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Optimal Handle Grip Span for Maximum Hand Grip Strength and Accurate Grip Control Strength Exertion according to Individual Hand Size

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Abstract

Background: Hand grip strength (HGS) and grip control strength (GCS) are two predictors of upper-extremity function to undertake activities of daily living. Numerous studies have indicated that hand size and handle diameter independently affect HGS. However, none has explored the effects of matching hand size to optimal grip span on ergonomic outcomes. The aim of this article was to investigate the relationships among grip strength, hand size, and grip span.

Methods: Seventy two healthy adults (age range 18-30 year) were divided into three hand size groups (small 23, medium 25, and large 24) and evaluated their HGS and GCS data three times on both hands. Hand size was measured from the base of hand to the tip of middle finger and three different grip spans (47.6, 60.3, and 73.0 mm) were executed.

Results: The results indicated that individual hand size was positively correlated with maximum HGS in the both hands ($p<0.01$) but did not significantly affect GCS ($p>0.05$). Analysis of variance demonstrated a clearly significant difference in HGS for men, not for women, in the three hand size groups. For participants in the three different hand size groups, a grip span of 47.6 mm would exert the maximum HGS.

Conclusion: Hand grip strength was influenced by hand size and grip span in both hands. There is an optimal grip span to which the dynamometer should be adjusted when measuring hand grip strength in people. These findings may guide occupational therapy clinicians and staff members designing ergonomic interventions.

Keywords: Grip control strength; Grip span; Hand grip strength; Hand size

Introduction

There are two kinds of important gripping strength in our daily tool operation, hand grip strength (HGS) and grip control strength (GCS). Hand grip strength is as an indicator of the total body strength, an objective test for physical capability, and a valid predictor of work capacity, degree of disease/injury, and rehabilitation outcomes [1]. Hand grip strength is a simple and economic evaluation that gives practical information about muscle, nerve, bone, or joint disorders [2,3]. The daily tool operation by hand is not only related to HGS, but is also relevant to GCS, a control ability of force exert accurately by hand palm [4,5]. Numerous studies have aimed to understand the factors related to occupational safety and application, specifically HGS and GCS [6-11]. Those studies indicated that hand grip strength was a critical source of power for work-related operations. Simultaneously, excessive or inappropriate grip force applications are the foremost cause of injuries to muscles and bones [12,13], especially regarding cumulative injuries (Cumulative Trauma Disorders, CTDs). Therefore, designing an intervention system that prevents injuries caused by inappropriate tool use is an important issue for modern pre-therapy pioneers.

Numerous studies also showed that HGS is influenced by several factors such as age; gender; posture; hand size; and grip span [14-17]. Occasionally, grip span is the most important factor that influences the strength exerting and offers the knowledge for a valid predictor of work capacity [18].

Recent studies have reported that the maximum volitional contraction (MVC) of hand is affected by various factors, including "grip span" and "hand size" which affect both strength output and muscle activity [16,19-22]. However, no study date has matched "grip span" and "hand size" to explore the best HGS and GCS outcomes, the latter in particular. The maximal hand grip strength from each of the fingers was obtained at a handle separation of 55-65 mm for males and in 50-60 mm for female's European people [20,23-25]. However, the population differences, optimal handle separation of maximum force exertion in Asia population might be different in European people.

Consequently, the purposes of this study were to investigate the effects of different grip spans of young adults in an effort to achieve maximum HGS and accurate GCS using a hand dynamometer and explore the correlation between hand size and grip span to optimize outcomes. Here, we evaluated the HGS and GCS of Taiwanese individuals in a "free" posture to identify the optimal grip span and improve occupational therapy interventions.

Methods

Design

Quantitative methods were used to investigate the relationships among grip strength, hand size, and grip span. The study was undertaken at a university-based participants' physical capability, and two experiments making evaluations on the value of HGS and GCS was executed. Hand grip strength was measured using a digital dynamometer (Japanese style, Tkk 5001), and the scores were recorded in kilograms. The reported precision of the dynamometer was 0.1 kg. The dependent variables were HGS and GCS, and the independent variables were hand size (small, medium, and large) and grip span (47.6, 60.3 and 73.0 mm). To conduct the relationship between hand grip strength and hand size, ANOVA and correlation analysis was used.

Participants

Due to HGS depends on age, and in generally, young people are reached the maximum value in grip strength in Taiwan (male 20 year, female 17 year) [26], hence, the study selected the young people as subject to evaluate their HGS and GCS. Seventy two healthy participants (29 males, 43 females) random selecting from Taiwan Shoufu University grade 1 to grade 4 students between the ages of 18 and 30 participated in the study after receiving information about the aim and clinical implications of the investigation. Mean age was 20.6 (± 1.88) years. All participants included in the present study did not have any muscle- or joint-related injuries and free of any lesion or impairment in the upper limbs. As previously reported study, participated subjects were encouraged to do their best when performing the tests and were advised not to perform strenuous physical in the 24 h preceding the test [27]. At the beginning of the experiment, informed Agree Consent was obtained and anthropometric measurements were made. Based on hand length each participant was assigned into one of the following three hand size groups in both genders [28,29]. Participants' anthropometric data of small, medium, and large hand size were shown in Table 1.

	Female			Male		
	Hand size			Hand size		
Variable	Small	Medium	Large	Small	Medium	Large
Number (n)	13	15	15	10	10	9
Percentile (%)	5-30	31-70	71-95	5-30	31-70	71-95
Age (years)	20.6 ± 1.42¶	20.6 ± 2.41	19.6 ± 1.35	20.5 ± 1.26	21.3 ± 2.00	21.0 ± 2.89
Hand length (cm)	15.9 ± 1.53	17.3 ± 0.21	18.3 ± 0.37	17.8 ± 0.42	19.1 ± 0.34	20.3 ± 0.71
Body height (cm)	155.8 ± 5.00	159.3 ± 4.44	162.4 ± 4.40	169.7 ± 4.52	175.4 ± 4.72	183.4 ± 7.16
Body weight (kg)	51.1 ± 9.99	57.5 ± 11.7	56.8 ± 8.87	67.0 ± 13.2	80.9 ± 13.2	86.4 ± 11.1

Table 1: Anthropometric data of small, medium, and large hand size participants†, †Hand size was measured from the base of hand to the tip of middle finger in right hand, ¶mean ± SD.

Quantitative Measures

Assessment of hand size: Hand size was measured in both hands at maximal length and by measuring the length of hands simply stretch out the palm up and use a measuring tape from the base of hand to the tip of middle finger [29-31]. The results of hand size were therefore rounded to the nearest whole centimetre.

Assessment of hand grip strength: Maximum hand grip strength was measured using the hand grip dynamometer. When operating the dynamometry, participants maintained the standard bipedal position during the entire test with the arm and upper arm at a 90 degree and did not touch any part of the body with the dynamometer except the hand being measured [32,33]. Each participant performed the test three times using different grip spans and held onto the dynamometer tightly for approximately 3 s, relaxed, and then repeated the operation three times. Participants took a 10 s break between each operation. After consecutively performing the experiment for 30 min, participants rested for at least 5 min. For each measurement, three grip spans and both hands were tested. The grip spans used were 47.6, 60.3, and 73.0 mm, which corresponded to 5 different positions on the TKK dynamometer.

Assessment of grip control strength: Grip control strength (GCS) was measured using the hand grip dynamometer on all occasions. Measurement processes of grip control strength were performed according to the methods and instruments used by previous studies [5,10]. Measurement of grip control strength used a specified value as the standard, and participants were asked to attain this standard value as accurately as possible, and the deviation between the standard value and the participants' grip estimates were calculated. The lower value of the deviation indicated the better grip control strength was. The higher value of the deviation indicated the worse grip control strength was. To determine the accuracy of GCS, Equation (1) was used, shown as below:

$$GCS_i=|F_0-F_i| \qquad (1)$$

GCS_i: accuracy of grip control strength (kg), F_0 (kg): an indicated hand grip value, F_i (kg): the estimated value of the actual grip of the subject being exerted, $|F_0-F_i|$ (kg): the absolute value after deduction between F_0 and F_i

F_0 adopted in this study was 70% of the value obtained from the average when a participant's maximum hand grip strength was tested three times as the standard value of GCS_i (the data were 70% of HGS). F_i was the estimated value of the actual grip of the subject being exerted. The benefits and disadvantages of GCS_i were determined according to the deviations between the hand grip value performed by the participants and the targeted loading value of 70% of HGS. A smaller absolute value of the deviation indicated a greater accuracy of the grip control strength was, whereas a larger absolute value of the deviation indicated a lower accuracy of the grip control strength was [5,10]. After completing the tests, all data were analyzed by SPSS 23.0 statistical software.

Quantitative data analysis

Data were summarized using descriptive statistics of mean and standard deviation. Inferential statistics of independent ANOVA were used to compare HGS and GCS among small, medium, and large hand size groups of men and women. Pearson's product moment correlation analysis was used to test the correlation between hand grip strength and hand size.

Results

The results are presented in four parts. Part one provides the assessment performance of hand grip strength (HGS). The second part presents the assessment performance of grip control strength (GCS). The third part shows the ANOVA test results for HGS and GCS, and the last part demonstrates the Pearson's product moment correlation test of relationship between hand grip strength and hand size.

Part 1: Assessment performance of hand grip strength (HGS)

The results showed a reliability coefficient of 0.980, 0.982 and 0.990 for the three time of three grip spans' tests in HGS, respectively.

Handle diameter (mm)	Female			Male		
	Hand size			Hand size		
	Small†	Medium†	Large†	Small†	Medium†	Large†
Left hand						
47.6 mm	22.7 ± 4.13¶	26.1 ± 5.60	24.7 ± 5.00	38.1 ± 5.40	45.3 ± 6.29	44.7 ± 3.84
60.3 mm	20.5 ± 4.41	23.0 ± 4.41	23.6 ± 5.25	36.0 ± 4.99	41.3 ± 4.38	44.4 ± 4.01
73.0mm	17.3 ± 4.27	19.6 ± 4.98	21.3 ± 4.08	31.4 ± 5.20	37.8 ± 1.93	40.2 ± 3.45
Right hand						
47.6 mm	23.0 ± 6.82	25.7 ± 6.41	24.5 ± 5.46	38.3 ± 4.19	43.5 ± 9.13	42.7 ± 6.18
60.3 mm	20.4 ± 5.80	24.8 ± 6.56	24.1 ± 5.20	36.8 ± 4.56	40.1 ± 7.32	44.6 ± 5.83
73.0 mm	18.6 ± 6.00	20.8 ± 6.23	22.3 ± 4.13	33.6 ± 5.60	35.4 ± 5.01	40.7 ± 5.15

Table 2: The means (SD) of HGS of small, medium and large hand size groups in female and male, †Small: 5–30 percentiles; medium: 31–75 percentiles; large: 76–95 percentiles for each gender, ¶mean ± SD of HGS (kg).

They would be an excellent reliability. The means and standard deviations (SD) of HGS of small, medium and large hand size groups in female and male was shown in Table 2.

As Table 2 shows, a grip span of 47.6 mm in the three hand size groups of female and male individuals exerted a larger HGS value in the left and right hands than the other two grip spans (60.3 and 73.0mm) in all groups except for male in the large hand size with a 60.3-mm span. For example, regarding to female's small size group, the HGSs of left hand at 47.6, 60.3 and 73.0mm grip span were 22.7, 26.1, and 24.7 kg, respectively. This result indicated that the scale of grip span at 47.6 mm would produce the maximal hand grip strength value. Thus, the optimal grip span for exerting the maximum hand grip strength would be at 47.6 mm in this study. This result was in accordance with the study by Liao [33]. On other hand, for fixed at a certain grip span, e.g. 47.6 mm, the medium hand size group always exerted the largest value of HGS, and the small hand size group always exerted the smallest value of HGS. This result indicated that the maximum volitional contraction of hand grip was a clear and strong related to hand size. The length of hand will influence the exerting of maximum volitional contraction closely. In both genders, and both hands, males always obtained the higher values of HGS at each grip span than females ($p<0.01$) (t-test data not shown). This result was in accordance with previous studies [10,33].

Part 2: Assessment performance of grip control strength (GCS)

The reliability coefficients of three time tests of GCS in the three grip spans were 0.975, 0.975, and 0.973, respectively. They would be an excellent reliability. The means and standard deviations (SD) of GCS of small, medium and large hand size groups in female and male was shown in Table 3.

As Table 3 shows, the small hand size group at a grip span of 47.6 mm exerted the smallest GCS value in the left hand.

Hand diameter (mm)	Female			Male		
	Hand size			Hand size		
	Small†	Medium†	Large†	Small†	Medium†	Large†
Left hand						
47.6 mm	0.33 ± 0.15¶	1.10 ± 1.36	1.32 ± 1.94	0.70 ± 0.70	1.04 ± 1.81	0.91 ± 0.85
60.3 mm	0.54 ± 0.36	0.74 ± 0.80	0.86 ± 1.22	0.39 ± 0.37	0.84 ± 0.39	0.58 ± 0.86
73.0mm	0.65 ± 0.67	0.60 ± 0.46	1.03 ± 1.04	0.62 ± 0.52	0.45 ± 0.55	0.76 ± 0.63
Right hand						
47.6 mm	1.25 ± 2.61	0.84 ± 1.42	0.57 ± 0.94	0.46 ± 0.28	0.46 ± 0.42	1.02 ± 1.04
60.3 mm	1.36 ± 2.94	0.80 ± 1.01	0.75 ± 0.54	0.46 ± 0.30	0.76 ± 0.60	1.20 ± 1.19
73.0mm	1.24 ± 2.05	0.98 ± 1.13	1.24 ± 2.11	0.91 ± 0.83	0.78 ± 0.56	0.49 ± 0.65

Table 3: The means (SD) of GCS of small, medium and large hand size groups in female and male, †Small: 5–30 percentiles; medium: 31–75 percentiles; large: 76–95 percentiles for each gender, ¶mean ± SD of GCS (kg).

For example, in female, the mean GCS of the small, medium, and large hand size groups was 0.33, 1.10, and 1.32 kg at 47.6 mm, respectively. Thus, for the small hand size participants, the optimal GCS would be 47.6 mm, and for medium and large hand size group participants, the optimal grip span for GCS would be 60–70 mm. These findings were different from those obtained during maximum volitional contraction.

Part 3: ANOVA test for HGS and GCS

In order to understand the group difference, one-way ANOVA was used to analysis the differences among the small, medium, and large hand size groups in HGS and GCS. Before the formal ANOVA performed, the basic assumption of a homogeneity test for ANOVA was first adopted.

The Levene results indicated that the homogeneity of women and men in the left and right hand HGS and GCS were not in violation of the basic assumption of ANOVA ($p>0.05$) [34] and that a second ANOVA test was indicated. The ANOVA test results of small, medium, and large hand size groups in HGS and GCS in both genders and both hands were shown in Table 4.

As Table 4 shows, the HGS of male in left hand, small, medium, and larger three hand size groups were significant differences ($F_{0.95}$=5.536, 8.573, and 13.92; p=0.010, 0.001, and 0.001, for grip span at 47.6, 60.3, and 73.0mm, respectively).

A post-hoc least significant differences (LSD) test showed significant differences between the large and small hand size groups and between the medium and small hand size groups at the three different grip spans.

HGS values of men's right hand in the small, medium, and large hand size groups were significantly different between 60.3 and 73.0mm grip spans ($F_{0.95}$=4.240, and 4.532; p=0.025 and 0.020 for grip spans of 60.3 and 73.0mm, respectively).

A post-hoc (LSD) test showed that significant differences existed between large and small hand size groups at the 60.3 mm grip span and a significant difference existed between large and medium hand size groups and between large and small hand size groups at the 73.0-mm grip span.

For female HGS and GCS, ANOVA tests showed no significant differences in the small, medium, and large hand size groups at the three grip spans in both the hands ($p>0.05$).

However, regarding the GCS of women in right hand, post-hoc (LSD) tests showed significant differences existed between large and small hand size groups at the 47.6 mm grip span and between large and small hand size groups at the 60.3 mm grip span.

Part 4: Hand grip strength and hand size correlation analysis

The Pearson's product moment correlation analysis of relationship between hand grip strength and hand size showed that the dependent variable (HGS) was positively correlated with hand size in left and right hand. The correlation coefficients of left hand size with left hand HGS at 47.6, 60.3, and 73.0mm grip spans were 0.557, 0.601, and 0.642, respectively ($p<0.01$). The correlation coefficients of left hand size with right hand HGS at 47.6, 60.3, and 73.0mm grip spans were 0.562, 0.596, and 0.633, respectively ($p<0.01$).

The correlation coefficients of right hand size with left hand HGS at 47.6, 60.3, and 73.0mm grip spans were 0.467, 0.560, and 0.568, respectively ($p<0.01$). The correlation coefficients of right hand size with right hand HGS at 47.6, 60.3, and 73.0-mm grip spans were 0.462, 0.548, and 0.544, respectively ($p<0.01$).

However, the Pearson's product moment correlation test of relationship between grip control strength (GCS) and hand size showed that no significant differences existed in left and right hand.

The results showed that hand size was correlated with GCS with a correlation coefficient (r) ranging from -0.013 ~ 0.126 for both hands ($p>0.05$). These findings are supported by previous researches [9,10].

Variable	Female			Male		
	Hand size			Hand size		
	F-ratio	p-value	Post-Hoc	F-ratio	p-value	Post-Hoc
HGS						
Left hand						
47.6 mm	1.589	0.217	-	5.536	0.010**	medium>small**
						large>small*
60.3 mm	1.429	0.252	-	8.576	0.001***	medium>small*
						large>small***
73.0mm	2.738	0.077	large>small*	13.92	0.001***	medium>small***
						large>small***
Right hand						
47.6 mm	0.662	0.521	-	1.654	0.211	-
60.3 mm	2.216	0.122	-	4.240	0.025*	large>small**
73.0mm	1.588	0.217	-	4.532	0.020*	large>small**
						large>medium*
GCS						
Left hand						
47.6 mm	1.849	0.171	-	0.192	0.826	-
60.3 mm	0.465	0.632	-	1.524	0.237	-
73.0mm	1.399	0.259	-	0.687	0.512	-
Right hand						
47.6 mm	0.517	0.600	-	2.560	0.097	large>small*
60.3 mm	0.518	0.600	-	2.183	0.133	large>small*
73.0mm	0.103	0.902	-	0.888	0.424	-

Table 4: Comparing the HGS and GCS difference in small, medium, and large hand size groups in female and male, Using one-way ANOVA and LSD post-hoc test†, $^{\dagger}n=72$, $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.

Conclusion and Discussion

This study has come to the following conclusions. First, the relationship between HGS and hand size was clearly positively correlated in both hands (p<0.01). A larger hand size will produce larger grip strength. Hand's length was a crucial significant factor that affecting the HGS. For instance, ANOVA clearly showed significant differences in HGS in men, not in women, among the three hand size groups. This finding was not in accordance with the study of Ruiz [22]. That study indicated that hand size was influenced by optimal grip span in women, not in men. These contrasting results may have been due to differences in hand size definitions. In Ruiz study, hand size was determined by measuring both, maximal width and the distance separating the distal extremes of the first and fifth digits. In the current study, hand size was measured from the base of the hand to the tip of the middle finger (Figure 2).

Second, ANOVA test indicated that three different hand size groups, small, medium, and large were not significant differences in GCS in both hands (p>0.05). This finding was in accordance with previous researches [10,33]. Third, this study also found that grip span 47.6 mm (1.874 in) at left hand would exert the maximum HGS value in small, medium, and large hand groups. This means that a grip span of 47.6 mm fit all hand sizes of these Taiwanese young people since it produced the largest HGS value. Consequently, a grip span of 47.6 mm would be optimal for this population.

In summary, this study results demonstrated that HGS was affected by hand size and grip span. People with a long hand would be shown as having strong HGS; however, GCS was not obviously affected by hand size. The data obtained in this study can be used as a reference to predict work capacity and ensure healthy diagnostics as well as in the design of hand tools and equipment. It could also be used to select physical athletes in cases in which grip strength is an indicator of physical status. However, hand size and grip span must be considered in any assessment.

Finally, the finding of this study could offer the data for tool handle design by ergonomic and occupational therapy staff members. Participates in this study included undergraduate students in an urban setting who did not perform hard manual activities (particularly women), so overall grip strength might be low. Further studies might enlarge the population to increase the reliability and validity. In addition, hand size and grip span might be further measured as described by Ruiz et al. [16]. It would be highly beneficial to re-conduct this study in the future to measure and compare the findings over two or more occurrences and perhaps consider subject age and dominant hand to provide further insight into this assessment's contributions to ergonomic tool design.

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