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Grip Strength and Endurance: Influences of Anthropometric Characteristics, Posture, and Gender

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SUMMARY

Background. The maximum grip strength measurement assesses the effectiveness of therapeutic approaches for upper limb dysfunction, provides an objective measure of the reliability of hand functions, and measures functional performance during occupational tasks.

Objective. The purpose of the study was to investigate muscle performance in terms of grip strength and endurance in both genders with different forearm and shoulder abduction postures.

Methods. Thirty-one healthy right-handed participants (15 men and 16 women) volunteered for this study. For present observational study, a full factorial experimental design of 2 × 3 × 3 was used: gender (male and female), different forearm posture (supination, pronation, and neutral) and shoulder abduction (0°, 90°, and 180°). The response was recorded in terms of maximal voluntary contraction (MVC) grip strength and grip endurance time at 50% MVC. A Multivariate analysis of covariance was performed using SPSS 25.0 at a significance level of 0.05

Results. The male participants had higher grip strength (698.1N ± 34.3N) and endurance (49.1 ± 3.2 seconds) as compared to females (321.6N ± 38.1N) and (34.9 ± 5.6 seconds) respectively. The forearm pronation postures showed the highest grip strength in male (724.9N ± 119.7N) and female (327.6N ± 90.2N). In addition, shoulder posture with 0° abduction showed highest grip strength in male (742.6N ± 124.5N) and female (369.8N ± 111.4N) participants. In addition, age ($p = 0.003$), weight ($p = 0.016$), palm length ($p < 0.001$), and palm circumference ($p = 0.012$) also significantly affect the grip strength.

Conclusions. A significant improvement in muscular performance in terms of hand grip strength and endurance were reported, however, they were significantly dependent on gender and anthropometric variables. Palm length and gender were the most important parameters affecting the grip strength and endurance.

KEY WORDS

Grip strength; grip endurance; anthropometric variables; gender; posture.

INTRODUCTION

Maximum grip strength measurements assess the effectiveness of therapeutic approaches for upper limb dysfunction (1), provide an objective measure of the reliability of hand function, and measure functional performance during occupational work in terms of grip strength (2). Precise measurement of grip strength is very essential in designing a hand tool or device. Especially when designers develop products for humans, the latest appropriate grip strength data is vital (3). The Jamar dynamometer is typically used to measure grip strength for ease and consistency (4). Gender and age are very vital factors affecting grip strength, and gender is a major proportion of the overall variance (5).

Grip strength is influenced by numerous factors including gender, hand posture, shoulder and forearm posture, whole-body posture, and anthropometry characteristics of the participant (6). In the literature, various previous results (7-11) provide a more precise estimation of forearm and/or hand dimensions and a better interpretation of grip strength than common anthropometric dimensions. Anthropometric measurements of the body: height and weight (12), and forearm and/or hand anthropometric variables: forearm circumference (12), palm length and palm width or circumference (12, 13) are turned out to be an important independent predictor of grip strength. In addition, previous studies (11, 14) have also confirmed that posture has a significant effect on grip strength and grip endurance. Fiebert *et al*. (15) stated supination posture to be the most significant posture for gripping during the endurance task (14). In addition, maximum grip strength was reported when the shoulders were flexed 180° with the elbows fully extended, while minimum grip strength was found with elbows flexed 90° with 0° shoulders (16). In contrast, Kattel *et al*. (10) shows maximum grip strength when the wrist was in a neutral position with upper arm abduction of 0° and elbow flexion of 135°. In addition, the maximum grip strength in pronation was significantly reduced compared to the supine and neutral forearm postures (17). Similarly, De Smet *et al.* (18) also reported minimal grip strength in the pronation compared to supine and neutral forearm postures in both male and female.

The purpose of the study was to investigate muscle performance in terms of grip strength and endurance in both genders with different forearm and shoulder abduction postures. Specificall , this study measured the grip strength and grip endurance time at 50% maximal voluntary contraction (MVC) for male and female participants in several settings, including different forearm posture (supination, pronation, and neutral) and shoulder posture abduction (0°, 90°, and 180°).

METHODS

Experimental design

For the present observational study, a full factorial design of 2 × 3 × 3 was used: gender (male and female), different forearm posture (supination, pronation, and neutral) and shoulder posture abduction (0°, 90°, and 180°). The response of the experiment was recorded randomly in terms of grip strength and endurance at 50% MVC in three different levels of forearm and shoulder postures. In addition, a stepwise multiple linear regression was used to find significant predictors of grip strength and grip endurance time.

Participants

Thirty-one healthy right-handed participants having sedentary lifestyle (15 men (range 18-26 years) and 16 women (range 19-27 years)) volunteered for this study. Participants were invited from the university campus to participate in the experiment voluntarily by notification, and the experiment plan was explained in detail. All participants signed a written informed consent form that agreed to the protocol procedure and data disclosure. The participants were excluded if they report any history of hand, forearm and wrist dysfunction. The research protocol was accepted by the Departmental Research Ethics Committee before the beginning of the evaluation (DREC/073/2020) and with the 1964 Helsinki declaration. All participants were informed that they were completely familiar with the procedure used in this study and can withdraw from the trail at any time. Participant anthropometric measurements (**table I**) were recorded according to the protocol used in previous studies (7, 8).

Apparatus and protocol for the experiment

Grip strength and endurance time were measured using hand gripper (model: G100; M/s Biometrics Ltd. UK) under all experimental conditions (**figure 1**). To record variables dependent on forearm posture, participants sat in a height-adjustable chair, with the forearm (supination, pronation and neutral),

Table I. The anthropometric variables of the participants.

Item	Male (mean ± SD) n = 15	Female (mean ± SD) n = 16
Age (years)	21.5 ± 2.5	22.6 ± 2.6
Weight(kg)	64.5 ± 9.8	49.5 ± 10.5
Length of palm (cm)	10.7 ± 0.6	9.3 ± 2.1
Circumference of Palm (cm)	21.4 ± 1.3	17.9 ± 4.5
Forearm Length (cm)	25.9 ± 1.5	22.9 ± 5.6
Circumference of forearm (cm)	28.2 ± 1.5	23.8 ± 5.9

resting horizontally on a platform and the height of the chair was adjusted for the comfort of the participants. Participant's right upper arm was on the coronal plane, abduction was 0°, and elbow angle was 90°-120°. The height of the platform was adjusted due to the inconsistency of the height of certain participants, shorter participants could not remain seated with their elbows bent at 90°; they were therefore allowed to flex their forearms further to around 30° (7). However, for shoulder abduction postures, participants sit in height-adjustable chairs and grip the grip dynamometer with shoulder abductions (0°, 90°, and 180°) postures. The shoulder abduction angles were measured with the aid of a rotary potentiometer-based goniometer (a similar goniometer was used by Bhardwaj *et al.* (19)). The stationary arm of the goniometer was aligned in parallel with the trunk while the movement arm was aligned with the humerus. In either position, the handle jammer grip dynamometer is squeezed to maximum capacity by the participants (two trials to record the MVC and two minutes rest between each trial) (20, 21) till the participants felt unbearable discomfort. The grip Jammer (Model: G100; Make: M/s Biometrics Ltd. UK) was directly interfaced with Data LINK via cable H2000 (Make: Biometrics Ltd. UK) and then connected to a Laptop (Compaq Core2Dual Processor) using USB1800 (Make: Biometrics Ltd. UK) connecting lead. Thereafter rest of five minutes was given to each participant to measure the grip endurance time at 50% MVC (taking reference as the highest value of the two trials). At 50% MVC of the respective subject, the subject was asked to sustain the grip force with ± 10% limits until they felt intolerable discomfort and could not maintain the exertion at the target level. The corresponding time was recorded as endurance time using the same Data LINK software for further analysis.

In addition, the forearm and shoulder postures were randomly selected during the trials and a 2-minute rest was granted between each experimental condition. The participants were blinded to the sequence of the experimental trials and were asked to perform 18 randomized trials (MVC and endurance measurement in supination, pronation, and neutral posture and in three different shoulder postures (0°, 90° and 180°)) depending on the experimental conditions.

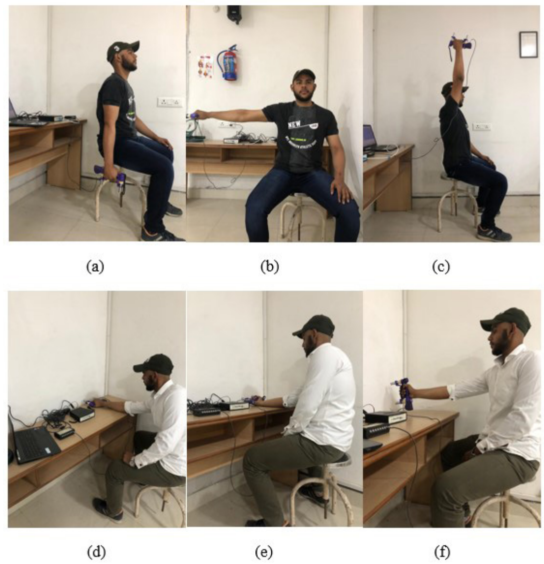

Figure 1. Measurement of grip strength (Maximal Voluntary Contraction) and grip endurance time in different forearm and shoulder abduction posture: **(a)** 0 Degree abduction, **(b)** 90 Degree abduction, **(c)** 180 Degree abduction, **(d)** Pronation, **(e)** Supination, and **(f)** Neutral.

Table II. Summary of statistically significant main effects and two-way interactions (P-values).

		Dependent Variables	
		Grip Strength	**Endurance Time**
Independent Variables	Gender	p < 0.001	p = 0.026
	Forearm Posture	p < 0.001	p = 0.036
	Shoulder Posture (abduction)	p = 0.007	p < 0.001
	Gender x Forearm Posture	p = 0.967	p = 0.701
	Gender x Shoulder Posture (abduction)	p = 0.920	p = 0.307
	Forearm Posture x Shoulder Posture (abduction)	p = 0.702	p = 0.443
Co-Variates	Age	p = 0.003	p = 0.541
	Weight	p = 0.016	p = 0.033
	Length of palm	p < 0.001	p = 0.455
	Circumference of palm	p = 0.012	p = 0.260
	Length of forearm	p = 0.181	p = 0.305
	Circumference of forearm	p = 0.340	p = 0.967

Data analysis

Table II summarizes the grip strength and endurance data for all postures. A Multivariate analysis of covariance (MANCOVA) was performed using SPSS 25.0 (SPSS Institute Inc.) at a significance level of 0.05 (**table III**). P-P plots were drawn to verify the normality of the grip strength and endurance data. In addition, Pearson's correlations tests were also accomplished to assess the correlation among the covariates and dependent variables (**table IV**). A stepwise multiple linear regression was used to find significant predictors of grip strength and grip endurance time. A multiple linear regression models were performed after selecting the predictors, to predict grip strength and endurance time as a function of anthropometry (**table V**).

RESULTS

Effects on grip strength and grip endurance time by gender

There was a significantly different effect of grip strength ($p < 0.001$) and endurance ($p = 0.026$) by gender (**table II**). The results showed that the male participants had higher grip strength and endurance than the female participants. The average grip strength of male and female participants was 698.1N ± 34.3N (mean ± SD) and 321.6N ± 38.1N (mean ± SD), respectively. In addition, the average endurance time of male and female participants was 49.1 ± 3.2 seconds (mean ± SD) and 34.9 ± 5.6 seconds (mean ± SD), respectively. The average grip strength and endurance time of female participants exhibited a decrease of 53.93% and 28.92% respectively compared to that of male participants (**table III**). However, the results showed that there were no two-way interaction effects of gender and different body postures on grip strength and endurance (**table II**).

Effects on grip strength and grip endurance time by posture

The effects of shoulder posture abduction and forearm posture on grip strength ($p < 0.001$) and endurance ($p < 0.05$) were significantly different (**table II**). In addition, shoulder posture with 0° abduction showed highest grip strength in male (742.6N ± 124.5N) and female (369.8N ± 111.4N) participants, followed by 180° abduction in male (715.14N ± 133.4N) and female (363.9N ± 114.7N) participants (**table III** and **figure 2**). The grip strength of the 90° and 180° shoulder abduction postures was not significantly different for both genders. The forearm pronation postures showed the highest grip strength in male (724.9N ± 119.7N) and female (327.6N ± 90.2N), followed by the supine posture in male (677.8N ± 130.4N) and neutral forearm posture in female (288.4N) ± 80.4N) participants (**table III** and **figure 2**).
Additionally, the 180° shoulder abduction posture showed the highest grip endurance time in male (53.2 ± 7.8 seconds) and female (44.2 ± 7.4 seconds) followed by 0° abduction in male (52.6 ± 13.1 seconds) and female (38.6 ± 11.2 seconds) participants (**table III** and **figure 3**). However, the grip endurance time in the 0° and 180° shoulder abduction positions was not significantly different for both genders. Neutral forearm postures showed the longest grip endurance time for male (49.3 ± 11.3 seconds), followed by pronation (47.1 ± 10.4 seconds); however, for female participants, the highest grip endurance time was shown by the pronation posture (33.7 ± 9.9 seconds), followed by the supine posture (33.2 ± 9.3 seconds) (**table III** and **figure 3**).

Table III. The summary of data on grip strength and endurance time.

		Grip Strength (N) (mean ± SD)		Endurance time (Seconds) (mean ± SD)	
Postures		Male	Female	Male	Female
	All Postures	698.1 ± 34.3	321.6 ± 38.1	49.1 ± 3.2	34.9 ± 5.6
Forearm Posture	Supination	677.8 ± 130.4	287.4 ± 86.3	47.1 ± 10.4	33.2 ± 9.3
	Pronation	724.9 ±119.7	327.6 ± 90.2	47.3 ± 12.8	33.7 ± 9.9
	Neutral	672.9 ± 126.5	288.4 ± 80.4	49.3 ± 11.3	31.7 ± 7.6
Shoulder Posture (Abduction)	0°	742.6 ± 124.5	369.8 ± 111.4	52.6 ± 13.1	38.6 ± 11.2
	90°	655.3 ± 120.5	292.4 ± 71.6	45.3 ± 12.2	28.3 ± 9.4
	180°	715.1 ± 133.4	363.9 ± 114.7	53.2 ± 7.8	44.2 ± 7.4

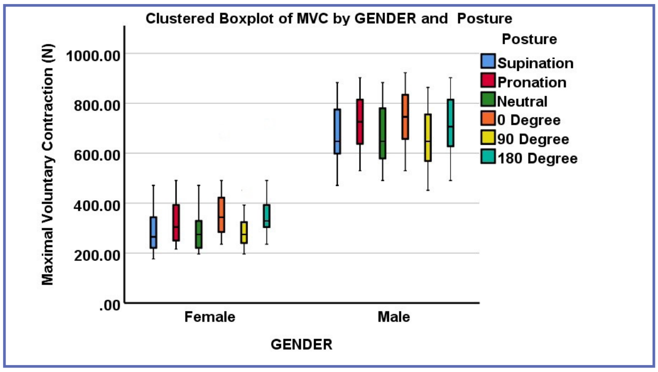

Figure 2. Clustered Boxplot of MVC grip strength by gender and posture.

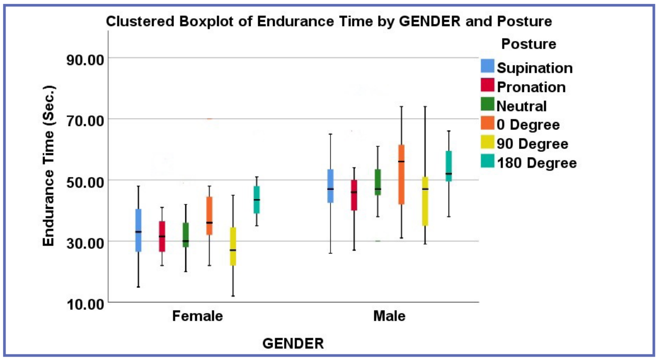

Figure 3. Clustered Boxplot of Endurance Time by gender and posture.

Effects of anthropometric variations on grip strength and endurance time

The present study results showed that age (p = 0.003), weight (p = 0.016), palm length (p < 0.001), and palm circumference (p = 0.012) significantly affect the grip strength. However, grip endurance was significantl differed only for weight (p = 0.033) (**table II**). Pearson correlation tests were also performed for the prediction of grip strength (N) and endurance time based on anthropometric measurements. Results showed that length of palm (r = 0.850, p < 0.001) was the best predictor of grip strength followed by circumference of palm (r = 0.729, p < 0.001) and length of forearm (r = 0.723, p < 0.001). Additionally, for endurance time, length of palm (r = 0.541, p < 0.001) was the best predictor, followed by circumference of palm (r = 0.497, p < 0.001) and length of the forearm (r = 0.413, p < 0.001) (**table IV**).

Linear regression analysis

Table V showed R-square value for predicting grip strength and endurance time based on anthropometric measurements. The results showed that the model was statistically significant (p < 0.001) and R-square value of the grip strength was 0.825 and for endurance was 0.298, and the RMS error of grip strength was 95.40N and the endurance was 9.39 seconds. In addition, the gender was the utmost important interpreter of grip strength and grip endurance time (an average decrease of 373N and 14.16 seconds for female).

DISCUSSION

The purpose of the study was to investigate muscle performance in terms of grip strength and endurance in both genders with different forearm and shoulder abduction postures. The results of the current study exhibited that gender, shoulder abduction and forearm postures (p < 0.05) significantly affect the grip strength and endurance. Similarly, Lee and Hwang (6) exhibited gender, handedness, and posture had also a significantly different effect on the grip strength. In addition, they conclud-

Table IV. Pearson correlation coefficients (r), and P-values, for prediction of grip strength (N) and grip endurance based on anthropometric measures.

	Age	Weight	FL	FC	PL	PC
Grip Strength	0.202 (p = 0.016)	0.603** (p < 0.001)	0.723** (p < 0.001)	0.237** (p < 0.001)	0.850** (p < 0.001)	0.729** (p < 0.001)
Endurance time	0.118 (p = 0.109)	0.313** (p < 0.001)	0.413** (p < 0.001)	0.078 (p = 0.289)	0.541** (p < 0.001)	0.497** (p < 0.001)

Table V. R-square, P-values, and RMSE value as a prediction of grip strength (N) and grip endurance time (seconds) based on anthropometric measures.

	Intercept	Gender	R-square	RMSE	P-value
Grip Strength	9.76	- 373.156	0.825	95.40	< 0.001
Grip endurance time	10.92	- 14.16	0.298	9.39	< 0.001

Indicated P-values < 0.05; male = 0; female = 1; RMSE = root-mean-square-error.

ed that the grip strength of male subjects was 2.05 times that of female subjects, and the 0° shoulder posture had a 3% higher grip strength than at 180°. Further, the grip strength of the neutral forearm posture was 2.4% higher than that of the supination posture (6). Similarly, the current results show that the grip strength of male subjects is 2.17 times that of female subjects. The grip strength at shoulder posture with 0° abduction is approximately 11.3% and 3.7% higher than the 90° and 180° abduction, respectively. In addition, the grip strength produced by the pronation posture is 7.2% higher than that of the neutral posture. In addition, consistent with current results, previous studies have shown that grip strength is higher in male than in female of comparable age groups (6, 22-30).

De Smet *et al.* (18) reported minimal grip strength in the pronation compared to supine and neutral forearm postures in both male and female. In contrary, present results showed the highest grip strength in male and female participants in the forearm pronation postures. In addition, shoulder posture with 0° abduction showed highest grip strength in both genders, followed by 180° shoulder abduction. Consistent with present results, Kattel *et al.* (10), shows maximal grip strength with a neutral wrist with an abduction of the upper arm of 0° and an elbow flexion of 135°. Su *et al.* (16) reported maximum grip strength when the shoulders were flexed 180° with the elbows fully extended, while minimum grip strength was found with elbows flexed 90° with 0° shoulders. However, the current results show that male (742.6N ± 124.5N) and female (369.8N ± 111.4N) participants with 0° shoulder abduction posture have highest grip strength, followed by men (715.14N ± 133.4N)) and female (363.9N ± 114.7N) participants with a 180° shoulder posture (abduction). In addition, grip strength decreased in both gender as the shoulder was positioned at 90° abduction. This findin indicates that the angle of the shoulder joint (90° abduction) does not affect the grip performance as compared to 0° and 180° shoulder abduction position. It can be speculated that the coordinated muscles of the back and shoulders may be able to work best when raising the shoulders in a 0° abduction or 180° shoulder posture (abduction). However, this requires further EMG studies to evaluate the comprehensive function of upper limb and back muscle activity in the grasping process of these shoulder postures (16). In addition, it is speculated that cultural and ethnic factors such as the level of physical activity, the roles of men and women in different societies, height and weight, *etc.*, may be related to this finding. This is an area that needs more research.

The results of present study showed that age ($p = 0.003$), weight ($p = 0.016$), length of palm ($p < 0.001$), and circumference of palm ($p = 0.012$) had a significant effect on grip strength. Similarly, Alam *et al.* (8) showed significant effects of length of palm, circumference of palm and length of forearm on grip strength. In addition, Wu *et al.* (14) found that palm length was the best significant factors influencing grip strength after age and gender. Similarly, present results showed that length of palm ($r = 0.850$, $p < 0.001$) was the best predictor of grip strength followed by circumference of palm ($r = 0.729$, $p < 0.001$) and length of forearm ($r = 0.723$, $p < 0.001$). Another study by Alam *et al.* (7) concluded that length of palm and age significantly affects the grip strength and length of palm, being the utmost decisive parameter ($r = 0.357$, $p < 0.001$). Crow and Ship (31) and Petrofsky and Lind (32) reported significantly different effect of age on grip strength ($p < 0.001$); however, age was not significantly affecting the endurance. Interestingly, present results also showed significant correlation of age with MVC grip strength ($r = 0.202$, $p = 0.016$), however, age was not significantly affecting the endurance ($r = 0.118$, $p = 0.109$).

CONCLUSIONS

It can be concluded that male participants have higher grip strength and endurance compared to females. Compared with women, the pronation position and 0° shoulder abduction position showed the highest grip strength among men. In addition, palm length is the best predictor of MVC grip strength and grip endurance time. Therefore, it is suggested that anthropometrics and grip strength data for specific postures may be useful for clinical and industrial applications in the Indian population.

Limitations and future scope

Initially, only young college students were considered, so this study did not investigate the influence of different age groups on grip strength. Future studies may investigate the impact of hand dominance (left and right) and collect grip strength in various age groups from young subjects to the elderly of same or different ethnic group.

FUNDINGS

None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

MMA: conceptualization, design and writing of the manuscript. AMA: developing of protocol for the study. IA, AS, MHK: data collection.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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