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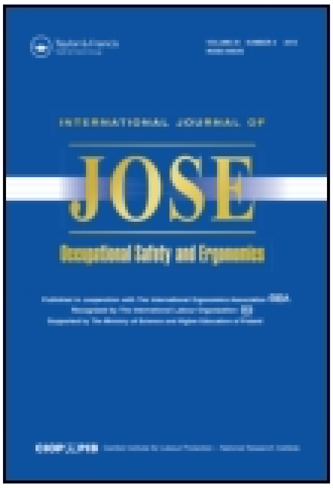

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Experimental Study on Gender Differences in Hands and Sequence of Force Application on Grip and Hand-Grip Control

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Experimental Study on Gender Differences in Hands and Sequence of Force Application on Grip and Hand-Grip Control

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The purpose of this study was to examine how gender of young adults in Taiwan affected the ability of their hands to apply force regarding the use of the left or right hand and the varying sequences of force application. Maximal voluntary contraction of grip (MVC_g) and hand-grip control ($HGC_{50\%}$) of 200 participants was measured. The study discovered that gender showed significant differences in the scale of MVC_g, whereas there were no significant differences in $HGC_{50\%}$. Left hand versus right hand resulted in significant differences in the scale of MVC_g, whereas there were no significant differences in the scale of $HGC_{50\%}$. The 5 levels of the sequence of force application showed no significant differences in either MVC_g or $HGC_{50\%}$. The interactive effects of the 3 factors (gender, hand, and sequence of force application) showed no significant differences. The results of the study can serve as a reference in designing tools.

maximal voluntary contraction of grip   grip   hand-grip control   gender differences

1. INTRODUCTION

Economic development and industrial progress have led to a widespread use of automated operations. However, many products are not yet automatically operated. Therefore, manual workers must still know how to use various hand tools and equipment. Although automated systems are prevalent, manual operations remain necessary. Force application of the hands is the most common method of operating hand tools and moving objects. Three chief types of force application are involved in using hands: grip, pinch, and torque, of which grip is used most frequently for controlling force application. However, excessive or inappropriate force application is the foremost cause of musculoskeletal injuries [1], especially regarding cumulative injuries and cumulative trauma disorders (CTDs). In addition, upper limb CTDs are often related to excessive force application when using hands, as well as repetitive and high-frequency actions [2, 3, 4, 5, 6]. Therefore, developing a method to avoid injuries caused by an inappropriate use of tools is an important issue in human factor engineering.

Hand injuries are related to many factors, e.g., tool use, method of force application, time and frequency of force application, and individual physique. Understanding the level of force application for each group is not only critical to tool design, but it is also important for developing a reference to create standards for force application. Shih, Fu, and Wang indicated that when a tool handle was ~38–50 mm long, both male and female users had greater grips [7]. Their study used five handle diameters (25.4, 38.1, 50.8, 63.5, and 76.2 mm) to exert maximal voluntary contraction (MVC). They found that 38–51 mm was the most suitable size for young adults in Taiwan to exert their maximal grip because this size produced more grip power than other diameters and was less likely to cause muscle fatigue. The relationship of MVC to grip diameter was not linear. Handle lengths with these specifications were the most labor-saving and least likely to cause injury. In addition, Shih et al. indicated that grip strength

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was related to the height of hands and elbows, signifying that body height was a potential influencing factor for grip strength [7]. Grant, Habes, and Steward [8] and Uetake and Shimoda [9] demonstrated that tool handle diameter affected force application. For example, when the handle diameter was 1 cm shorter than the longest inner diameter of a hand, maximal voluntary contraction of grip (MVC_g) was greatest. Therefore, grip is affected by tool handle diameter. This means that handle size requires attention when new tools are designed.

Furthermore, muscle injuries are often related to the number and frequency of hand grip use. Using tools too many times or too frequently, or exceeding the MVC_g range, can easily cause muscle injuries, and reduce tool use efficiency. According to Hung, when consecutively applying force using grip, taking 30-s breaks between each operation resulted in the best results for all three types of loading weight operations [10]. Therefore, Hung recommended short breaks between each measurement during experiments on grip.

The strength of force application is related to individual physique and gender. Studying gender differences has become increasingly important as more women have entered the workforce. Kuo showed that in every grip distance and positioning of the hand or wrist, MVC_g was greater in males than in females [11]. The MVC_g of females was ~58% that of males. Regardless of whether the participants wore or did not wear gloves of any type, the males all had greater MVC_g than the females.

In addition, Shih et al. showed an obvious difference in the ability to apply force between young males and females in Taiwan, in that the MVC_g of females was ~46% that of males [7]. Li and Hunag discussed factors, such as gender, arm position, the angle of hand inclination, and showed that the use of the left or right hand created significant differences for MVC_g [12]. However, some studies showed no differences in the action and reaction times between males and females. Yandel and Spirduso showed that there were no significant differences between the action and reaction times of males and females in sports [13]. According to Lin, some studies on the reaction time for males and females during exercise showed differences between males and females, whereas others did not [14]. Results on grip and sports performance differences between genders depend on many factors, such as the experimental design and scale of sampling [15].

Some researchers found gender differences to influence sports performance [7, 11, 12, 16], whereas others did not [13, 14, 15]. However, none of those studies excluded interference from related variables, e.g., height and body weight. No study has examined grip differences between genders after excluding height and body weight. Therefore, there are no conclusions on whether gender influences grip, and action and reaction time. Thus, when investigating the influence of gender on grip, and action and reaction time, all variables must be strictly controlled.

Using both hands is a requisite condition for human labor. However, for this study, we did not consider whether humans used one hand more than the other (because the use of the left or right hand is unequal) or whether this was caused by the differing abilities of each hand. To consider the chances of operating with the left and right hand as unequal, it is necessary to establish first which hand is dominant. Most young adults in Taiwan are right-hand dominant. According to Chang, over 99% of young adults (15–22 years) in Taiwan use their right hand to write, and over 94% (males: 94%, females: 96%) chiefly use their right hand during sports [17]. There are no differences between the grip of the left and right hand for males and females who use their dominant hand to write. Jing conducted a study on the control characteristics in the left and right hand when swinging a stick [18]. Jing found that when participants swung the stick, the reaction time of the right hand decreased with an increase of broad band, in which the reaction time of the right hand was generally shorter than that of the left hand. The abilities of the left and right hand differ according to operational circumstances. Right-handed people have an increased chance of injuring their right hand [19, 20, 21, 22]. In addition, research on whether differences exist in MVC_g between the left and right hand is scant. MVC_g is an important source of power during human labor operations. The influence of gender on the left and right hand and the sequence of force application, as well as the differences in these aspects, can be used as important references for filtering and selecting personnel and work designs.

The operation of force application by hand is not only related to MVC$_g$, but is also relevant to assessing the ability to attain different levels of force application [23]. This ability is known as hand-grip control (HGC). HGC is the precise level of the control power of the palm, known as grip force control. For example, what is the exact amount of power required to cut an electrical wire? How much power is required to drill a screw? HGC is the answer. HGC can also be used as a reference for tool resistance and for establishing reaction time. Problems with HGC are also indicators of work performance and safety. HGC is commonly used in daily tasks. Hoeger and Hoeger showed that by taking advantage of the percentage of MVC$_g$, researchers usually took the figures as test standards [24]. Excellent HGC can facilitate tasks and reduce the number of force applications, whereas people with poor HGC work harder and tire more easily. HGC is an important factor for success in sports [25]. Furthermore, it is an assessment category on the action sensations test [26]. Kuo demonstrated that in operating safety, other than requesting the strength of force application (MVC$_g$) to reach the assessment of different levels of force application (HGC), a researcher should consider the HGC effects [11]. Many operations use grip force control. HGC is an important factor in industrial safety and ergonomics. An understanding of HGC in all types of workers can also help in designing new hand tools.

The purpose of this study was to examine how gender of young adults in Taiwan affected the ability of their hands to apply force with their left or right hand, and the varying sequences of the force of application. This study examined the interactions among the variables of gender, hand, and sequence of force application in MVC/HGC. Research on the relationship between HGC and gender or hand, and sequence of force application has been scant. The relationships among these variables are crucial. Tasks involving HGC are numerous. However, we often consider MVC$_g$ only, instead of using HGC to solve work-related problems. Developing relevant research and data on hand grip and HGC in young adults in Taiwan is necessary for the development and application of industrial safety and sanitary standards and procedures.

2. METHOD

2.1. Participants and Instruments

This study consisted of two experiments that evaluated MVC$_g$ and HGC. Two hundred people aged 18–27 years participated in the experiments: 117 men and 83 women. The participants' handedness was unspecified in this study. However, according to Chang, most young adults in Taiwan are right-hand dominant [17]. Table 1 shows anthropometric data. None of the participants had any muscle or joint injuries. For MVC$_g$ and HGC, a hand-grip dynamometer in minute style (TKK 5001 from Takkei, Japan; five levels of 34.9, 47.6, 60.3, 73.0, and 85.7 mm) was the examination tool (Figure 1). During the tests, the handle diameter of the dynamometer was set at 47.6 mm as this was capable of producing the highest MVC$_g$, was least likely to cause muscle fatigue, and was well-suited for young adults in Taiwan [7, 9, 27].

2.2. Experiment Design

MVC$_g$ and HGC were the dependent variables. Gender (male/female), hand (left/right), and sequences of force application (I–V) were the independent variables. The sequence of force application was the order of hand-grip operations, i.e., when the participants first operated the hand-grip, the data produced were labeled sequence I; the second time was labeled sequence II. The participants continued until they completed five trials.

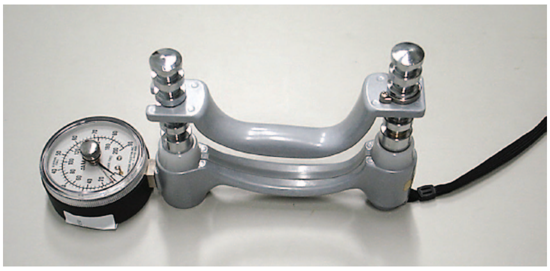

Figure 1. Hand grip dynamometer in minute style.

TABLE 1. Anthropometric Data of Participants

Characteristic	Gender	*M* (*SD*)	Range
Age (years)	male	20.2 (0.98)	18–27
	female	19.9 (1.01)	18–25
Height (cm)	male	171.3 (5.29)	162–185
	female	159.1 (6.16)	151–175
Body weight (kg)	male	73.5 (9.21)	51–85
	female	47.6 (7.81)	40–65

Notes. Of the 200 participants, 117 were male, 83 were female.

2.3. Experimental Processes

Experimental steps and procedures were implemented in accordance with the methods discussed by Caldwell, Chaffin, Dukes-Dobos, et al. [28]. MVC_g and HGC were tested in a seated posture with the participants' arms straight down their sides (Figure 2). The participants' grip power was affected by posture [7]. However, the effect was not significant. To simplify the experimental design, we used a fixed posture to collect data. Before conducting individual MVC_g and HGC tests, the participants had sufficient rest and became familiarized with the experimental procedure. While applying force, they held onto the hand-grip dynamometer tightly for ~3 s, relaxed, and then repeated the operation 5 times. They took 10-s breaks between each operation. After performing the experiment for 30 min, the participants rested for at least 5 min.

Tests for HGC were performed in accordance with the methods and instruments discussed by Murase, Kinoshita, Ikuta, et al. [25]; an indicated hand grip value of 50% of MVC_g was the standard. The participants were asked to attain this standard as accurately as possible, and the deviation between the standard and the participants' grip levels was calculated. A lower value of the deviation indicated better HGC. Equation 1 determined the accuracy of HGC:

$$E_i = |F_0 - F_i|, \tag{1}$$

where E_i = accuracy of hand-grip control (kg), F_0 = value of hand grip (kg), F_i = estimated value of participant's actual grip (kg), $|F_0 - F_i|$ = absolute value after deducting F_i from F_0 (kg).

The F_0 adopted in this study was one half of the value obtained from the average when a participant's MVC_g was measured 5 times as the standard of $HGC_{50\%}$; the data were 50% of MVC_g ($HGC_{50\%}$). $HGC_{50\%}$ was measured 5 times. The advantages and disadvantages of $HGC_{50\%}$ were determined on the basis of the deviations between the value of hand grip performed by the participants and the targeted loading value of $MVC_{50\%}$. A lower absolute value of the deviation indicated higher precision of $HGC_{50\%}$, whereas a higher absolute value of the deviation indicated lower precision of $HGC_{50\%}$ [25]. After the tests, all data were analyzed with SPSS version 17.0.

2.4. Statistical Analysis

Statistical analysis included an analysis of descriptive statistics, the basic assumption test of covariance, and group differences comparing MVC and HGC. Analysis of variance (ANOVA) was used to compare the group differences among gender, hand, and sequence of force application for MVC/HGC. For analysis of covariance (ANCOVA), height and body weight were used to test the covariance effect of the group differences among gender, hand, and sequence of force application for MVC/HGC.

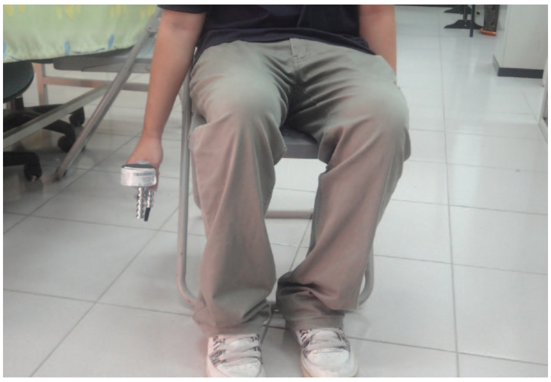

Figure 2. Participants' posture for MVC_g/HGC testing. *Notes.* MVC_g = maximal voluntary contraction of grip, HGC = hand-grip control.

3. RESULTS

3.1. Basic Assumption Test of ANCOVA

The basic assumption test of ANCOVA includes the moderating variables selection and the variables correlation test. Height, body weight, and body mass index (BMI) were assumed to be the moderating variables in ANCOVA. The results of these effects were that MVC_g had a positive correlation with height ($r = .722^{**}$, $p < .001$) and body weight ($r = .782^{**}$, $p < .001$), whereas $HGC_{50\%}$ had a negative correlation with body weight ($r = -.140^{*}$, $p < .05$). BMI is a statistical measure of body weight based on a person's weight and height. The correlation between BMI and weight was .942, and the correlation between BMI and MVC was .690.

3.2. Test of Homogeneity

The homogeneity test was chiefly adopted using homogeneity of within regression. Mauchly's sphericity test can be expressed with the Greenhouse–Geisser value because it shows both the within- and between-group effects. The Greenhouse–Geisser value for hand grip was .912, and the HGC result was .954. Therefore, the dependent samples did not violate the basic assumption of ANOVA [31], and it was possible to further conduct ANOVA.

3.3. ANCOVA for Height and Body Weight

Tables 2–3 show the results collected with ANOVA with no moderator variable, height, body weight, and height and body weight as moderator variables. Tables 2–3 show that if interference from height and body weight is not eliminated, ANOVA can be used directly; there were no significant differences between MVC_g and $HGC_{50\%}$ for sequence of force application. However, after excluding the interference of height, body weight, and height and body weight, there were no significant differences between MVC_g and $HGC_{50\%}$ for sequence of force application. Height and body weight did not

TABLE 2. Analysis of Covariance (ANCOVA) for MVC_g With Various Moderator Variables (p)

	Moderator Variable			
Group	**None**	**Height**	**Body Weight**	**Height + Body Weight**
Gender (A)	<.001***	<.001***	<.001***	<.001***
Hand (B)	<.001***	.007**	.001**	.007**
Sequence of force application (C)	<.001***	.724	.395	.682
A × B	.741	.661	.822	.929
A × C	<.001***	.032	.078	.369
B × C	.034	.752	.406	.621
A × B × C	.293	.310	.439	.431

Notes. *$p < .05$, **$p < .01$, ***$p < .001$; MVC_g = maximal voluntary contraction of grip.

TABLE 3. Analysis of Covariance (ANCOVA) for $HGC_{50\%}$ With Various Moderator Variables (p)

	Moderator Variable			
Group	**None**	**Height**	**Body Weight**	**Height + Body Weight**
Gender (A)	.224	.308	.447	.638
Hand (B)	.053	.890	.627	.957
Sequence of force application (C)	<.001***	.959	.891	.991
A × B	.496	.401	.737	.646
A × C	.539	.733	.895	.895
B × C	.655	.526	.389	.666
A × B × C	.219	.390	.515	.747

Notes. ***$p < .001$; $HGC_{50\%}$ = hand-grip control.

affect the significance of MVC_g for gender and hands.

3.4. ANCOVA for MVC_g

In ANCOVA for MVC_g, this study used height, body weight, and height and body weight as moderator variables to investigate the differences for MVC_g with the independent variables of gender, hand, and sequences of force application (Table 4).

3.5. Means of MVC_g for Each Group

After ANCOVA on the experimental data, the means and standard errors of MVC_g for each group were determined (Table 5).

TABLE 4. Summary of Analysis of Covariance (ANCOVA) for MVC_g (B and C Factors Are Repeated Measure Design)[a]

	Source of Variance				
Group	***SS***	***df***	***MS***	***F***	***p***
Gender (A)	21442.871	1	21442.871	113.764	<.001***
Hand (B)	202.451	1	202.451	7.549	.007**
Sequence of force application (C)	21.330	4	5.332	0.573	.682
A × B	0.214	1	0.214	0.008	.929
A × C	39.908	4	9.977	1.072	.369
B × C	19.703	4	4.926	0.658	.621
A × B × C	28.614	4	7.513	0.956	.431

Notes. ** $p < 0.01$, *** $p < 0.001$; a = height and body weight as the moderator variable; MVC_g = maximal voluntary contraction of grip.

TABLE 5. Experimental MVC_g (kg) Measured for Each Independent Variable, *M* (*SE*)

Group			**Level of Variables**				
Gender (A)			male			female	
			40.4 (0.563)			28.3 (0.733)	
Hand (B)			right			left	
			36.2 (0.346)			32.5 (0.342)	
Sequence of force application (C)			I	II	III	IV	V
			36.4 (0.315)	35.3 (0.331)	34.1 (0.381)	33.4 (0.368)	32.7 (0.362)
A × B				right		left	
	male			42.3 (0.605)		38.6 (0.599)	
	female			30.2 (0.788)		26.5 (0.780)	
B × C			I	II	III	IV	V
	right		38.5 (0.347)	37.5 (0.373)	35.9 (0.451)	35.1 (0.407)	34.2 (0.427)
	left		34.3 (0.342)	33.1 (0.370)	32.3 (0.460)	31.7 (0.411)	31.1 (0.393)
A × C			I	II	III	IV	V
	male		42.8 (0.551)	41.5 (0.578)	40.6 (0.668)	39.1 (0.644)	38.4 (0.633)
	female		30.1 (0.717)	29.1 (0.753)	27.9 (0.869)	27.6 (0.839)	27.0 (0.824)
A × B × C			I	II	III	IV	V
	male	right	44.7 (0.607)	43.7 (0.653)	42.3 (0.789)	40.7 (0.713)	40.3 (0.747)
		left	40.9 (0.598)	39.4 (0.647)	38.4 (0.711)	37.7 (0.720)	36.4 (0.688)
	female	right	32.3 (0.789)	31.3 (0.849)	29.6 (1.03)	29.8 (0.927)	28.1 (0.973)
		left	27.8 (0.779)	26.8 (0.842)	26.2 (0.924)	25.6 (0.937)	25.8 (0.896)

Notes. MVC_g = maximal voluntary contraction of grip.

3.6. ANCOVA for $HGC_{50\%}$

In ANCOVA for $HGC_{50\%}$, this study used height, body weight, and height and body weight as moderator variables to investigate the influence of the independent variables of gender, hand, and sequence of force application on $HGC_{50\%}$ (Table 6).

3.7. Means of $HGC_{50\%}$ for Each Group

After ANCOVA on the experimental data, the means and standard errors of $HGC_{50\%}$ for each group were determined (Table 7).

TABLE 6. Summary of Analysis of Covariance (ANCOVA) of $HGC_{50\%}$ (B and C Factors Are Repeated Measure Design) [a]

	Source of Variance				
Group	***SS***	***df***	***MS***	***F***	***p***
Gender (A)	2.824	1	2.824	0.222	.638
Hand (B)	0.017	1	0.017	0.003	.957
Sequence of force application (C)	0.808	4	0.202	0.070	.991
A × B	1.314	1	1.314	0.211	.646
A × C	3.157	4	0.789	0.274	.895
B × C	0.602	4	1.505	0.596	.666
A × B × C	4.902	4	1.225	0.485	.747

Notes. a = height and body weight as the moderator variable; $HGC_{50\%}$ = hand-grip control.

TABLE 7. Experimental $HGC_{50\%}$ (kg) Measured for Each Independent Variable, *M* (*SE*)

Group			**Level of Variables**				
Gender (A)			male			female	
			2.34 (0.146)			2.21 (0.190)	
Hand (B)			right			left	
			2.39 (0.116)			2.16 (0.085)	
Sequence of force application (C)			I	II	III	IV	V
			2.79 (0.122)	2.34 (0.110)	2.17 (0.114)	2.07 (0.121)	2.01 (0.108)
A × B				right		left	
	male			2.41 (0.204)		2.28 (0.149)	
	female			2.36 (0.265)		2.05 (0.204)	
B × C			I	II	III	IV	V
	right		2.88 (0.162)	2.54 (0.162)	2.34 (0.166)	2.10 (0.147)	2.06 (0.151)
	left		2.70 (0.147)	2.15 (0.128)	2.00 (0.137)	2.01 (0.161)	1.99 (0.125)
A × C			I	II	III	IV	V
	male		2.83 (0.214)	2.29 (0.193)	2.27 (0.200)	2.15 (0.212)	2.18 (0.190)
	female		2.75 (0.278)	2.39 (0.251)	2.06 (0.261)	1.99 (0.276)	1.84 (0.247)
A × B × C			I	II	III	IV	V
	male	right	2.81 (0.284)	2.49 (0.283)	2.51 (0.290)	2.22 (0.258)	2.71 (0.265)
		left	2.85 (0.258)	2.10 (0.223)	2.30 (0.240)	2.08 (0.281)	2.08 (0.219)
	female	right	2.96 (0.369)	2.60 (0.368)	2.44 (0.378)	1.99 (0.336)	1.86 (0.345)
		left	2.56 (0.336)	2.20 (0.290)	1.70 (0.312)	1.98 (0.366)	1.81 (0.286)

Notes. $HGC_{50\%}$ = hand-grip control.

4. DISCUSSION

4.1. Basic Assumption Test

We used ANCOVA to investigate the differences in hand grip and HGC in various groups (gender, hand, and sequence of force application). Gender, hand, and sequence of force application were the independent variables. MVC_g and $HGC_{50\%}$ were the dependent variables, and height, body weight, and height and body weight were the moderator variables. Height and body weight are basic characteristics of human physiology that affect the actions of daily life. Luna-Heredia, Martin-Peña, and Ruiz-Galiana found that grip strength in healthy people was positively correlated with height [29]. Height and body weight were selected as moderator variables because of their influence on hand grip and HGC. The moderator variables were selected in accordance with Bryman and Cramer's recommendations [30]. Bryman and Cramer proposed that if the correlation coefficients of two moderator variables were both over .80, either could be selected as a moderator variable. However, we found that the correlation coefficient of height and body weight was .79, i.e., under the necessary .80. Therefore, height and body weight were used as moderator variables for ANCOVA. In accordance with the principles of selecting moderator variables, we selected weight as the co-variable, not BMI.

4.2. Test of Homogeneity

When performing ANCOVA, we had to focus on whether the sampling met the basic assumption of ANCOVA, including normality and homogeneity, as well as the basic assumption of the dependent sample. For the data in this research, hands and sequence of force application results were the dependent sample, and in turn we needed to work on the basic assumption test of the dependent sample. When the test met the basic assumption, it was followed with ANCOVA. Verification of the dependent sample required using the Greenhouse–Geisser value as an indicator for testing.

The homogeneity test was chiefly adopted using homogeneity of within regression. The test results for hand grip, other than the group of gender × hands × body weight, the homogeneity of within regression for each group had $p > .05$. Therefore, the null hypothesis was not rejected, meaning that the slope of the regression line for each group was the same. After eliminating the interference of height and body weight, hand grip of each group did not change because of the differences in each handling level of each independent variable. Therefore, it was possible to perform ANCOVA.

For the results of homogeneity of within regression for hand-gripping control, $p > .05$ for each group (gender, hand, and sequence of force application; gender × hand; hand × sequence of force application; gender × sequence of force application; and gender × hand × sequence of force application), although they did not reach a level of significance of .05. Therefore, the null hypothesis was not rejected. Furthermore, this indicates that the slope of the regression line for each group was the same. After eliminating the interference of height and body weight, the HGC of each group did not change because of the differences in each handling level of each independent variable. This was not in violation with the basic assumption of ANCOVA, and the basic assumption test on hand grip and hand-grip control was suitable for performing ANCOVA [32].

4.3. Summary of MVC_g Analysis

Table 4 shows the results of ANCOVA (height and body weight as moderator variables). The chief effects of the three independent variables follow. First, the test of between-participant effects of gender reached a level of significance, indicating that the male and female groups both reached a level of significance; $F(1, 196) = 113.764$, $p < .001$. This study is important because an increasing number of males and females operate handle grip systems, such as tools. Previous research supports the findings of this study [7, 11, 12, 33, 34]. Second, the test for hand within-participant effect reached a level of significance; $F(1, 196) = 7.549$, $p = .007$. This indicates that the left and right hand reached a level of significance. Third, the test for the sequence of force application within-participant effect did not reach a level of significance; $F(1, 784) = 0.573$, $p = .682$. This indicates that there were no differences for MVC_g from the various sequences of force application.

For the interactive effects of the variances between two factors, the A × B group ($F(1, 196) = 0.008$, $p = .929$) did not reach a level of significance; the A × C group ($F(4, 784) = 1.072$, $p = .369$) did not reach a level of significance; and the B × C group ($F(1, 4) = 0.658$, $p = .621$) did not reach a level of significance (Table 4). Therefore, for the two-factor variance among the three groups, there were no interactive effects and there was no need to perform a simple main-effect analysis. Furthermore, for the two-factor groups (gender × hands, and gender × sequences of force application; and hands × sequences of force application), there were no differences for MVC_g. Regarding the interactive effects of the three-factor variances, the A × B × C group ($F(4, 784) = 0.956$, $p = .431$) did not reach a level of significance. This demonstrates that there were no interactive effects among the three factors (gender × hands × sequences of force application). There was no need to perform a simple main-effects analysis. Finally, the group had no differences for MVC_g.

4.4. Means of MVC_g for Each Group

Table 4 shows there were significant differences in MVC_g between males and females. MVC_g of females in Taiwan was ~70.0% that of males (28.3/40.4). These results support Hallbeck and McMullin's findings [33] (Table 8). However, there were slight differences between our study and those by Shih et al. [7], Uetake and Shimoda [9], and Swanson, Matev, and de Groot [34]. Many factors could have caused differences between the percentages of force application for males and females, including physiology, ethnicity, age, and differences in the use of instruments and handles [7, 9, 17]. Table 4 shows there were significant differences in MVC_g between the left and right hand. MVC_g for the left hand of young adults in Taiwan was ~89.8% that for the right hand (32.5/36.2), possibly because most Taiwanese use their right hand more often than their left one. Regarding the results for the sequence of force application, the first sequence had the greatest value, followed by decreases of 3% per sequence until the fifth and final sequence. This decrease was caused by repeated force application and muscle fatigue, which led to decreased hand-grip strength [4, 10].

Thereafter, the effects of MVC_g with two and three factors were investigated. Table 5 shows that MVC_g of the males' right hand was highest at 42.3 kg, whereas the value for the left hand was 38.6 kg. For females, MVC_g for the right hand was 30.2 kg and 26.5 kg for the left one. However, as the results of ANOVA indicate, there were no obvious interactive effects between gender and left/right hand. The differences between MVC_g for the left and right hand were possibly caused by most participants being right-hand dominant, which made their right hand stronger and produced higher MVC_g [17].

Regarding the effects of MVC_g on hands and sequence of force application (B × C), Table 5 shows that the values of MVC_g for the right hand were all higher than for the left one. All participants produced greater MVC_g during the first sequence (right hand, 38.5 kg; left hand, 34.3 kg). Following the first force application, MVC_g gradually decreased. The value of MVC_g was lowest during the fifth sequence (right hand, 34.2 kg; left hand, 31.1 kg). In accordance with the increase in force application, MVC_g for the right hand decreased by an average of 2.9% for

TABLE 8. Comparison of MVC_g (kg) for Males and Females in Various Studies

Gender	This study	Uetake & Shimoda [9]	Hallbeck & McMullin [33]	Swanson, Matev, & de Groot [34]	Shih, Fu, & Wang [7]
Male	40.4	50.5	39.4	47.6	38.1
Female	28.3	33.9	28.6	24.6	17.4
Female/male	70.0%	67.1%	72.6%	51.7%	45.7%

Notes. MVC_g = maximal voluntary contraction of grip.

each sequence and an average of 2.4% for each sequence for the left hand. The decreasing trends for the left and right hand were similar, although their values were different. However, there were no interactive effects between hand and sequence of force application.

Regarding the influence of gender and sequence of force application (A × C) on MVC_g, the values of MVC_g for the males were all higher than those for the females (Table 5). All male and female participants produced highest MVC_g during the first force application (males, 42.8 kg; females, 30.1 kg). After the first force application, MVC_g of the male and female participants gradually decreased. Force application and hand grip gradually decreased until the fifth sequence, where the value of MVC_g was lowest (males, 38.4 kg; females, 27.0 kg). In accordance with the increase in force application, the value of MVC_g decreased an average of 2.7% for each sequence for both males and females. The decreasing trends for males and females were similar. However, there were no interactive effects between gender and sequence of force application.

Regarding the influence of gender, hand, and sequence of force application on MVC_g, the highest value was for the right hand of the male group during the first force application (44.7 kg), whereas the fifth force application for the left hand of the female group was the lowest (25.8 kg). There were no interactive effects among the three factors.

4.5. Summary of $HGC_{50\%}$ Analysis

Table 6 shows the results of ANCOVA (height and body weight as the moderator variable). The chief effects of the three independent variables follow. First, the test for the between-participant effects of gender did not reach a level of significance ($F(1, 196) = 0.222$, $p = .638$), indicating that $HGC_{50\%}$ between males and females did not reach a level of significance. Thompson, Mann, and Harris [35] and Sherman [36] reported that males and females differed in their performance of spatial and cognitive tasks. Irwing and Lynn performed a meta-analysis of 22 studies of university samples on progressive matrices and found that males had an advantage averaging between 3.3 and 5.0 IQ points [37]. Other studies showed that males had higher test score variances than females. The results of those previous studies do not support the findings of this study. This may be because the tasks performed in those studies chiefly involved strength control, causing gender-independent human performance. More research is necessary to understand how IQ can be correlated with HGC accuracy. Second, the test examining hand within-participant effect did not reach a level of significance ($F(1, 196) = 0.003$, $p = .957$), indicating that $HGC_{50\%}$ between the left and right hand did not reach a level of significance. Third, the test investigating sequences of force application within-participant effect did not reach a level of significance ($F(1, 784) = 0.07$, $p = .991$), demonstrating that there were no differences for $HGC_{50\%}$ among the varying sequences of force application.

Regarding the interactive effects of variances between two factors, the A × B group ($F(1, 196) = 0.211$, $p = .646$) did not reach a level of significance; the A × C group ($F(4, 784) = 0.274$, $p = .895$) did not reach a level of significance; and the B × C group ($F(1, 4) = 0.596$, $p = .666$) did not reach a level of significance. Therefore, for the two-factor variance among the three groups, there were no interactive effects and there was no need to perform a simple main-effects analysis. Furthermore, for the two-factor variances of the three groups (gender × hands; gender × sequences of force application; and hands × sequences of force application), there were no differences for $HGC_{50\%}$.

The interactive effects of the three-factor variances for the A × B × C group ($F(4, 784) = 0.485$, $p = .747$) did not reach a level of significance, indicating that there were no interactive effects among the three factors (gender × hands × sequences of force application), and there was no need to perform a simple main-effects analysis. Furthermore, there was no difference for $HGC_{50\%}$.

In summary of these analyses, we found that, after excluding the effects of height and body weight, gender, hand, and sequences of force application had no significant influence on force application. Furthermore, there were no interactive effects among the influences of two and three factors.

4.6. Means of $HGC_{50\%}$ for Each Group

Table 7 shows there were significant differences for the $HGC_{50\%}$ means between the males and females. The deviation value of $HGC_{50\%}$ of the females was ~94.4% that of the males (2.21/2.34). The deviation value of $HGC_{50\%}$ for the females was lower than that of males. Therefore, $HGC_{50\%}$ of the females was better than that of the males. This may have been because the females were more careful while performing the test, leading to lower deviations. However, they did not reach a level of statistical significance.

The deviation value of $HGC_{50\%}$ for the left hand of young adults in Taiwan was ~90.4% that for the right hand (2.16/2.39). The deviation value of $HGC_{50\%}$ for the left hand was lower than that for the right hand. Consequently, $HGC_{50\%}$ for the left hand was higher than that for the right hand. However, neither the right or left hand results reached a level of statistical significance (Table 3). The lower deviation for the left hand may have been caused by the participants being more vigilant while using their left hand.

Regarding the sequence of force application, the deviation of $HGC_{50\%}$ was highest during the first force application (Table 7), gradually decreasing after each sequence until the fifth and final sequence, where it was lowest. The value on the second sequence was ~83.9% of the first sequence (2.34/2.79); the value of the third sequence was ~92.7% of the second sequence (2.17/2.34); the value of the fourth sequence was ~95.4% of the third sequence (2.07/2.17); and the value of the fifth sequence was ~97.1% of the fourth sequence (2.01/2.07). As demonstrated by the trends, in addition to the increased frequency of force application, the deviation value of $HGC_{50\%}$ decreased linearly by an average of 7.7% per sequence. The gradual reductions of the deviations of HGC were probably caused by fatigue from repeated force application, as well as increased familiarity. However, there were no significant differences for the statistics of each force application. Previous studies showed that precision of HGC could increase as a result of frequent operation.

We also investigated the effects of various factors on $HGC_{50\%}$. This study first examined how gender and hands (A × B) affected $HGC_{50\%}$. The lowest value of $HGC_{50\%}$ was recorded for the left hand of the males (2.28 kg), whereas the right hand score was 2.41 kg (Table 7). For the females, the lowest value of $HGC_{50\%}$ was recorded for the left hand (2.05 kg), and the value for the right hand was 2.36 kg. However, the results of ANOVA indicated that there were no interactive effects between gender, and left and right hand (A × B, $p = .496$) (Table 3).

Regarding the effects of hand and sequence of force application (B × C) on $HGC_{50\%}$, the values of $HGC_{50\%}$ for the right hand were all higher than those of the left hand during the sequence tests (Table 7). All participants recorded higher $HGC_{50\%}$ during the first sequence (right hand, 2.88 kg; left hand, 2.70 kg). Following the initial sequence, $HGC_{50\%}$ gradually decreased until the fifth and final force application sequence, which had the lowest values (right hand, 2.06 kg; left hand, 1.99 kg). With an increase in force application, $HGC_{50\%}$ decreased by an average of 7.0% for the right hand following each sequence and an average of 7.1% following each sequence for the left hand. The values recorded during the fourth sequence were higher than those during the fifth sequence, possibly because of deviations created during the experiment. Although the decreasing trends between the left and right hands were similar, their values were different. However, there were no interactive effects between hands and sequences of force application.

Regarding the effects of gender and sequences of force application (A × C) on $HGC_{50\%}$, the values of $HGC_{50\%}$ during the sequence tests were higher for males than for females (Table 7). All participants recorded higher MVC_g during the first sequence (males, 2.83 kg; females, 2.75 kg). Following the initial sequence, $HGC_{50\%}$ gradually decreased for males and females until the fifth and final sequence of force application, which had the lowest values (males, 2.18 kg; females, 1.84 kg). In accordance with the increase in force application, the value of $HGC_{50\%}$ for males decreased by an average of 6.1% per sequence. The values recorded during the fourth sequence were higher than that of the fifth sequence, possibly because of deviations during the experiment. Furthermore, the values for the female group decreased by an average of 9.5% per sequence. The decreasing trends of the males were lower than those of the females; however, there were no interactive effects between gender and sequence of force application.

5. CONCLUSION

Based on the results and discussion, and excluding the interference of height, body weight, and height and body weight, this study offers the following conclusions. There were significant differences between MVC_g scores for males and females, using height, body weight, and height and body weight as moderating variables. However, no significant differences were observed in the deviation values of $HGC_{50\%}$. There were significant MVC_g variations for force application using the left and right hand, but there were no significant $HGC_{50\%}$ discrepancies. For sequences of force application, there were no significant differences between MVC_g and $HGC_{50\%}$ for each application.

The MVC of grip and HGC exertion performances of young adults were different regarding gender and hand and sequence of force application. However, when considering individual body weight, and the height variable effect, there were no differences in the MVC of grip and HGC exertion performances between genders and hand and sequences of force application groups. Anthropometric variables, such as body weight and height, play an important role in predicting the outcome of the MVC of grip and HGC.

These findings underscore that occupational safety must consider anthropometric variable effects for grip and hand-grip control exertion. The data obtained in this study can be used as a reference in relevant industries for selecting tools, training personnel, and designing hand tools and equipment.

REFERENCES

1. Holbrook TL, Grazier K, Kelsey JL, Stauffer RN. The frequency of occurrence, impact, and cost of selected musculoskeletal conditions in the United States. Chicago, IL, USA: American Academy of Orthopedic Surgeons; 1984.
2. Hymovich L, Lindholm M. Hand, wrist, and forearm injuries: the result of repetitive motions. J Occup Med. 1966;8(11):573–7.
3. “Repetition strain injury”: an iatrogenic epidemic. Med J Aust. 1989;151(10): 598–600.
4. Holmström E. Musculoskeletal disorders in construction workers related to physical, psychosocial and individual factors. Lund, Sweden: Department of Physical Therapy, Lund University; 1992.
5. Kurumatani N, Tajima T, Matsuura Y, Dejima M, Moriyama T. Carpal tunnel syndrome in three public school lunch cooks Sangyo Igaku. 1992;34(1):44–5. In Japanese.
6. Huppes G, Koningsveld MD. Repetitive motions and RSI: extent of the problem, assessment and practice. In: McFadden S, Innes L, Hill M, editors. Proceedings of the 12th Triennial Congress of the International Ergonomics Association. Mississauga, ON, Canada: Human Factors Association of Canada, Toronto; 1994. vol. 5, p. 327–30.
7. Shih YC, Fu SL, Wang MJJ. The effect of hand posture on grip, pinch and torque exertions capabilities of hand. Journal of Occupational safety and Health. 1996; 4(1):43–57. In Chinese, with an abstract in English.
8. Grant KA, Habes DJ, Steward LL. An analysis of handle designs for reducing manual effort: the influence of grip diameter. Int J Ind Ergon. 1992;10(3):199–206.
9. Uetake T, Shimoda M. Experimental study on the grip and hold strength for stanchions and handrails in buses. J Hum Ergol (Tokyo). 2006;35 (1–2):11–9.
10. Hung RY. The validity study of measuring the falling rate of griping strength [master thesis]. Pingtung, Taiwan: National Pingtung University of Science and Technology; 2006. In Chinese.

11. Kuo S. Evaluating the effects of grip span, maximum wrist extension/flexion, and gloves on grip strength and time needed to reach different levels of exertion [master thesis]. Bade, Taiwan: National Defense University; 2003. In Chinese.
12. Li KW, Hunag TW. Effects of posture and weight on grip forces. In: Annual Conference of the Chinese Institute of Industrial Engineers. Taiwan: Chinese Institute of Industrial Engineers; 1999. p. 26–9. In Chinese.
13. Yandell KM, Spirduso WW. Sex and athletic status as factors in reaction latency and movement time. Res Q Exerc Sport 1981; 52(4):495–504.
14. Lin SC. The Influence of three factors of training group, gender, and test time to sample reaction time, choice reaction time, movement time, total response time and the success ratio in table tennis forehand [master thesis]. Pingtung, Taiwan: National Pingtung University of Science and Technology; 2007. In Chinese.
15. Wen TS. Female pilots in ROC air force: aeromedical considerations. Journal of Aviation Medicine and Science, Republic of China. 1999;13(1):3–22. In Chinese.
16. Chen KH. The study of the attack-defend skills and performances of the elite in table tennis contests. Sports & Exercise Research. 2004;6(1):169–80. In Chinese.
17. Chang SY. Grip and key pinch strength: norms for 7 to 22 years-old students in Taiwan. Tzu Chi Medical Journal. 2002; 14(4);241–52. In Chinese.
18. Jing HS. Difference of human compensatory tracking behavior between the left and right hands [master thesis]. Tainan, Taiwan: National Cheng Kung University; 2003. In Chinese.
19. Goodman G, Staz S. Occupational therapy for musicians with upper extremity overuse syndrome: patient perceptions regarding effectiveness of treatment. Med Probl Perform Art. 1989;(1)4:9–14.
20. Chung IS, Ryu J, Ohnishi N, Rowen B, Headrich J. Wrist motion analysis in pianists. Med Probl Perform Art. 1992;7(1):1–5.
21. Pak CH, Chesky K. Prevalence of hand, finger, and wrist musculoskeletal problems in keyboard instrumentalists. Med Probl Perform Art. 2001;16(1):17–23.
22. Dawson WJ. Intrinsic muscle strain in the instrumentalist. Med Probl Perform Art. 2005;20(2):66.
23. Liao KH. The correlative study of the spatial ability and hand-gripping control on eye-hand coordination task [abstract]. In: Annual Conference of the Chinese Institute of Industrial Engineering [CD]. Taiwan: Chinese Institute of Industrial Engineers; 2008.
24. Hoeger WWK, Hoeger SA. Principles and labs for fitness and wellness. 6th ed. Belmont, CA, USA: Wadsworth/Thomson Learning; 2002.
25. Murase T, Kinoshita H, Ikuta K, Kawai S, Asami T. Discrimination of grip force preschool children aged 5 to 6 years. Percept Mot Skills. 1996;82(1):255–63.
26. Mackin EJ. Sensibility evaluation. In: Tubiana R, Thomine JM, Mackin E, editors. Examination of the hand & upper limb. Philadelphia, PA, USA: WB Saunders; 1984. p. 176–94.
27. Ayoub MM, Presti PL. The determination of optimal size cylindrical handle by use of electromyography. Ergonomics. 1971;14(4): 509–18.
28. Caldwell LS, Chaffin DB, Dukes-Dobos FN, Kroemer KH, Laubach LL, Snook SH, et al. A proposed standard procedure for static muscle strength testing. Am Ind Hyg Assoc J. 1974;35(4):201–6.
29. Luna-Heredia E, Martin-Peña G, Ruiz-Galiana J. Handgrip dynamometry in healthy adults. Clin Nutr. 2005;24(2):250–8.
30. Bryman A, Cramer D. Quantitative data analysis with SPSS for Windows. London, UK: Routledge; 1997.
31. Girden ER. ANOVA: repeated measures. Newbury Park, CA, USA: Sage; 1992.
32. Hair JF, Anderson RE, Tatham RL, Black WC. Multivariate data analysis: with readings. 4th ed. Englewood Cliffs, NJ, USA: Prentice Hall; 1995.
33. Hallbeck MS, McMullin DL. Maximal power grasp and three-jaw chuck pinch force as function of wrist position, age, and glove type. Int J Ind Ergon. 1993;11(3): 195–206.

34. Swanson AB, Matev IB, de Groot G. The strength of the hand. Bull Prosthet Res. 1970; 10–14:145–53. Retrieved February 15, 2014, from: http://www.rehab.research.va.gov/jour/70/7/2/swanson.pdf.
35. Thompson EG, Mann IT, Harris LJ. Relationship among cognitive complexity, sex, and spatial task performance in college studies. Brit J Psychol. 1981;72(Pt 2): 249–56.
36. Sherman JA. Problems in sex differences in space perception and aspects of intellectual functioning. Psychol Rev. 1967;74(4): 290–9.
37. Irwing P, Lynn R. Sex differences in means and variability on the progressive matrices in university students: a meta-analysis. Brit J Psychol. 2005;96(Pt 4):505–24.