample size**	**D/ND**	**GS (N)**
Peebles and Norris (2003)	UK	M	71-80	8	D	373.3±30.3
Peebles and Norris (2003)	UK	F	71-80	12	D	225.4±48.5
Almeida Silva *et al.* (2013)	Brasil	M	70-79	42	D	320.68±75.51
Almeida Silva *et al.* (2013)	Brasil	M	80-100	27	D	232.42±65.7
Almeida Silva *et al.* (2013)	Brasil	F	70-79	93	D	178.48±51.96
Almeida Silva *et al.* (2013)	Brasil	F	80-100	52	D	136.31±51.98
Neves *et al.* (2018)	Brasil	M	65-93	141	D	295.18±108.85
Neves *et al.* (2018)	Brasil	F	65-90	246	D	167.7±60.8
Hu *et al.* (2018)	China	M	65-85	50	D	382.46±107.87
Hu *et al.* (2018)	China	F	65-85	58	D	205.94±51

Table 6.42. Summary of comparisons.

Population of Turkey vs.	Country	Gender	Age range	Sample size	% difference	t-value (p-value)
Desrosiers *et al*. (1995)	Canada	M	70-79	60	-28	6.14 (<0.000)
Desrosiers *et al*. (1995)	Canada	M	80+	60	-35	7.23 (<0.000)
Desrosiers *et al*. (1995)	Canada	M	70-79	60	-32	6.91 (<0.000)
Desrosiers *et al*. (1995)	Canada	M	80+	60	-37	6.88 (<0.000)
Desrosiers *et al*. (1995)	Canada	F	70-79	60	-9	2.03 (0.044)
Desrosiers *et al*. (1995)	Canada	F	80+	60	-24	5.08 (<0.000)
Desrosiers *et al*. (1995)	Canada	F	70-79	60	-14	3.02 (0.003)
Desrosiers *et al*. (1995)	Canada	F	80+	60	-29	5.33 (<0.000)
Bohannon and Magasi (2015)	USA	M	70-74	42	-21	3.28 (0.02)
Bohannon and Magasi (2015)	USA	M	75-79	26	-4	0.59 (0.56)
Bohannon and Magasi (2015)	USA	M	80-85	46	-1	0.15 (0.884)
Bohannon and Magasi (2015)	USA	F	70-74	46	0	0.002 (0.981)
Bohannon and Magasi (2015)	USA	F	75-79	54	7	-0.083 (0.409)
Bohannon and Magasi (2015)	USA	F	80-85	21	-14	2.16 (0.0036)
Mat Jais *et al*. (2018)	Singapor	M	70-74	24	29	-4.79 (<0.000)

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

Table 6.42. Summary of comparisons (cont.).

Population of Turkey vs.	**Country**	**Gender**	**Age range**	**Sample size**	**% difference**	**GS (N)**
Mat Jais *et al*. (2018)	Singapor	M	75-79	19	24	-3.64 (<0.000)
Mat Jais *et al*. (2018)	Singapor	M	80-85	15	36	-4.75 (<0.000)
Mat Jais *et al*. (2018)	Singapor	M	85+	11	13	-1.37 (0.178)
Mat Jais *et al*. (2018)	Singapor	F	70-74	33	28	-4.04 (<0.000)
Mat Jais *et al*. (2018)	Singapor	F	75-79	21	42	-5.87 (<0.000)
Mat Jais *et al*. (2018)	Singapor	F	80-85	18	42	-5.88 (<0.000)
Mat Jais *et al*. (2018)	Singapor	F	85+	16	0	0 (1)
Wang *et al*. (2018)	USA	M	70-74	226	-15	3.68 (<0.000)
Wang *et al*. (2018)	USA	M	75-79	161	-8	1. 68 (0.064)
Wang *et al*. (2018)	USA	M	80-85	243	-11	2. 34 (0.02)
Wang *et al*. (2018)	USA	F	70-74	282	-10	2. 37 (0.018)
Wang *et al*. (2018)	USA	F	75-79	153	-7	1.58 (0.015)
Wang *et al*. (2018)	USA	F	80-85	248	-8	1.74 (0.083)
Ribom *et al*. (2011)	Sweden	M	70-80	999	-24	7.66 (<0.000)

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

Table 6.42. Summary of comparisons (cont.).

Population of Turkey vs.	**Country**	**Gender**	**Age range**	**Sample size**	**% difference**	**GS (N)**
Peebles and Norris (2003)	UK	M	71-80	8	-15	1.77 (0.08)
Peebles and Norris (2003)	UK	F	71-80	12	-6	0.75 (0.045)
Almeida Silva *et al.* (2013)	Brasil	M	70-79	42	-7	1.36 (0.0177)
Almeida Silva *et al.* (2013)	Brasil	M	80-100	27	7	-1.27 (0.208)
Almeida Silva *et al.* (2013)	Brasil	F	70-79	93	16	-3.91 (<0.000)
Almeida Silva *et al.* (2013)	Brasil	F	80-100	52	14	-2.44 (0.016)
Neves *et al.* (2018)	Brasil	M	65-93	141	-2	0.5 (0.617)
Neves *et al.* (2018)	Brasil	F	65-90	246	9	-2.41 (0.016)
Hu *et al.* (2018)	China	M	65-85	50	-23	4.65 (<0.000)
Hu *et al.* (2018)	China	F	65-85	58	3	-0.72 (0.473)

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

7. CONCLUSIONS

The aims of this study were estimating the maximal voluntary isometric grip strength of elderly population of Turkey and investigating the effects of age, BMI, occupation and some anthropometric variables on grip strength. The findings of this study can be summarized as follows:

(i) The grip strength of elderly population of Turkey were estimated.
(ii) In agreement with other studies, mean male grip strength was found significantly higher than female grip strength.
(iii) The age was found the most important factor affecting the hand grip strength for elderly people. Age had significant negative correlation with grip strength for both genders. The maximum grip strength starts to decrease after (70-74) age group and this decrease is dramatic after 80 years for both genders.
(iv) For both males and females, grip strength is greater in dominant hand in comparison to nondominant hand.
(v) Previous occupations of retired elderly people did not have significant effect on grip strength for both males and females.
(vi) There was a significant and positive relationship between grip strength response with hand length, hand breadth and forearm circumference for both genders.
(vii) While, height and weight were found significantly correlated with grip strength response for both genders, BMI was found significant for males only.
(viii) Grip strength of elderly population of Turkey is found significantly lower compared to the some of world populations and the same or significantly higher compared to some other world populations.

7.1. Limitations and Recommendations

Socio-economic factors, such as nutrition, daily physical activity, smoking and alcohol consumptions was not taken into consideration for the current study. However, these factors might affect elderly grip strength response as well.

Aging process causes many physiological changes to the body including loss of muscle mass and reduced muscle strength. To evaluate hand function of elderly people and to design for elderly the data provided by this study can be used for designing products that help to improve daily physical activities of elderly people.

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APPENDIX A: FORMS

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

(i) 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.

(ii) Personal Data Form: The participants also give the information related age, occupation, family origin, and father’s birthplace, dominant hand, preferred hand grip span, these informations are recorded on form, which called “Personal Data Form”. Some anthropometric measurements like height, weight, dominant & non-dominant hand length, dominant & non-dominant hand breadth, dominant & non-dominant hand wrist circumference and dominant & non-dominant hand forearm circumference are also measured during the study and are recorded on “Personal Data Form” by experimenter.

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

A.1. Personal Consent Form

In this thesis study, the aim is to determine the maximum grip strength statistics of elderly population of Turkey ranging between 70 and 98 years old in sitting postures while grip span measurement. 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 elderly population of Turkey 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.

(i) Before the experiments, your birthday, birth place, your family origin, occupation, dominant hand will be asked, after that, your height, weight, dominant hand length and breadth, and wrist and forearm circumference will be measured.

(ii) Experiments will be performed in a predetermined random order and utilizing Caldwell protocol. The experiments will be performed in neutral sitting posture for both dominant and non-dominant hands. Maximal grip strengths were recorded while the subjects were comfortably sitting on an adjustable chair with 90° elbow angle and dynamometer supported by the experimenter. 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 both dominant hand and non-dominant hand in the sitting posture by repeating the tests at least two times, so at least 16 tests will be done. The tests will be performed in a predetermined order and there will be 2 minutes break between two successive experiments. Whenever the strength variation is more than 10 per cent between two trials corresponding to the same test combination, the trials will be repeated as many times as needed.

(iii) 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 Hayriye Duygu Üstün or Dr. Mahmut Ekşioğlu from Department of Industrial Engineering of Boğaziçi University.

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

Signature of Participant: Date:

A.2. Kişisel Kabul Formu

Bu tez çalışmasında, 70 ile 98 yaş Türkiye yaşlı nüfusunun statik el-kavrama verilerini oturarak ve her iki elleriyle, uygulayacakları maksimum static el-kuvvet istatistiklerini belirlemek hedeflenmektedir. Bu çalışmaya katılabilmeniz için 70 yaşından büyük ve herhangi zihinsel, büyük bir fiziksel engelinizin ve ciddi bir sağlık sıkıntınızın olmaması yeterlidir.

Bu projede amaçlanan, Yaşlı Anadolu insanının maksimum statik el-kavrama kuvveti dağılımının cinsiyet, yaş, meslek ve vücut özelliklerine bağlı olarak hesaplanarak; fiziksel iş gücü gerektiren meslek, bölgesel faktörler, Anadolu insanın ilerleyen yaşlarında el-kavrama kuvveti üzerindeki etkilerinin incelenmesidir. Ülkemizde konu ile ilgili çalışmalar olmakla birlikte, yaşlı insanların el-kavrama kuvvet dağılımına ilişkin detaylı bir veri tabanı bulunmamaktadır.

Eğer katılmaya karar verdiyseniz, lütfen aşağıdaki hususlara dikkat ediniz.

(i) Deneye başlamadan önce doğum tarihiniz, doğum yeriniz, ailenizin doğum yeri, mesleğiniz, baskın eliniz, sorulacak ve akabinde boyunuz, kilonuz, baskın el uzunluğunuz, baskın el genişliğiniz, bilek ve önkol çevreniz ölçülecektir.

(ii) Deneyler rastege 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. Dinanometreyi, uygun şekilde tutmanız sağlandıktan sonra hazır olduğunuzda, deneyi yapan kişi tarafından; 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 her iki eliniz için oturarak 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.

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

Katılımınız tamamen gönüllü olup. katılmanız için herhangi bir zorlamayla karşılaşmayacaksınız. Dilediğinizde. çalışmanın herhangi bir aşamasında çalışmayı terk edebilirsiniz. Elde edilecek kişisel bilgiler kimseyle paylaşılmayacak. tez çalışmasında ise sadece verilerin ortalaması (kime ait olduğu belirtilmeksizin) ve maksimum ve minimum değerleri belirtilecektir.

Bu çalışmayla ilgili sorularınız ve katkılarınız olması durumunda Boğaziçi Üniversitesi Endüstri Mühendisliği Bölümü'nde Hayriye Duygu Üstün veya Prof. 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.3. 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	
Fatrher’s birthplace	
Gender	
Occupation	
Dominant hand	

2. Anthropometric Measurements of the Subject

Stature (cm)	
Weigth (kg)	
Dominant Hand length (cm)	
Dominant Hand breadth (cm)	
Dominant Hand Circumference of wrist (cm)	
Dominant Hand Circumference of forearm (cm)	
Non-Dominant Hand length (cm)	
Non-Dominant Breadth (cm)	
Non-Dominant Circumference of wrist (cm)	
Non-Dominant Circumference of forearm (cm)	

3. Grip Strength Data of the Subject

Measure	**Dominant Hand**			**Non-Dominant Hand**		
	Trial 1	Trial 2	Trial 3	Trial 1	Trial 2	Trial 3
Grip strength						

APPENDIX B: REGRESSION EQUATION

B.1. Regression Models for Grip Strength for Males (in N)

Grip Strength	-	N
Age	-	Years
Height	-	Cm
Weight	-	Kg
BMI	-	Kg/m^2
DHL	-	Cm
DHB	-	Cm
DHCW	-	Cm
DHCF	-	Cm

Table B.1. Regression model table of males for all alternatives.

Models	**Equations**
Model 1	D Grip Strength = 92 + 38.07*DHL – 6.132*Age
Model 2	D Grip Strength = – 67 – 5.262*Age + 32.75*DHL + 7.09*DHFC
Model 3	D Grip Strength = – 729 + 10.7*Age + 30.03*DHL + 7.03*DHFC + 0.436*Height – 0.098*Age*Age
Model 4	D Grip Strength = – 687 + 10.2*Age + 30.93*DHL + 8.59*DHFC + 0.430*Height – 4.28*DHWC – 0.095*Age*Age
Model 5	D Grip Strength = – 635 + 9.0*Age + 31.89*DHL + 8.82*DHFC – 5.22*DHWC + 7.5*DHB – 0.088 Age*Age
Model 6	D Grip Strength = – 712 + 10.2*Age + 29.94*DHL + 8.58*DHFC – 5.10*DHWC + 7.0*DHB + 0.404*Height – 0.095*Age*Age
Model 7	D Grip Strength = – 618 + 10.2*Age + 30.94*DHL + 8.67*DHFC – 4.22*DHWC – 1.33*BMI + 0.458*Weight – 0.095*Age*Age

Table B.1. Regression model table of males for all alternatives (cont.).

Model 8	D Grip Strength = – 709 + 10.2*Age + 29.91*DHL + 8.65*DHFC – 5.07*DHWC – 0.07*BMI + 0.391*Height + 7.0*DHB – 0.095*Age*Age
Model 9	D Grip Strength = – 649 + 10.1*Age + 30.91*DHL + 8.66*DHFC – 4.23*DHWC – 0.7*BMI + 0.20*Height + 0.24*Weight – 0.095*Age*Age
Model 10	D Grip Strength = – 678 + 10.2*Age + 29.92*DHL + 8.65*DHFC – 5.06*DHWC – 0.7*BMI + 0.19*Height + 0.22*Weight + 7.0*DHB – 0.095*Age*Age

B.2. Regression Models for Grip Strength for Females (in N)

Table B.2. Regression model table of females for all alternatives.

Models	Equations
Model 1	D Grip Strength = 227.2 + 37.8*DHB – 4.143*Age
Model 2	D Grip Strength = 247.9 – 4.451*Age – 0.390*Weight + 41.9*DHB
Model 3	D Grip Strength = 243.6 – 4.242*Age + 39.3*DHB – 0.651*BMI
Model 4	D Grip Strength = 173 – 4.193*Age + 41.0*DHB – 0.669*Weight + 3.30*DHFC
Model 5	D Grip Strength = 206 – 3.989*Age + 43.9*DHB – 8.73*DHWC + 4.59*DHFC
Model 6	D Grip Strength = 203 – 3.989*Age + 44.7*DHB – 8.48*DHWC + 5.50*DHFC – 0.953*BMI
Model 7	D Grip Strength = – 217 + 5.5*Age + 50.6*DHB – 8.44*DHWC + 6.45*DHFC + 1.05*BMI – 1.091*Weight – 0.0606*Age*Age

Table B.2. Regression model table of females for all alternatives (cont.).

Model 8	D Grip Strength = – 209 + 8.1*Age + 45.0*DHB – 9.42*DHWC + 6.44*DHFC – 1.399*BMI – 1.043*Height + 6.09*DHL – 0.0760*Age*Age
Model 9	D Grip Strength = – 39 – 4.264*Age + 45.3*DHB – 8.46*DHWC + 6.64*DHFC + 3.89*BMI + 1.04*Height + 5.48*DHL – 2.36*Weight
Model 10	D Grip Strength = – 467 + 7.2*Age + 45.0*DHB – 9.20*DHWC + 6.75*DHFC + 3.28*BMI – 2.08*Weight + 0.78*Height + 6.50*DHL – 0.0702*Age*Age