

Norms for Grip Strength in the Dominant and Non-Dominant Hand of Male and Female Apparently Healthy Adolescents

Okpala Benedict Chidubem, Onuka Samuel, Ezeukwu Antoninus Obinna, and
Okezue Obinna Chinedu

Department of Medical Rehabilitation, Faculty of Health Science and Technology,
University of Nigeria, Enugu Campus, Enugu State, Nigeria

Abstract. Hand dominance could be described as the phenomenon that occurs when one hand is preferred over the other for fine motor skills tasks. Hand grip strength is a physiological variable that is affected by a number of factors including age, gender and body size. The aim of this study was to ascertain norms for grip strength in the dominant and non-dominant hands of adolescent in Anambra state. A total of 2537 adolescents in Anambra secondary school were tested with the instrument Baseline Pneumatic hand dynamometer through multistage sampling technique in ex-post facto or Causal Comparative Research design. The instrument estimates peak grip strength over a 10 seconds period and sustained grip strength averaged across 10 seconds. Data were analysed using descriptive statistics, mean, standard deviations and parametric inferential statistics of Pearson correlation. A normative data table was established indicating peak and grip strength. Male and female show increase in grip strength with age. Boys also show more strength in their peak and grip strength on both dominant and non-dominant hands more than females. Peak grip strength in dominant hands was higher than those of the non-dominant hand across gender. Strong correlation existed between grip strength, peak grip strength and the anthropometric measures, weight, height and in particular hand length. It also shows that as the child increased in age, height and weight, their grip strength significantly increases. These data may enable physiotherapists and physicians to compare a patient's score with the scores, of normally developed children according to age gender, handedness and body measures and also to measure the outcome of any surgical procedure involving the hand.

Key Words: Hand Dominance, Hand grip Strength, Adolescent, Hand length

Introduction

Hand grip strength is a physiological variable that is affected by a number of factors and these factors include age, gender and body size (Koley & Palsignh 2010). Many of our daily functions and sporting activities requires high activity levels of the flexor musculature of the forearm and hand and these are the muscles involved in gripping strength. Often overlooked or taken for granted, the strength of one's grip plays a key role in injury prevention and rehabilitation (Budoff, 2004; Fryetal, 2006; Tietjen-Smith et al., 2006; Yasuoetal, 2005). In many cases, strengthening of the grip has been a prescription for rehabilitation from injuries such as golf and tennis elbow. According to Polquin (2006), these ailments are often caused by improper strength ratio between the elbow muscles and the forearm muscles. Health of the rotator cuff has also been correlated to the strength of one's grip. Yasuo et al (2005) found grip strength had a significant correlation with the muscle strength of 45 degrees shoulder abduction an external rotation in the affected (injury) side.

The stages of hand development include one to three months, child become aware of both visually and tactilely, three to six months child reaches out with both hands to get object, five to ten months child transfer from one hand to another, ten to eighteen months child holds object with one hand and manipulate it with the other hand, eighteen to thirty-six months, child uses both hand to manipulate but for different activities (Green, 2009).

A reliable and valid evaluation of hand strength is of importance in determining the effect of different treatment strategies or effects of different procedures (Incel et al., 2002). For

children it has also become a routine or as part of the clinical assessment of hand function since many children with various diseases or lesion has reduced grip strength (Häger-Ross, & Rösblad, 2002). An estimation of grip strength is made to identify the level of development and degree of disability. It is also used for treatment planning and evaluation (Häger-Ross, & Rösblad, 2002). Limitation of hand functions due to hand and arm injuries, stroke, cerebral palsy and other conditions are among the serious medical and socio economic problem leading to considerable restriction in professional, social and every day activities of the patient (Zverev & Kanadyaapa, 2001). Hand strength measurement have been used for a long time for assessment of disability rating, setting strength goals for patients with damaged hands and evaluation of effectiveness of various types of treatment (Young et al, 1989).

Hand dominance is the phenomenon that occurs when one hand is preferred over the other for fine motor skill task and everyday task like feeding, throwing a ball and to punch a bag (Green, 2009). It has been estimated that 85% to 90% of the world's population is right handed (Black, 2010). A selected few individuals are known to be ambidextrous which means they have the ability to handle fine motor skills tasks equally as well with either hand (Black, 2010). Some hand dominance appears to be genetically determined to a certain extent, even if both parents are left handed, there is still only a 1 out of 4 chance that the child will also be left handed (Green, 2009). According to Black (2010), the theories to explain hand dominance is that the left side of the brain controls much of the communication and functioning and therefore would be natural to control the hand an individual uses to write.

The environment can also play a role in choosing dominant hand. Desk and other materials are normally geared to make it more convenient for those who are right handed (Black, 2010). Evidence suggests that although left-handedness is partly because of genetic factors, there are other factors that contribute to the condition. Experts have identified a connection between a gene called LERTM1 and left-handedness (Black, 2010). Its presence on the father's side of the family might increase the chances of a person being a left-hander. Infact, research into identical twins has shown that if one is left-handed, there is a 76% chance that the other will also be left-handed (Black, 2010). According to research about 10% of the population has left hand dominance, studies has shown that only 2% of children of right hand parents are left handed (Green, 2009). Approximately 20% of the population has mixed dominance or other irregularities in the development of dominance. The 10% rule serves such purpose, the rule states that "grip strength of the dominant hand is 10% higher than that in non-dominant hand (Petenson et al., 1989). In many studies the hand used for writing is classified as the dominant hand and subjects are classified into left and right handers. However hand dominance is not consistent in some people because a person might prefer to use different hand for different behavioral activities or equally prefer both hands to certain manipulation and three categories of handedness namely right, left and mixed hander are well recognized (Zverev & Kamadyaapa, 2001).

There are studies done on grip strength in pediatric and sport outside the country and also few studies done in pediatric within Nigeria, but this work will focus more on determining the difference between the hand grip strength of male and female adolescent in relation to their hand length, weight and height of the individual located in Anambra state.

Without the adequate knowledge of hand dominance of grip strength there will be no normative data and there will be no bases of comparison in case of hand injuries of dominant and non-dominant hand in hand rehabilitation in Nigeria children. Also without the adequate knowledge of hand dominance on grip strength especially some conditions like cerebral palsy, which will result in limitation of hand function and this may also lead to limitation in social life, educational and everyday activities in children. Accurate and reliable evaluation of hand grip strength measurement can be used to monitor and compare the effectiveness of any surgical or non-surgical intervention of hand problem (Kamaruletal, 2006).

The estimating of hand grip strength is of great importance in determining the efficiency of different treatment strategies of hand and also in hand rehabilitation (Koley & Palsingh, 2010). It is necessary from childhood to provide enough grip force to manage independently everyday task the child will need, like eating and playing (Häger-Ross, & Rösblad, 2002).

Methods and Procedure

Procedure

The study was conducted in different secondary school in Anambra state, involving both public and private schools in Anambra state among male and female adolescent studying in selected secondary schools in Anambra state.

The participants were apparently healthy adolescent from the selected secondary schools who gave their informed consent to participate in the study. Data was collected on the participant's weight, age, height and hand length. Their grip strength and peak grip strength was obtained using the hand held dynamometer both on the their dominant and their non-dominant hand respectively with the participants seated on a chair, mid prone position of the elbow flexed in 90 degree and forearm in semi prone position with the shoulder adducted. The hand length was measured using tape rule from base of the wrist to the tip middle finger. Each grip was recorded after three trials and the average was taken. Their heights and weights were measured using standard procedure with the child standing on the standiometer barefooted and values taken from vertex of head to the foot and weight measured with the child standing upright on weighting scale.

The study employed multistage sampling techniques that were done by taking a series of simple random samples in stages. The researcher divided Anambra into three senatorial zone, and 8 local governments was drawn out of the 21 local governments in Anambra state, and one school each was selected out of the 8 local government, a total of 2401 participants were selected for the study then a casual comparative research design to compare the grip strength and peak grip strength of the dominant and non-dominant hands of adolescent in Anambra state.

Statistical Data Analysis

The data collected was analyzed using descriptive statistics, mean standard deviation and inferential and non-parametric inferential statistics of Pearson correlation, t-test, ANOVA. alpha level was set at 0.05.

Results

Table 1. Grip strength of dominant hand of males and females adolescent

Male			Female		
Age	N	Grip strength of dominant hand	Age	N	Grip strength of dominant hand
11	97	4.68±1.29	11	22	3.09±0.96
12	117	4.90±0.82	12	99	4.39±0.99
13	212	5.19±0.93	13	189	5.19±1.00
14	59	5.51±0.98	14	146	5.35±1.22
15	282	5.82±1.12	15	274	5.81±0.94
16	233	6.27±1.07	16	311	5.97±1.10
17	138	6.92±1.69	17	140	5.89±1.11
18	90	6.46 ±1.15	18	128	4.52 ±1.55
Total	1228		Total	1309	

Table 1 shows grip strength of dominant hands of both males and females of different age groups. Males most often showed greater increase in grip strength more than females except in age 13 years where female showed slight increase in grip strength more than males and in age 18 where both showed reduced grip strength

Table 2. Grip strength of non-dominant hand of males and females adolescent

Male			Female		
Age	N	Non-dominant hand grip strength	Age	N	Non-dominant hand grip strength
11	97	4.46±1.32	11	22	2.80±.01
12	117	5.00±1.03	12	99	3.90±1.20
13	212	5.08±1.14	13	189	5.01±0.99
14	59	5.59±0.98	14	146	5.49±1.25
15	282	5.69±1.33	15	274	5.60±1.04
16	233	6.09±1.15	16	311	5.63±1.20
17	138	6.39±0.95	17	140	5.59±1.21
18	90	6.25±1.19	18	128	4.28±1.65
Total	1228		Total	1309	

Key: n=total population

Table 2 shows grip strength of non-dominant hands of both males and females of different age groups. Males most often showed greater increase in grip strength more than their female counterparts. Except in age 18, where both had reduced grip strength.

Table 3. Peak grip strength of dominant hand of males and females adolescent

Male			Female		
Peak grip strength of dominant hand			Peak grip strength of dominant hand		
Age	N	Mean±SD	Age	N	Mean±SD
11	97	4.81±1.31	11	22	2.95±0.00
12	117	5.03±0.80	12	99	4.53±0.95
13	212	5.41±0.93	13	189	5.37±0.99
14	59	5.71±0.98	14	146	5.56±1.24
15	282	5.98±1.06	15	274	6.01±0.93
16	233	6.40±1.05	16	311	6.14±1.13
17	138	6.79±0.66	17	140	6.01±1.07
18	90	6.64±1.06	18	128	4.84±1.79
Total	1228		Total	1309	

Table 3 shows peak grip strength of dominant hands in both males and females adolescent in Anambra state. Males equally show more peak grip strength in dominant hand. More than their females counterparts except in age 15 years where females peak grip strength were recorded higher than the males and both showed reduced peak grip strength in age 18.

Table 4. Peak grip strength of non-dominant hand of male and female adolescent

Male			Female		
Peak grip strength of non-dominant hand			Peak grip strength of non-dominant hand		
Age	N	Mean±SD	Age	N	Mean±SD
11	97	4.64±1.30	11	22	2.95±0.00
12	117	5.11±1.05	12	99	4.14±1.23

13	212	5.29±1.17	13	189	5.17±0.99
14	59	5.81±0.97	14	146	5.66±1.25
15	282	5.87±1.29	15	274	5.76±1.03
16	233	6.24 ±1.19	16	311	5.82±1.17
17	138	6.58±0.93	17	140	5.71±1.19
18	90	6.53±1.16	18	128	4.42±1.64
Total	1228		Total	1309	

Table 4 shows peak grip strength of non-dominant hands in both males and females adolescent in Anambra state. Males equally shows more peak grip strength in dominant hand more than their female counterparts except in age 18 where females and male peak grip strength were recorded.

Table 5. The correlation and significant level for age 11

Variable	Male of age 11		Female of age 11	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.35	0.000	0.81	0.000
Grip strength versus hand length of non-dominant hand	0.23	0.000	-0.42	0.000
Peak grip strength versus hand length of dominant hand	0.25	0.000	0.00	0.000
Peak grip strength versus hand length of non-dominant hand	0.24	0.000	0.00	0.000
Peak grip strength of dominant hand versus weight	0.111	0.000	0.00	0.000
Peak grip strength of dominant hand versus height	0.10	0.000	0.00	0.000
Peak grip strength of non-dominant hand versus weight	0.10	0.000	0.00	0.000
Peak grip strength of non-dominant hand versus height	0.06	0.000	0.00	0.000

Key: R=correlation; P=significant level.

Table 6. The correlation and significant level for age 12

Variable	Male of age 12		Female of age 12	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	-0.20	0.000	0.73	0.000
Grip strength versus hand length of non-dominant hand	-0.16	0.000	0.35	0.000
Peak grip strength versus hand length of dominant hand	-0.19	0.000	0.72	0.000
Peak grip strength versus hand length of	-0.17	0.000	0.34	0.000

non-dominant hand				
Peak grip strength of dominant hand versus weight	0.16	0.000	0.55	0.000
Peak grip strength of dominant hand versus height	0.47	0.000	0.76	0.000
Peak grip strength of non-dominant hand versus weight	0.21	0.000	0.41	0.000
Peak grip strength of non-dominant hand versus height	0.51	0.000	0.61	0.000

Table 7. The correlation and significant level for age 13

Variable	Male of age 13		Female of age 13	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.4	0.000	0.22	0.000
Grip strength versus hand length of non-dominant hand	0.12	0.000	0.26	0.000
Peak grip strength versus hand length of dominant hand	0.39	0.000	0.19	0.000
Peak grip strength versus hand length of non-dominant hand	0.11	0.000	0.28	0.000
Peak grip strength of dominant hand versus weight	0.49	0.000	0.13	0.000
Peak grip strength of dominant hand versus height	0.36	0.000	0.22	0.000
Peak grip strength of non-dominant hand versus weight	0.41	0.000	0.32	0.000
Peak grip strength of non-dominant hand versus height	0.23	0.000	0.29	0.000

Table 8. The correlation and significant level for age 14

Variable	Male of age 14		Female of age 14	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.47	0.000	0.15	0.000
Grip strength versus hand length of non-dominant hand	0.33	0.000	0.94	0.000
Peak grip strength versus hand length of dominant hand	0.45	0.000	0.15	0.000
Peak grip strength versus hand length of non-dominant hand	0.37	0.000	0.05	0.000
Peak grip strength of dominant hand versus weight	0.44	0.000	0.20	0.000

Peak grip strength of dominant hand versus height	0.30	0.000	0.18	0.000
Peak grip strength of non-dominant hand versus weight	0.48	0.000	0.11	0.000
Peak grip strength of non-dominant hand versus height	0.34	0.000	0.13	0.000

Table 9. The correlation and significant level for age 15

Variable	Male of age 15		Female of age 15	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.15	0.000	0.19	0.000
Grip strength versus hand length of non-dominant hand	0.19	0.000	0.03	0.000
Peak grip strength versus hand length of dominant hand	0.10	0.000	0.55	0.000
Peak grip strength versus hand length of non-dominant hand	0.14	0.000	0.02	0.000
Peak grip strength dominant hand versus weight	0.36	0.000	-0.21	0.000
Peak grip strength of dominant hand versus height	0.40	0.000	0.55	0.000
Peak grip strength of non-dominant hand versus weight	0.30	0.000	-0.22	0.000
Peak grip strength of non-dominant hand versus height	0.33	0.000	-0.11	0.000

Table 10. The correlation and significant level for age 16

Variable	Male of age 16		Female of age 16	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.41	0.000	0.02	0.000
Grip strength versus hand length of non-dominant hand	0.55	0.000	-0.07	0.000
Peak grip strength versus hand length of dominant hand	0.40	0.000	0.01	0.000
Peak grip strength versus hand length of non-dominant hand	0.50	0.000	-0.07	0.000
Peak grip strength of dominant hand versus weight	0.50	0.000	-0.03	0.000
Peak grip strength of dominant hand versus height	0.34	0.000	0.01	0.000
Peak grip strength of	0.46	0.000	0.09	0.000

non-dominant hand versus weight				
Peak grip strength of non-dominant hand versus height	0.31	0.000	0.00	0.000

Table 11. The correlation and significant level for age 17

Variable	Male of age 17		Female of age 17	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.04	0.000	0.19	0.000
Grip strength versus hand length of non-dominant hand	0.40	0.000	0.03	0.000
Peak grip strength versus hand length of dominant hand	0.70	0.000	0.55	0.000
Peak grip strength versus hand length of non-dominant hand	0.42	0.000	0.02	0.000
Peak grip strength of dominant hand versus weight	0.11	0.000	- 0.21	0.000
Peak grip strength of dominant hand versus height	0.34	0.000	0.55	0.000
Peak grip strength of non-dominant hand versus weight	-0.30	0.000	- 0.22	0.000
Peak grip strength of non-dominant hand versus height	0.29	0.000	-0.11	0.000

Table 12. The correlation and significant level for age 18

Variable	Male of age 18		Female of age 18	
	R value	P value	R value	P value
Grip strength versus hand length of dominant hand	0.52	0.000	-0.62	0.000
Grip strength versus hand length of non-dominant hand	0.30	0.000	- 0.64	0.000
Peak grip strength versus hand length of dominant hand	0.50	0.000	-0.60	0.000
Peak grip strength versus hand length of non-dominant hand	0.33	0.000	-0.24	0.000
Peak grip strength of dominant hand versus weight	0.42	0.000	-0.37	0.000
Peak grip strength of dominant hand versus height	0.20	0.000	0.35	0.000

Key: GSD=grip strength of dominant hand; GSNONDHL=grip strength of non-dominant hand; PGSDHL=peak grip strength of dominant hand; PGSNONDHL=peak grip strength non-dominant hand; HT= height; WT= weight.

Discussion

Normative Data for Grip Strength in Dominant Hand of Males and Female Adolescents

There were 2537 adolescent that participated in the research work, 1228 male and 1309 female. The grip strength in male generally got increased across their age till about 13 years when the grip strength of males and female recorded equal value. At age 16 years the grip strength in male shows sharp increase which also progressively increased at age 17 years but declined at 18 years. In female the grip strength also increase as the child increase in age till at about age 16 years when the grip strength showed a sharp increase, after which at age 17 years their grip strength began to decline.

Comparing across different genders, males show more dominance in their grip strength than females. The grip strength of males was higher than those of the females as the age progress, till at the age of 13 years when females show equality in grip strength of their dominant hand with male. After which the strength in males equally increased as the age progress. This results are in line with work done by Sartorio, *et al.*, (2002) they discovered that age dependant increase of hand grip strength in boys and girls as well as inter-gender differences are strongly associated with changes of fat free mass during childhood. This may be due to accumulation of fat mass in the child as the child develops which may be a factor in increase in their grip strength.

Normative Data for Grip Strength in Non-Dominant Hand of Adolescents

There are 2537 adolescent that participated in the study with males being 1228 while females 1309. Males grip strength in non-dominant hand show gradual increase in grip strength in the non-dominant hand till at the age of 14 years when the strength greatly increased and continued till age 17 years after which it declined at age 18 years. In females' non-dominant hand their strength increases as their age progresses, but declined at age 18 years. Males grip strength in non-dominant hand shows more dominance than their female counterparts across different ages, also at age 14 years females have little increase in their grip strength. Comparing the grip strength in dominant and non-dominant hand among males and females, males show increase in their grip strength in dominant hand than their non-dominant hand in most of the ages. In line with research work done by Incel et al (2002) who reported that grip strength is higher in dominant hand than non-dominant hands. In females the grip in dominant hand generally shows slight increase than their non-dominant hand, except in age 14 where the non-dominant hand recorded higher than the dominant hand.

Normative Data for Peak Grip Strength in Dominant Hand of Adolescents

Total of peak grip strength of 2537 children was recorded in table 7 with male showing highest peak grip strength of 6.77 ± 0.66 in age 17 years and female with highest peak grip strength of 6.14 ± 1.13 in age 16 years. Peak grip strength in male increased with age. At age 13 male started manifesting high increases in peak grip strength. The maximum force of contraction was highest at age 17 years after which it declined at age 18 years. In females the peak grip strength shows progressive increase as age increase. At age 16 in female there was also high increases in Peak grip strength and began to decline from age 17 years. This is in line with the study conducted by Foo (2007), who reported that Handgrip strength is found to be significant determinant of bone mineral content and bone at the forearm sites and has a positive correlation with lean body mass and physical activity it determines the muscular strength of an individual.

Comparing the two genders: male showed a higher peak grip strength than the female counterpart, but at age 15 years only the peak grip strength of females was more than the male. But as the age progress to 18 years, the male's peak grip strength increases more than female.

Normative Data for Peak Grip Strength in Non-Dominant Hand of Adolescents

The maximal muscle contraction on the non-dominant hand of males is 6.58 ± 0.93 while that of females is 5.82 ± 1.17 . Male peak grip strength progressively increases with age till at the age of 14 when the strength greatly increased. At age 15 the strength of peak grip was slightly higher than the strength of age 14, while peak grip strength at 14 years till age 17 years increased greatly enough and reduced slightly at age 18 years. In females the strength among them of different ages increases as the female's progress in age. The peak grip strength of non-dominant hands increased well enough at ages 14 years. Female peak grip strength greatly increase well enough as it progress to age 14 and 15, 16 and began to decline from age 17 years. Comparing Peak grip strength in non-dominant among genders peak grip strength in male was higher than females. As the age progresses males equally dominate in grip strength of non-dominant hand.

Grip Strength and Hand Length of Dominant Hand

The results shows that the R values were 0.40 in male and 0.73 in female (alpha level at 0.05). It means that there is a strong positive relationship existing among them. As the child increase in hand length the grip strength becomes stronger. This also in line with work done by Malina *et al* (1987) Ross *et al* (2002) whose work reported that there is a strong correlation existing between grip strength and various anthropometric traits (Weight, height, hand length).

Grip Strength and Hand Length of Non-Dominant Hand

The results show that the rvalue were 0.12 in male and 0.35 in female (alpha level at 0.05). It means that there was a weak positive relationship existing among them as the child increase in hand length the grip strength becomes stronger. This is also in line with work done by Malina, et al (1987), whose work reported that there is a strong correlation existing between grip strength and various anthropometric traits (Weight, height, hand length).

Peak Grip Strength in Dominant Hand with Variable Height, Weight, and Hand Length

The results show that Dominant hand Peak grip with height, weight and with hand length correlate, male (0.40, 0.50, 0.40), female (0.76, 0.55, 0.72) respectively. It means that the three results show strong correlation existing between them. It also shows that as the child increased in age, height and weight, their grip strength significantly increases. This is also in line with research work done by Chattersand et al (1991) who reported that right and left hand grip strength was positively correlated with weight, height and body surface area. Also strong correlation existed between grip strength and various anthropometric trait (weight, height, hand length) (Malina et al., 1987).

Peak Grip Strength in Non-Dominant Hand with Variable Height, Weight, and Hand Length

The result shows that non-dominant peak grip with height, weight and hand length all correlated together, male (0.30, 0.42, 0.12), female (0.60, 0.40, 0.34) respectively. It shows also that as the child increase in age, height and weight, their grip strength significantly increase in their non-dominant hand. This also is in line with work done by Kamarul et al (2005).

They reported that there is correlation noted between hand dominance, sex, height and weight on hand grip strength. Koley (2008) studied on association of hand grip strength, weight and BMI in boy and girls aged 6-25 years of Amristar Punjab of India the result shows that there is a strong correlation existing between them. Also in line with work done by Malina, et al (1987) and Ross et al (2002) whose work reported that there is a strong correlations existing between grip strength and various anthropometric traits (weight, height, hand length).

Conclusion

Based on the findings of this study the researcher reached the following conditions:

1. There is relationship between the grip strength and hand length of the dominant and non-dominant hand of male adolescent.
2. There is relationship between the grip strength and hand length of non-dominant hand of females adolescent.
3. There is relationship between peak grip strength in dominant and non-dominant hand with variable height, weight and hand length in male and female adolescent.

Recommendation

Each hospital should have a normative data table of grip strength to aid in proper management of conditions that result in reduction in functional abilities due to loss of grip strength. A normative data table should be used in academic setting to enable the students to be aware of a normal value of grip strength in children. Further studies should be done establishing normative data using other types of dynamometer (Baseline Pneumatic dynamometer).

References

- Annett, M. (1976). Handedness and cerebral representation of speech. *Annals of Human Biology*, 3(4), 317-328.
- Barnes, R. M. (1937). *Motion and time study*. New York: Wiley.
- Best, C. H., & Taylor, N.B. (1937). *The physiological basis of medical practice*. Baltimore: The Williams and Wilkins Company.
- Black, K. (2011). What causes hand dominance. Wise Geek, 1/26/11. Retrieved from <http://www.wisegeek.com/what-causes-hand-dominance>
- Brookfield, J. (2002). *The grip master's manual*. Nevada City, California: IronMind Enterprises, Inc.
- Budoff, J. (2004). The prevalence of rotator cuff weakness in patients with injured hands. *J Hand Surg Am.*, 29(6), 1154-9.
- Cappaert, T. (1999). Review: time of day effect on athletic performance: an update. *Journal of Strength and Conditioning Research*, 13(4), 412-421.
- Corbetta, D., & Thelen, E. (1994). Interim coordination in the development of reaching. In: J.H.A. van Raceme & J. Laszlo (Eds.), *Motor development: Aspect of normal and delayed development* (pp. 11-24). Amsterdam: Free University Press.
- Coren, S. (1989). Left-handedness and accident related injury risk. *American Journal of Public Health*, 79(8), 1040-1041.
- Crosby, C.A., Wehbe, M.A., & Mawr, B. (1994). Hand strength: normative values. *J Hand surg.*, 19A, 665-70.
- Dal Monte, A., & Dragan, I. (1988). *The Olympic Book of Sports Medicine*. Cambridge: Ma.
- Dempster, W. T., & Finerty, J. C. (1947). Relative activity of wrist moving muscles in static support of the wrist joint; an electromyographic study. *Am. J. Physiol.*, 150(4), 596-606.
- Falconer, J., Hughes, S.L., Naughton, B.J., Singer, R., Chang, R.W., & Sinacore, J.M. (1991). Self report and performance based hand function tests as correlates of dependency elderly. *Journal of American Geriatric Society*, 39(7), 695-699.
- Fick, R. (1911). *Handbuch der Anatomie und Mechanik der Gelenke*. Jena: Dritter Teil.
- Fisher, A.G. (1992). Functional measures. Part 1: What is function, what should we measure and how should we measure it? *American Journal of Occupational Therapy*, 46(2), 183-185.

- Goh, V. H. H., Tong, T. Y. Y., Lim, C. L., Low, E. C. T., & Lee, L. K. H. (2001). Effects of one night of sleep deprivation on hormone profiles and performance efficiency. *Military Medicine*, 166(5), 427-431.
- Häger-Ross, C., & Rösblad, B. (2002). Norms for grip strength in children aged 4–16 years. *Acta Paediatrica*, 91(6), 617-625.
- Ibikunle, P. O., Okpago, C. B., Ihegihu, Y. E., & Okonkwo, P. (2012). Sex difference and relationship among peak grip strength, grip strength and anthropometric measures in dominant and non-dominant hands of children aged 4-16 in Southeast Nigeria. *Tropical Journal of Medical Research*, 16(2), 60-66.
- Inman, V. T., & Ralston, H. J. (1954). The mechanics of voluntary muscle. In: P.E. Klopsteg, & P.D. Wilson (Eds.), *Human Limbs and Their Substitutes* (pp. 296-317, Chapter 1). New York: McGraw-Hill.
- Kamarul, T., Ahmad, T., & Loh, W. (2006). Hand grip strength in the adult Malaysian population, *Journal of Orthopedic Surgery*, 14(2), 172-176.
- Keller, A. D., Taylor, C. L., & Zahm, V. (1947). *Studies to determine the functional requirements for hand and arm prosthesis*. Department of Engineering, University of California at Los Angeles.
- Kimmerle, M., & Mainwaring, L. (2000). *Dominance transfer issues: From the lab to the clinic*. Poster session presented at the annual meeting of the North American Society for psychomotor behavior, San Diego, CA.
- Kuzala, E. A., & Vargo, M. C. (1992). The relationship between elbow position and grip strength. *American Journal of Occupational Therapy*, 46(6), 509-512.
- Mackenzie, C. R. & Iberall, T. (1994). *The grasping hand*. Amsterdam: North-Holland.
- Mathiowetz, V., Kashman, N., Volland, G., Weber, K., Dowe, M., & Rogers, S. (1985). Grip and pinch strength: normative data for adults. *Archives of Physical Medicine and Rehabilitation*, 66(2), 69-74.
- Momiyama, H., Kawatani, M., Yoshizaki, K., & Ishihama, H. (2006). Dynamic movement of center of gravity with hand grip. *Biomedical Research*, 27(2), 55-60.
- Newcombe, F. G., Ratcliff, G. G., Carrivick, P. J., Hiorns, R. W., Harrison, G. A., & Gibson, J. B. (1975). Hand preference and IQ in a group of Oxfordshire villages. *Annals of Human Biology*, 2(3), 235-242.
- Petersen, P., Petrick, M., Connor, H., & Conklin, D. (1989). Grip strength and hand dominance: challenging the 10% rule. *American Journal of Occupational Therapy*, 43(7), 444-447.
- Poliquin, C. (2006). *The Poliquin International Certification Program Theory II Manual* (pp. 2-42). East Greenwich, RI.
- Provins, K.A. (1997). The specificity of motor skill and manual asymmetry: A review of the evidence and its implications. *Journal of Motor Behaviour*, 29(2), 183-192.
- Rudman, D., & Hannah, S. (1998). An instrumental evaluation framework: Description and application to assessment of hand function. *Journal of Hand Therapy*, 11(4), 266-277.
- Shechtman, O., Mann, W. C., Justiss, M. D., & Tomita, M. (2004). Grip strength in the frail elderly. *American Journal of Physical Medicine & Rehabilitation*, 83(11), 819-826.
- Stetson, R. H., & McDill, J. A. (1923). Mechanism of different types of movement. *Psychological Monographs*, 32(3), 18.
- Su, C. Y., Lin, J. H., Chien, T. H., Cheng, K. F., & Sung, Y. T. (1994). Grip strength in different positions of elbow and shoulder. *Archives of Physical Medicine and Rehabilitation*, 75(7), 812-815.
- Tietjen-Smith, T., Smith, S. W., Martin, M., Henry, R., Weeks, S., & Bryant, A. (2006). Grip strength in relation to overall strength and functional capacity in very old and oldest old females. *Physical & Occupational Therapy in Geriatrics*, 24(4), 63-78.