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Article

Assessments of Work Gloves in Terms of the Strengths of Hand Grip, One-Handed Carrying, and Leg Lifting

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Abstract: Gloves are used at workplaces to protect hands and fingers from potential hazards. Three types of work gloves were assessed in terms of the strength of grip, carrying, and lifting. Thirty adults (14 males and 16 females) joined as human participants. The strength data were measured under bare hand and three gloved conditions. The grip spans in the grip strength measurements included 45 mm, 55 mm, 65 mm, and 75 mm. The carrying strength was measured for both dominant and non-dominant hands under leg straight and semi-squat postural conditions. The lifting strength was measured at a semi-squat posture. The results showed that glove ($p < 0.0001$), grip span ($p = 0.001$), gender ($p < 0.0001$), and handedness ($p < 0.0001$) all affected grip strength significantly. Wearing the gloves tested in this study led to a decrease of grip strength up to 22.9%, on average, depending on gender, grip span, and hand tested. Wearing the cotton gloves led to a decrease of one-handed carrying strength ranged from 3.5% to 9.7% for female participants. All the participants took advantages in carrying strength when wearing the cut-resistant gloves. The leg lifting strength data indicated that the effects of the gloves were insignificant. The information of this study is beneficial for practitioners in the design of manual materials handling tasks concerning the use of work gloves.

Keywords: glove; grip span; grip strength; posture; carrying strength; lifting strength

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1. Introduction

Abrasions, cuts, and bruises have been some of the leading causes of occupational injury. In Taiwan, they are the second most common injury type at workplaces [1]. Nearly 80% of the abrasions, cuts, and bruises lead to hand or finger injuries. Research [2], studying the incidences involving hand injuries for the US coal mine workers found that 18% of the total hand injuries were responsible for 84% of the total lost work days for the workers. The median lost workdays of those workers due to hand injuries were more than 30 days. The official statistics of the Bureau of Labour of the USA indicated that cuts and lacerations of hand accounted for 64.8% of all cut and laceration incidents [3]. Hand injuries lead to a substantial economic burden, with both high health-care expenditures and productive costs [4,5]. Hand protections at work are essential for both the safety and health of workers but also for the welfare and well-beings of workers' families [5].

Work gloves are used for the protection of hands from potential physical, chemical, and biological hazards [6–12]. Typical physical hazards of hand exposure at work include cuts and stabs [13], vibrations of tools and machines [14–17], load and pressure [18–20], high and low temperature [11,21–23], and so on. Typical chemical and biological hazards, on the other hand, include hazardous substances (such as pesticides and acids) and organisms such as insects, germs, and even viruses [9,12].

Work gloves may impose unwanted effects on hand performance [21,24]. Gloves separate the hand and the contact object and thus reduce the tactile sensitivity of the hand [25–28]. In addition, the structure of the glove could hamper fingers' movements. This could reduce hand dexterity [13,21,29,30]. The literature [7], has found a negative linear relationship between glove thickness and hand dexterity. In other words, hand dexterity decreases when the thickness of gloves is increased.

Wearing gloves could change the hand force exertion of a person. The literature indicates that wearing gloves increases forearm muscle activation [31]. This leads to early muscle fatigue and thus increased the risk of musculoskeletal disorders (MSDs) [29,32–34]. The literature has also found that increasing glove thickness could decrease grip strength in addition to decreasing hand dexterity [27,35,36]. The range of grip strength reduction varies, depending on factors such as the number of layers and fitness of the gloves [15,24,30,33,37,38]. Even though the effects of gloves on grip strength have been reported, further investigations are required to examine how those effects are affected by handedness and the grip span of the handle. Such information will be beneficial for glove design and selection of work gloves on a worksite.

There are studies assessing the effects of wearing gloves on both hand dexterity and grip strength [31,37]. However, investigations of the effects of wearing gloves on the capability of lifting and carrying materials are not common. Work gloves are made of various materials. Cotton polyester yarn glove, or simply cotton glove, is one of the most commonly used work gloves. This glove provides limited protection for the hand against contacting sharp objects and high/low temperature. It is commonly used in agricultural, construction, and manufacturing industries. Gloves made of knitwear and coated with composite rubber material on the palm are common. The coating on the palm increase friction at the hand-object interface and thus facilitates hand grip of the object being handled. Knitwear gloves incorporated with glass fibers provide resistance to cuts and stabs. However, such a design could increase the stiffness of the protective gloves and thus may change the material handling capabilities of hands. Studies discussing these issues are significant. They will provide useful information for practitioners to choose proper gloves in performing manual materials handling tasks. The objective of this study was to assess these three types of work gloves in terms of strengths of hand grip, one-handed carrying, and leg lifting. The performances of these gloves were discussed along with their characteristics in thickness, stiffness, and friction in the palmar regions.

2. Materials and Methods

2.1. Participants

Thirty healthy adults, including 14 males and 16 females, were recruited as human participants. Ninety percent (27) of them were right handlers. The age and anthropometric data of the participants are shown in Table 1. None of the participants had musculoskeletal injuries within 12 months of the study. All the participants were requested not to engage in strenuous physical activities at least an hour prior to the experiment.

2.2. Strength Measurement Apparatus

A grip dynamometer (TKK 5001, GRIP-A, TAKEI, Tokyo, Japan) was used to measure the grip strength. The grip spans included 45 mm, 55 mm, 65 mm, and 75 mm, respectively. An apparatus was adopted to measure the one-handed carrying and leg lifting strength. This apparatus included a loadcell and displayer (FG-5100, Lutron, Taiwan), a steel plate, iron chain, and two handles (see Figure 1). One of the metal handles was short (17.4 cm), which was used in the one-handed carrying strength measurement. The other handle was a long one (32.0 cm) and was wrapped with rubber. This one was used for leg lifting strength measurement. Both of these handles have a diameter of approximately 3.2 cm. Iron chains were used to connect the handle, the force gauge, and the steel plate. The height of the handle might be controlled by adjusting the length of the chains to the anchorage of the steel plate to fulfil the requirements of different measuring conditions.

Table 1. Mean and standard deviations of the basic data of the participants.

Variables	Female	Male
Age (years)	30.2 (±10.6)	42.8 (±10.0)
Body weight (kg)	55.5 (±7.7)	80.7 (±15.1)
Body height (cm)	157.6 (±6.0)	169.1 (±7.5)
Shoulder height (cm)	128.2 (±5.0)	138.2 (±7.3)
Elbow height (cm)	98.2 (±4.1)	104.3 (±6.2)
Knuckle height (cm)	69.2 (±4.4)	72.0 (±5.5)
Knee height (cm)	42.9 (±2.4)	47.1 (±2.8)
Hand length, Dominant (cm)	16.7 (±1.4)	19.0 (±1.0)
Hand length, Non-Dominant (cm)	17.0 (±0.9)	19.0 (±0.9)
Hand width, Dominant (cm)	7.5 (±0.3)	8.8 (±0.6)
Hand width, Non-Dominant (cm)	7.4 (±0.5)	8.7 (±0.6)
Circumference of upper arm, dominant (cm)	26.7 (±3.1)	31.9 (±5.6)
Circumference of upper arm, non-dominant (cm)	26.2 (±3.4)	31.8 (±5.2)
Circumference of lower arm, dominant (cm)	23.2 (±1.8)	27.9 (±1.8)
Circumference of lower arm, non-dominant (cm)	22.6 (±1.6)	27.2 (±2.0)

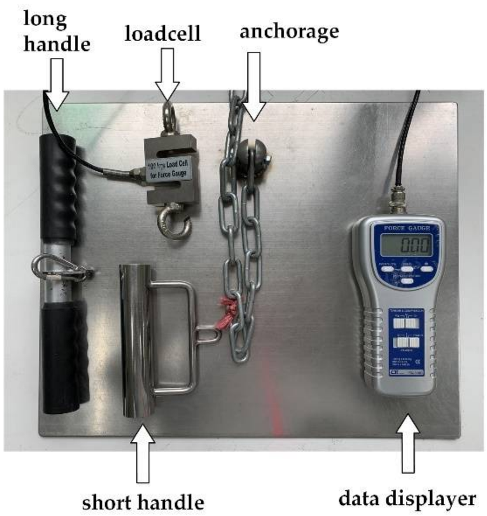


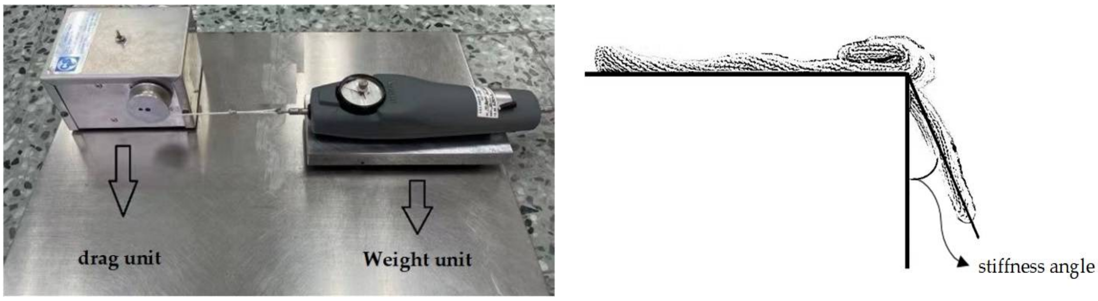
Figure 1. Carrying and lifting strength measurement apparatus.

2.3. Gloved Conditions

There were four gloved conditions: bare hand and wearing one of the three types of work gloves prepared. Three types of work gloves were purchased from a local hardware store (see Figure 2). Glove 1, or simply cotton glove, is a knitted cotton polyester yarn glove. Glove 2 (SS-100, 3M, Seoul, Korea), or simply glove with NBR coating, is a knitted glove with nylon and is coated nitrile rubber (NBR) in the palmar region. Glove 3, or simply cut resistance glove, is a safety glove protecting against cuts and stabs (CP-500, 3M, Seoul, Korea). This glove is knitted with nylon, spandex, and glass fiber, and is also coated with NBR on the palmar region. The thickness of the gloves was measured in the palmar region of these gloves using a caliper (SV-03-150, E-BASE, Yunlin, Taiwan).

The coefficient of friction (COF) between the surface of the palmar region of each type of glove on a steel plate was measured using a Horizontal Pull Slipmeter (HPS) (C.S.C. Force Measurement, Inc., Agawam, MA, USA; ASTM, F609-13) [39]. When measuring the COF, three circular (Ø 1 cm) glove samples were cut from one of each type of glove and were attached to the bottom of the weight unit of the HPS (see Figure 3a). The operator pushed the drag unit downward to fix it and then turned on the power of this unit. The drag unit pulled the weight unit until the latter started to move. The COF reading was shown on the meter.

Figure 2. Gloves tested.



(**a**) (**b**)

Figure 3. Friction measurement (**a**) and stiffness measurement (**b**) of a glove.

A simple test was performed to measure the stiffness of these gloves. In this test, a tested glove was placed on the edge of a workbench with the middle finger sleeve extended outside the bench and drooped. The angle between this sleeve and the vertical, or stiffness angle, was measured to indicate the stiffness of the glove (see Figure 3b). A large angle indicates high stiffness of the sleeve.

Three different sizes were prepared for each of gloves 2 and 3 so that each participant could choose the one that fit his or her hands best. Glove 1 is relatively cheap and has only one size. The glove information is summarized in Table 2.

Table 2. Glove information.

Variable	Glove 1	Glove 2	Glove 3
Size	one size	M/L/XL	M/L/XL
Thickness (mm)	2.17 (±0.02)	1.03 (±0.03)	1.51 (±0.03)
COF	0.30 (±0.02)	0.89 (±0.02)	0.91 (±0.02)
Stiffness angle (°)	28.8 (±0.1)	34.6 (±0.3)	72.1 (±0.7)

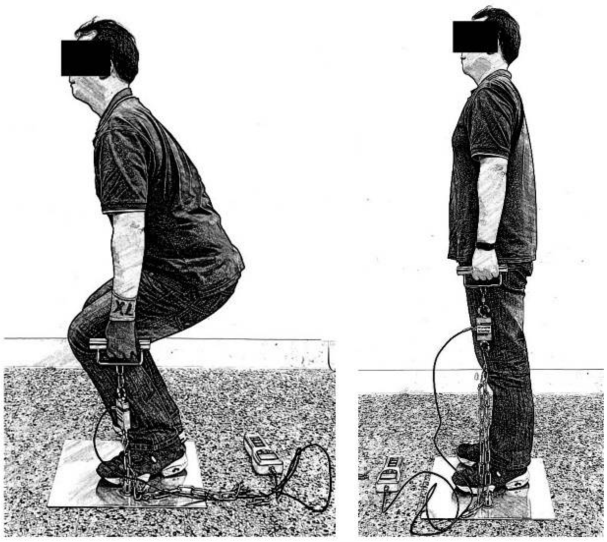
2.4. Grip Strength Test

For grip strength measurement, the participant stood with his or her arm straight down by the side (see Figure 4) and gripped the dynamometer at his or her maximum voluntary contractions for approximately 5 s. Both dominant and non-dominant hands were tested under the four gloved conditions and four grip span conditions. The experimental condition was randomly arranged. The participant took a rest for five minutes or longer between two consecutive trials on the same hand.

Figure 4. Grip strength measurement.

2.5. Carrying Strength Measurements

One-handed carrying strength was measured. These strengths were measured using either dominant or non-dominant hand under the gloved conditions and with two different leg postures: semi-squat and leg straight. For the semi-squat posture, the short handle of the strength measurement apparatus was at the participant's knee height. The participant bent his or her knee to grasp the handle to pull up at his or her maximal strength (see Figure 5a). This posture mimicked the posture when a person is lifting an object from the ground and prepares to carry it on the side. For the straight posture, the participant stood upright with his or her arm straight-down by the sides (see Figure 5b). The height of the handle was adjusted to allow the participant to grasp the handle at his or her knuckle height. This posture mimicked the posture when a person is carrying an object using one hand on the side.



(a) (b)

Figure 5. Carrying strength measurement: (**a**) semi-squat posture, and (**b**) leg straight.

When measuring the carrying strength, the participant grasped the handle and pulled upward at his or her maximal force for 4–6 s. The participant took a break for 10 min or longer between any two trials of the same hand. The order of the experimental condition in terms of glove, posture, and handedness was randomly arranged.

2.6. Lifting Strength Measurement

For lifting strength measurement, the participants grasped the long handle using both hands with a semi-squat posture (see Figure 6). This posture simulates that of lifting an object from the ground using a squat posture. The handle was 38 cm above the test plate. The participant pulled upward at his or her maximal force for 4–6 s. This measurement was conducted under four gloved conditions. The order of the gloved condition was randomly arranged. The participant took a break for 10 min or longer between any two trials.

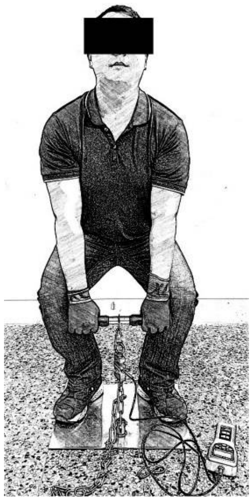


Figure 6. Posture of lifting strength measurement.

2.7. Experiment Design and Data Analysis

A total of 960 (4 gloved conditions $\times$ 2 hands $\times$ 4 grip spans $\times$ 30 participants), 480 (4 gloved conditions $\times$ 2 hands $\times$ 2 postures $\times$ 30 participants), and 120 (4 gloved conditions $\times$ 30 participants) data were collected for the strength of grip, carrying, and lifting. Descriptive statistics were performed. Analyses of variance (ANOVA) were conducted to examine the significances of the factors on the strengths. Duncan's multiple range tests were adopted as the post-hoc test to compare the difference between each pair of treatments for each factor. To study the relationship between grip strength and grip span, we performed regression analysis without intercept using grip strength as dependent variable and grip span as an independent variable for each of the gender, handedness, and gloved condition. The statistical analyses were performed using SAS® 9.0 (SAS Institute Inc., Cary, NC, USA) software. A significance level of $\alpha = 0.05$ was used.

3. Results

3.1. Grip Strength

Table 3 contains the means and standard deviations of the grip strength data. The ANOVA results showed that the main effects of the gender, grip span, handedness, and gloved conditions were all significant ($p \leqq 0.001$) on grip strength. Duncan's multiple range test results showed that the grip strength for males (33.7 $\pm$ 7.8 kgf) was significantly ($p < 0.05$) higher than that for female (20.3 $\pm$ 4.6 kgf). The dominant hand (27.7 $\pm$ 9.5 kgf) had significantly ($p < 0.05$) higher grip strength than non-dominant hand (25.4 $\pm$ 8.7 kgf). The grip strength of bare hand condition (28.9 $\pm$ 9.9 kgf) was significantly ($p < 0.05$) higher than those of glove 1 (25.8 $\pm$ 8.5 kgf), glove 2 (26.7 $\pm$ 9.1 kgf), and glove 3 (24.8 $\pm$ 8.6 kgf) conditions. The grip strength of glove 2 condition was significantly ($p < 0.05$) higher than that of glove 3 condition. The grip strength of glove 1 condition was not significantly different from that of glove 2 condition. Neither was the grip strength of glove 1 condition was significantly different from that of glove 3 condition.

Table 3. Grip strength (kgf) under experimental conditions.

Grip Span (mm)	Glove	Female		Male	
		Dominant	Non-Dominant	Dominant	Non-Dominant
45	0 §	23.9 (±4.8)	22.3 (±3.8)	34.6 (±10.0)	33.5 (±8.9)
	1	19.8 (±4.2)	18.0 (±3.6)	30.7 (±7.1)	28.7 (±6.2)
	2	20.4 (±5.0)	20.0 (±5.6)	33.2 (±7.3)	30.2 (±6.9)
	3	18.9 (±4.0)	17.0 (±3.1)	31.1 (±7.8)	27.9 (±6.1)
55	0	25.4 (±5.5)	23.0 (±5.0)	37.3 (±6.8)	35.0 (±7.1)
	1	21.6 (±3.5)	20.4 (±4.0)	33.9 (±6.0)	31.9 (±5.1)
	2	21.9 (±5.3)	20.0 (±3.9)	36.6 (±4.8)	33.3 (±6.7)
	3	21.3 (±3.9)	20.0 (±3.9)	33.5 (±4.9)	30.1 (±4.5)
65	0	22.8 (±5.0)	20.1 (±5.3)	38.2 (±5.4)	35.0 (±7.6)
	1	22.2 (±3.8)	20.0 (±4.1)	34.2 (±5.5)	31.8 (±6.1)
	2	21.7 (±4.7)	20.3 (±4.8)	35.0 (±6.2)	31.9 (±5.4)
	3	19.8 (±3.5)	18.5 (±3.2)	32.4 (±5.6)	29.1 (±5.6)
75	0	21.5 (±4.9)	19.2 (±5.4)	40.6 (±10.2)	37.8 (±10.3)
	1	19.5 (±4.2)	17.7 (±4.0)	36.9 (±11.3)	32.4 (±6.8)
	2	20.1 (±4.1)	17.9 (±4.0)	37.6 (±9.5)	33.8 (±9.3)
	3	18.8 (±3.9)	16.9 (±3.6)	36.8 (±11.5)	32.1 (±9.1)

§ bare hand condition.

The reduction of grip strength when wearing gloves, compared with that of the bare hand condition, was termed RGS and was calculated using the following equation for each of the with-glove condition:

$$\text{RGS} = \frac{GS_{barehand} - GS_{with-glove}}{GS_{barehand}} \times 100\% \quad (1)$$

where $GS_{barehand}$ and $GS_{with\text{-}glove}$ are the grip strength for the bare hand and one of the with-glove conditions, respectively.

Table 4 shows the means and standard deviations of the RGS for the gender, handedness, grip span, and gloved conditions. The ANOVA results showed that the effects of grip span and gloved conditions were all significant ($p < 0.0001$) on RGS. Duncan's multiple range test results showed that RGS of the 45 mm grip span condition (13.4 ± 15.0%) was significantly ($p < 0.05$) higher than those of the 55 mm (10.0 ± 13.0%), 75 mm (8.9 ± 11.7%), and 65 mm (6.5 ± 14.0%) conditions. The RGS of the 55 mm grip span condition was significantly ($p < 0.05$) higher than that of the 65 mm condition. The difference of the RGS between the 55 mm and that of the 75 mm conditions was insignificant. Neither was the difference of the RGS between the 65 mm condition and that of the 75 mm condition significant. Duncan's multiple range test results comparing the three gloved conditions showed that the RGS of glove 3 (12.8 ± 14.5%) condition was significantly ($p < 0.05$) higher than that of glove 1 (9.4 ± 12.5%) condition. The latter was significantly ($p < 0.05$) higher than that of glove 2 (6.8 ± 13.3%) condition.

Table 4. RGS (%) under experimental conditions.

Grip Span (mm)	Glove	Female		Male	
		Dominant	Non-Dominant	Dominant	Non-Dominant
45	1	16.5 (±10.8)	19.0 (±9.3)	9.2 (±13.1)	13.1 (±8.9)
	2	15.0 (±8.3)	11.6 (±13.2)	0.7 (±20.4)	8.1 (±13.3)
	3	20.0 (±11.9)	22.9 (±11.5)	6.1 (±26.2)	14.8 (±14.5)
55	1	13.7 (±10.8)	10.6 (±8.0)	7.5 (±18.4)	7.3 (±12.5)
	2	13.9 (±8.7)	12.1 (±11.2)	0.2 (±13.0)	4.5 (±9.8)
	3	15.3 (±8.5)	12.6 (±8.3)	7.4 (±23.2)	12.2 (±12.7)
65	1	1.0 (±11.1)	−2.1 (±17.3)	10.3 (±10.1)	8.3 (±10.3)
	2	3.7 (±14.2)	−3.3 (±15.4)	8.5 (±10.0)	7.0 (±13.7)
	3	11.7 (±11.9)	4.5 (±18.0)	15.2 (±9.2)	15.8 (±10.4)
75	1	8.4 (±9.9)	5.4 (±13.6)	9.9 (±8.2)	12.6 (±9.6)
	2	5.5 (±8.7)	4.3 (±17.2)	6.8 (±10.6)	9.8 (±9.7)
	3	11.5 (±12.2)	9.4 (±14.9)	10.0 (±9.2)	13.9 (±12.4)

Both the interaction effects between gender and grip span ($p < 0.0001$) and between gender and handedness ($p < 0.01$) were significant. Interaction effects between the gloved condition and grip span ($p = 0.056$) and between the gloved condition and gender ($p = 0.48$) were both insignificant. The three-way interaction effects of gender, grip span, and gloved condition were significant ($p < 0.05$). The regression analysis results of the grip strength over grip span are shown in Table 5.

Table 5. Regression analysis results of the grip strength over grip span.

Gender	Hand	Glove	Regression Coefficient	p-Value	R^2
female	Dominant	0 §	3.73	<0.0001	0.91
		1	3.35	<0.0001	0.93
		2	3.38	<0.0001	0.92
		3	3.17	<0.0001	0.93
	Non-dominant	0	3.36	<0.0001	0.89
		1	3.06	<0.0001	0.92
		2	3.13	<0.0001	0.90
		3	2.91	<0.0001	0.93
male	Dominant	0	6.13	<0.0001	0.94
		1	5.53	<0.0001	0.94
		2	5.78	<0.0001	0.94
		3	5.44	<0.0001	0.93
	Non-dominant	0	5.73	<0.0001	0.93
		1	5.06	<0.0001	0.94
		2	5.23	<0.0001	0.93
		3	4.84	<0.0001	0.94

§ bare hand condition.

3.2. Carrying Strength

Table 6 shows the means and standard deviations of the carrying strength. The ANOVA results showed that the effects of the gender, posture, and gloved conditions were all significant ($p < 0.01$) on carrying strength. The effects of handedness were not significant. Duncan's multiple range test results showed that the carrying strength for males (51.7 ± 12.3 kgf) was significantly ($p < 0.05$) higher than that for female (30.1 ± 6.9 kgf). The carrying strength under straight posture (41.4 ± 14.7 kgf) was significantly ($p < 0.05$) higher than that under semi-squat posture (39.0 ± 14.4 kgf). The carrying strength with glove 2 (41.5 ± 14.8 kgf) and glove 3 (42.7 ± 14.8 kgf) conditions were significantly ($p < 0.05$) higher than those with glove 1 (37.6 ± 14.3 kgf) and bare hand (38.9 ± 14.2 kgf) conditions. The difference between gloves 2 and 3 conditions was not significant. The difference between glove 1 and bare hand conditions was also insignificant.

Table 6. Carrying strength (kgf) under experimental conditions.

Postures	Glove	Female		Male	
		Dominant	Non-Dominant	Dominant	Non-Dominant
Semi-squat	0 §	28.7 (±6.4)	27.1 (±6.6)	53.6 (±12.0)	49.5 (±10.3)
	1	26.7 (±6.3)	26.0 (±6.6)	52.2 (±12.5)	45.2 (±8.5)
	2	32.0 (±7.9)	31.5 (±8.2)	45.7 (±20.6)	48.5 (±11.4)
	3	30.9 (±5.5)	30.6 (±7.6)	54.3 (±11.2)	52.2 (±8.6)
Straight	0	30.3 (±5.1)	30.1 (±6.9)	50.2 (±15.2)	47.9 (±10.6)
	1	28.5 (±5.4)	26.4 (±4.5)	53.0 (±11.4)	48.7 (±10.8)
	2	33.2 (±6.5)	32.8 (±7.0)	56.5 (±8.3)	57.2 (±11.2)
	3	33.0 (±7.1)	33.0 (±7.4)	59.4 (±15.2)	53.9 (±9.7)

§ bare hand condition.

The reduction of carrying strength when wearing gloves, compared to that of the bare hand condition, was termed as RCS. It was calculated using an equation similar to Equation (1). Negative RCS values indicate an increase in the carrying strength because of wearing gloves. Table 7 shows the means and standard deviations of the RCS for different gender, handedness, and glove conditions. The ANOVA results showed that the effects of posture ($p < 0.01$) and gloved conditions ($p < 0.0001$) were both significant on the RCS. Duncan's multiple range test results showed that the semi-squat posture condition had significantly ($p < 0.05$) less carrying strength increase (−2.8 ± 19.4%) than that of straight posture (−9.3 ± 22.4%). Wearing glove 1 led to a reduction of 3.1 (±16.1)% of carrying strength while wearing gloves 2 and 3 resulted in carrying strength increases of 9.8 (±23.7)% and 11.6 (±20.0)%, respectively. The RCS of both gloves 2 and 3 were significantly different from that of glove 1 condition. The RCS between gloves 2 and 3 was not significant. Both the interaction effects between gender and posture ($p < 0.0001$) and between gender and glove ($p < 0.05$) on RCS were statistically significant (see Figure 7).

Table 7. RCS under experimental conditions (%).

Posture	Glove	Female		Male	
		Dominant	Non-Dominant	Dominant	Non-Dominant
Semi-squat	1	6.8 (±11.5)	3.5 (±14.5)	2.9 (±7.4)	7.5 (±12.6)
	2	−11.7 (±18.1)	−17.0 (±13.5)	11.3 (±36.6)	1.5 (±17.0)
	3	−10.1 (±16.6)	−14.9 (±18.2)	−2.7 (±16.2)	−7.0 (±14.5)
Straight	1	5.7 (±11.0)	9.7 (±16.0)	−9.6 (±23.2)	−3.6 (±21.8)
	2	−10.0 (±16.9)	−11.1 (±22.1)	−18.0 (±23.9)	−21.7 (±23.5)
	3	−9.8 (±20.4)	−10.8 (±16.1)	−23.0 (±34.3)	−14.2 (±16.4)

Figure 7. Interaction effects of gender and posture and between gender and gloved condition on the reduction of carrying strength.

3.3. Lifting Strength

The reduction of lifting strength when wearing gloves compared to that of barehanded condition was termed RLS. It was also calculated using an equation similar to Equation (1). Table 8 shows the means and standard deviations in the lifting strength and RLS for different gender and gloved conditions. Negative RLS values imply increases of lifting strength due to wearing gloves. The ANOVA results showed that the effects of gender were significant ($p < 0.05$) on lifting strength. The lifting strength for males (77.6 ± 21.9 kgf) was significantly higher than that for female (46.0 ± 13.3 kgf). However, the effects of gender on RLS were insignificant. The gloved condition was insignificant on both lifting strength and RLS.

Table 8. Lifting strength and RLS under experimental conditions.

Glove	Lifting Strength (kgf)		RLS (%)	
	Female	Male	Female	Male
0 §	45.6 (±12.9)	77.6 (±23.9)	-	-
1	42.0 (±13.1)	77.2 (±21.9)	3.3 (±28.1)	−1.6 (±16.4)
2	48.7 (±13.9)	77.2 (±22.9)	−7.8 (±12.3)	−1.3 (±18.5)
3	47.8 (±13.6)	78.5 (±21.1)	−6.8 (±19.0)	−5.1 (±22.3)

§ bare hand condition.

4. Discussion

4.1. Grip Strength

The literature has shown that wearing gloves could lead to a reduction of grip strength up to 23% [40]. It is well known that gender, handedness, and grip span all have significant effects on grip strength [41–44]. It is also known that there is a grip span that allows the production of maximum grip strength for each individual [45–48]. Grip strength declines when the object being handled is larger than this grip span. Our grip strength data were consistent with those in the literature.

Our grip strength data showed that wearing gloves led to declines in grip strength under most of the experimental conditions. These declines are lower than those in the literature [38]. This was because the thickness of our gloves is much less than those in the latter. The cut resistance gloves (glove 3) showed the highest decline than the other gloves, and the knitted gloves with NBR coating showed the lowest decline. Based upon EMG assessments of forearm muscles, a literature [49] has found that declination of grip strength is linearly related to the thickness of the gloves. This was partially consistent with our findings. The grip strength decline of the thickest gloves (9.4%), or the cotton gloves, was less than that of the cut resistant glove (12.8%). The thinnest glove (glove 2) showed the lowest grip strength decline (6.8%). The reason for this may be that our glove thickness was in a narrower range (1.03 mm~2.17 mm) than that in [49] (1.2 mm~8.2 mm). This may also imply a decline of grip strength due to wearing gloves not only depending on glove thickness but also the stiffness of the gloves. The literature [31] has reported strong correlation (0.77–0.94) between a glove's longitudinal stiffness and grip strength. The glass fibers in the cut resistance gloves in our study increase the stiffness of the gloves and hence hamper the production of grip force. The stiffness angle of glove 2 (34.6°) was higher than that of glove 1 (28.8°) but the former had a significant ($p < 0.05$) lower RGS than the latter. This was because the effects of stiffness on the grip strength was impeded by glove thickness.

The relationships between grip strength and grip span are shown in Table 5. Grip span also affected the decline of grip strength when wearing gloves especially for females. Table 4 shows that at a grip span of 65 mm, female participants experienced averages of 2.1% and 3.3% grip strength increase, instead of decrease, when wearing gloves 1 and 2, respectively, on their non-dominant hands. Their dominant hands, however, experienced 1% and 3.7% declines of grip strength on the same grip span and gloved conditions, respectively. These percentages are relatively small implying insignificance of wearing gloves on grip strength at a grip span of 65 mm for females. Declines of grip strength for female participants were more obvious at the grip spans other than 65 mm for those we had tested. For male participants, the grip strength reduction wearing glove 2 at both 45- and 55-mm grip spans on the dominant hand were also negligible.

4.2. Carrying Strength

The carrying strengths with gloves 3 (42.7 kgf) and 2 (41.5 kgf) were both significantly higher than those of glove 1 (37.6 kgf) and bare hand (38.9 kgf) conditions, indicating that the former two gloves were superior to the latter two. The reason for this may be attributed to the friction of the gloves. The COF of gloves 2 and 3 (≈0.9) were much higher than that of glove 1 (0.3). They were also believed to be much higher than that of the skin even though we could not measure the COF of the bare hand of the participants on the handle. High COF allows better hand-handle coupling and thus enhances the carrying strength of the participants. This was consistent with the discussions in [50]. The effects of the gloves on the reductions of carrying strength between the two genders were different. Figure 7 shows that female participants lost 6.4% of their carrying strength when wearing the cotton gloves. They, however, gained 12.4% and 11.4% of their strength when wearing the knitted gloves with NBR coating and the cut resistant gloves, respectively. Male participants, on the other hand, gained a negligible amount (0.7%) of carrying strength when wearing the cotton gloves. They gained 6.7% and 11.7% of the carrying strength when wearing the knitted gloves with NBR coating and the cut resistant gloves, respectively. Females seemed to gain equivalent benefits when using the latter two gloves in performing carrying tasks. Males, on the other hand, gained more benefits using the cut resistant gloves than that of the knitted gloves with NBR coating.

Wearing the cotton gloves led to carrying strength reduction in the range of 2.9% to 7.5%, on average, for female and male participants using semi-squat posture (see Table 7). There were also 5.7% and 9.7% carrying strength declines, on average, for female participants wearing this glove using the straight posture. The inferiority of the cotton gloves on carrying strength might be attributed to the low friction (0.3) of this glove. Slip of the hand might occur on the handle when the friction between the hand-handle interface was insufficient. This would hamper the force application of the participant on the handle.

Wearing the knitted glove with NBR coating led to carrying strength reductions of 11.3% and 1.5% on dominant and non-dominant hands, respectively, for male participants using semi-squat posture. However, this glove led to carrying strength increases (10~21.7%) in all other postural, gender, and handedness conditions. Both male and female participants showed higher carrying strength for both of their hands under both semi-squat (2.7~14.9%) and straight (9.8~23%) postures when wearing the cut resistance gloves.

4.3. Lifting Strength

The insignificance of the gloved condition on the lifting strength indicated that the participants received negligible benefits on their lifting strength when wearing the gloves tested in this study. Neither did they suffer strength reduction because of wearing gloves. These results seem to be inconsistent with those in the carrying strength. In general, the participants showed higher carrying strength when wearing knitted gloves with NBR coating and cut resistant gloves. Their carrying strength declined when wearing the cotton gloves. There were differences between the measurements of the carrying and lifting strength. The carrying strength measurements were conducted using the short handle while the lifting strength was measured using the long handle. The short handle has a circular steel surface while the long handle has a rubber sleeve with finger grooves. The rubber sleeve was beneficial in providing friction required for the leg lifting strength measurements for all the gloved conditions and thus diminished the discrepancies of lifting strength among the gloved conditions. This implies that the effects of the gloved condition on lifting strength may be ignored if the handle provides enough friction to couple with the hand. Workers may be reluctant to wear gloves when they gain little benefits in their capabilities in lifting the materials being handled [51].

4.4. Limitations

There are limitations to the study. The literature has proposed methodologies to measure glove stiffness [52]. Those methods were not adopted in the current study due to our lack of measurement devices. We measured the stiffness of the gloves using a simple drooping test. The stiffness angle was used to quantify the stiffness of the gloves tested in this study. This test method was original without prior validation. The stiffness angle used to indicate the stiffness of the gloves needs to be validated in future research. Only three types of gloves were assessed. The results of this study may not be generalized to other types of gloves. Future research may be performed to cover more work gloves used in the industry.

5. Conclusions

Three work gloves were assessed in terms of the strength of grip, carrying, and lifting. It was found that the gloves, grip span, gender, and handedness were all significant factors affecting grip strength. Wearing gloves could result in a reduction of grip strength up to 22.9%, on average. The reduction of grip strength varies and depends on gender, handedness, grip span, and gloves used. The gloves, posture, and gender all significantly affected the carrying strength. The cotton gloves led to carrying strength declines while both the knitted gloves with NBR coating and cut resistant gloves could increase the carrying strength. The inferiority of cotton gloves was primarily because of their insufficient friction in the palmar region. Wearing the gloves tested in this study did not change the leg lifting strength due to the good slip resistance characteristics of the long handle. This implies that gloves have little effects on the lifting strength when the handle could provide adequate friction at the hand-handle interface. These findings are beneficial for practitioners in selecting proper gloves in manual materials handling tasks.

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