

Grip Force and Muscle Activity Differences Due to Glove Type

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The purpose of this study was to investigate the effects of different types and sizes of gloves on external grip force and muscle activity. Twenty-one male and seven female volunteers served as subjects. Each subject performed two maximum voluntary grip contractions while wearing each of the 10 glove types. Results indicated significant differences in the effects of different glove types on the peak force, ratio of peak force to normalized flexor muscle EMG activity, and the ratio of peak force to coactivity.

Keywords: electromyography, gloves, hand strength

The use of gloves is common in industry today (e.g., meat packing, construction, warehousing). They may be used as protection from temperature, abrasive conditions, or hazardous materials. Although the benefits of gloves to hand safety are well known,⁽¹⁾ less information has been presented regarding the effects gloves may have on the quality and efficiency of work performed, or the potential risk associated with cumulative trauma.

The effects of gloves on work performance are easily discernible. Gloves may inhibit movement of the hands, causing problems with both precision and speed and ultimately creating problems with production. In addition, the effects of gloves on the individual worker are more difficult to identify. Gloves may reduce the level of force that may be exerted on an object.⁽²⁾ Therefore, an elevated internal force must be attained to reach the force output required for the task. This increased internal force may raise the risk for both acute and cumulative injuries. Acute injuries may occur when fatigue of the primary muscles leads to recruitment of smaller, secondary muscles. As these secondary muscles are typically used for motion control rather than strength, they may not be capable of providing adequate strength. As a result, problems may occur with both material handling and tool control. Acute injury may also occur when muscles are pushed beyond their normal threshold to reach a desired force, causing strains or sprains within the muscles.

Gloves may also contribute to the high incidence of cumulative trauma disorders (CTDs). Since 1989, CTDs have accounted for more than 50% of occupational illnesses.⁽³⁾ Although it is unknown how many of these jobs involved the

use of gloves, many industrial jobs involve some type of gripping. Evidence has been presented that links repetitive use and forceful exertions to CTDs.⁽⁴⁾ Because gloves may alter the recruitment and force of the forearm muscles, long-term use of these muscles and increased force requirements may therefore lead to cumulative trauma. The increased force also creates an increase in the biomechanical stress on the tendons, another contributing factor to cumulative damage.

Gloves have been evaluated for their effects on several different tasks. Rosenblad-Wallin⁽⁵⁾ examined the effects of gloves on dexterity of the individual. This study found that dexterity was reduced with the addition of gloves. Cadoret and Smith⁽⁶⁾ found that friction, rather than texture, was the determining factor in exerted force and object manipulation. Friction between handle and glove surfaces also has been shown to be the primary factor affecting maximal torque exertions.⁽⁷⁾

A link between gloves and risk of injury may be found by evaluating the effects of gloves on the exertion of force. Previous studies have shown how glove size or type may affect the force exerted. Shih and Wang⁽⁷⁾ evaluated gloves of different thicknesses, and found that the thicker the gloves, the greater the maximum volitional torque exertion on supination. Another study, Riley et al.,⁽¹⁾ showed that a single layer glove increased the exerted force on an object compared with bare hand force exerted. However, this study examined only one type of glove, and examined push and pull forces rather than grip force directly.

These studies have shown that gloves have several effects on object manipulation as well as

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TABLE I. Anthropometric Data

Subjects	Right/ Left	Males/ Females					
28	23/5	21/7					
Males	Age (yrs)	Hand Thickness	Palm Breadth	Hand Length	Forefinger Length	Palm Length	
Average	22.5	2.68	8.50	19.00	12.28	11.02	
SD	1.9	0.22	0.43	0.82	0.73	0.55	
Max	28.0	3.20	9.20	20.50	13.80	12.10	
Min	20.0	2.20	7.80	17.40	10.90	10.20	
Females	Age (yrs)	Hand Thickness	Palm Breadth	Hand Length	Forefinger Length	Palm Length	
Average	23.7	2.31	7.54	17.57	11.13	10.07	
SD	4.3	0.23	0.31	0.92	1.06	0.55	
Max	33.0	2.60	8.00	18.40	12.50	10.50	
Min	20.0	2.00	7.10	16.00	9.60	8.90	

Note: All dimensions given in centimeters.

the exertion of force. However, none have directly linked glove types to grip force. Because many industrial jobs involve not only gloves, but also some type of gripping, it is important that the effects of gloves on grip force exertions be known. One study was performed that examined the effects of gloves on grip exertions.⁽²⁾ This showed that gloves reduced the level of maximal force exerted, whereas the activity of the flexor and extensor muscles remained consistently high. However, this study did not examine the varying effects on force due to different types and sizes of gloves. Also, several confounding factors such as wrist and elbow posture were not controlled.

A void remains in our understanding of the literature regarding the direct effects of glove size and type on grip force and muscle activity. Both glove size and type may have significantly different effects on the external force and/or internal muscle activity of workers. The purpose of this study was to investigate these effects for several different types of gloves commonly seen in industry.

METHODS

Subjects

Twenty-eight volunteers were used as the subjects for this experiment; 21 males and 7 females. The age range was 20–33, with an average age of 22.8 (standard deviation 2.6). Anthropometric data was collected for each of the subjects for age; gender; handedness; hand length; forefinger length; palm length; hand thickness; and palm breadth according to standard procedure,⁽⁸⁾ and is shown in Table I. Measurements were taken on the dominant hand. Subjects were also questioned regarding their previous history of any hand or wrist trauma; any with recent injury or cumulative trauma disorders were excluded from the study.

Experimental Design

A repeated measures design was used for this experiment, with glove type (including size) as the independent variable. Dependent variables included peak and mean grip force, peak and mean electromyographical (EMG) activity of the flexor digitorum superficialis and extensor digitorum, the ratios of peak force to flexor and extensor EMG activity, the ratio of flexor to extensor EMG activity (coactivity), and the ratio of peak force to coactivity. The



FIGURE 1. Glove types. Top row (left to right): leather, jersey, surgical; bottom row (left to right): neoprene, PVC, cotton

ratio of force to EMG activity was examined to evaluate the transfer of internal EMG to peak grip force. The ratio of flexor to extensor EMG activity was considered to evaluate coactivity between the muscles.

Apparatus

Ten different types of gloves were tested including leather, surgical (latex with powder lining), cotton, neoprene, PVC, jersey (cotton-polyester blend), and bare hand. The various gloves can be seen in Figure 1. Also included as glove types were oversized gloves of the same material for leather, surgical, and jersey gloves, intended to give insight on the effects of glove fit. The neoprene and PVC gloves had cotton blend linings. All gloves were selected for best-fit conditions, excluding the PVC, cotton, and neoprene, which were available in only one size. Glove fit was assessed by visually examining the amount of glove remaining at the fingertips (if any) and the gap between the webbing of the fingers and the glove. Best-fit gloves had no gap and no remaining space at the ends of the fingertips. Glove sizes were subjectively chosen based on which size minimized these two factors. The surgical gloves used in this study were form-fitting, worn stretched over the hand, and comparatively thin with respect to the other gloves used in this study. Jersey and surgical gloves were the only gloves that were appreciably elastic, stretching to fit snugly over the hand. Jersey and surgical were the thinnest gloves. The cotton, PVC, and neoprene gloves were sized as “one size fits all.” Oversized gloves were sized one size larger than their regular counterparts, except oversized jersey, which were sized two sizes larger than regular jersey.

A grip dynamometer (TM Stoelting Co., Wood Dale, Ill.) was fixed on a post to place the forearm at 90° to the torso. The grip opening (diameter, the distance between the aluminum handle and fixed bar) was set at 2.75 inches. A linear potentiometer was attached to the grip dynamometer to record grip force. The potentiometer was calibrated before the data collection process began. To maintain the 90° angle between the forearm and torso, an elbow stand was used. A level shoulder position as well as minimal elbow abduction were maintained by the subject and not quantitatively measured. The elbow stand was composed of two wooden beams at 90° to each other, mounted on a tripod. The

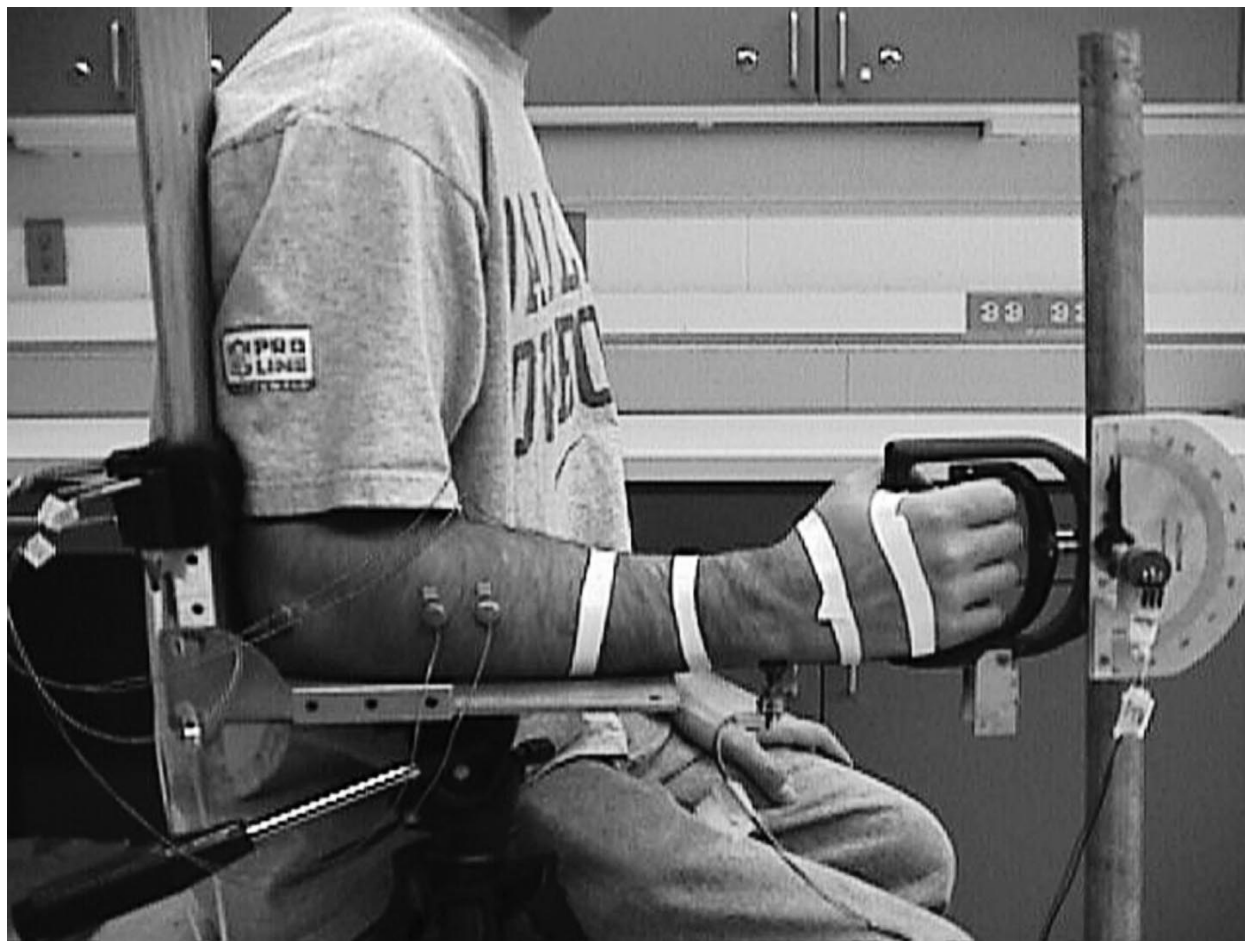


FIGURE 2. Experimental setup

bottom beam of the stand was parallel to the floor. The horizontal beam of the elbow stand extended the length of the forearm to avoid any radial or ulnar deviation of the wrist. The vertical beam extended behind the upper arm to avoid extension of the elbow. The arm of the subject was placed on the stand in a neutral position, and pencil markings were made on the wooden beams to visually keep the arm aligned. A linear potentiometer (goniometer) was attached to the wrist (at the lateral edge of the wrist with the center of rotation of the goniometer coinciding with the approximate center of rotation of the wrist) using surgical tape to record any flexion or extension of the wrist from the neutral position. Details of this monitor are described in Marras and Schoenmarklin.⁽⁹⁾ The experimental setup is shown in Figure 2.

Bipolar silver-silver chloride surface electrodes spaced 3 cm apart were used to collect the EMG activity of the flexor digitorum superficialis and the extensor digitorum.⁽¹⁰⁾ Electrode placement was performed using standard procedures.⁽¹⁰⁾ Resistance between the electrodes of each muscle was kept below 1 M, with typical values less than 250 k. A ground electrode was placed at the lateral epicondyle.

The data acquisition system used collected data for each exertion for 5-sec intervals at a frequency of 1000 Hz. Electrodes were connected to preamplifiers located close to the body, where they were preamplified; high-pass and low-pass filtered at 30 Hz and 1000 Hz, respectively; rectified; and integrated via a 20-msec sliding window hardware filter. Data was stored on an IBM[®] PC for

future analysis. Video recordings were taken of each subject to view the position of the elbow and wrist.

Procedure

Before any data was collected, each subject read and signed a consent form. The anthropometric data was collected, and the goniometer and electrodes were placed on the subject.

To maintain a standard posture for all subjects, the height of the dynamometer was adjusted to place a 90° angle between the forearm and torso. The elbow stand was adjusted to maintain this position. No backrest was provided for the subjects, and they were instructed to sit with their backs straight. During exertions, subjects were instructed to keep their upper legs directly in front and lower legs at a 90° angle to the floor.

The flexion/extension plane wrist angle was recorded as 0° at its neutral position (in which the back of the hand was parallel to the forearm). This position was used as a reference to monitor the movement of the wrist during the exertion. Trial exertions were performed to practice controlling the wrist angle, until the wrist could be controlled within the desired range of $\pm 6^\circ$ (flexion/extension). Subjects were asked to give their maximum voluntary contraction for 3 sec for each condition. Each glove condition was performed twice with all trials presented in a randomized order. During each contraction, wrist angle and shoulder and elbow posture were controlled. Subjects were given visual feedback on their

TABLE II. Significance Table for Peak Values

	MANOVA (p-values) Wilk's lambda	ANOVA (p-values)						
		Force	Extension/EMG	Flexion	Force/Extension	Force/Flexion	Coactivity	Force/Coactivity
Glove Type	0.0001 ^A	0.0001 ^A	0.2039	0.6506	0.0564	0.0015 ^A	0.2513	0.0005 ^A

^A Indicates significance at $p < 0.05$.

wrist angles throughout the exertion via a computer display to maintain an acceptable wrist angle. Trials were repeated if the flexion or extension angle of the wrist exceeded 6° . Positions of the shoulder and elbow were previously marked on the elbow stand in the neutral position of the subject and were monitored visually. The subject was not given any feedback on the force exerted. Two minutes of rest was given between each trial to limit fatigue.⁽¹¹⁾

Data Analysis

Peak grip force values were determined by selecting the point at which both the wrist angle was maintained within -6 to 6° from neutral and the maximum external grip force was exerted. Mean grip force was determined by averaging the values over the interval from 1 sec prior to the peak force. Actual peak and mean EMG muscle activity were normalized for each subject using the barehanded and extension condition as the maximum EMG value. Equation 1 was used for normalization:

$$\text{Normalized EMG} = \frac{\text{EMG}_{\text{Trial}}}{\text{EMG}_{\text{Maximum bare hand}}} \quad (1)$$

Grip force and EMG activity were then statistically analyzed using a multivariate analysis of variance (MANOVA) as well as a one-way analysis of variance (ANOVA) with alpha equal to 0.05 for each. The significant dependent variables were analyzed using an ANOVA analysis with least squared difference (LSD) to show glove type groupings.

RESULTS

Table II shows a significance summary of results for each analysis using glove type as the independent variable. The ratio of force to extensor, force to flexor, flexors to extensor (coactivity), as well as force to coactivity (output/input) EMG are also observed. MANOVA as well as ANOVA results are reported.

The MANOVA analysis showed a significant glove effect

($\alpha=0.05$). Using the ANOVA for follow-up analysis, the maximum force and the ratio of force to flexor were found to be significant, but no significance was found in extensor and flexor EMG, or for the ratio of force to extensor and flexor to extensor EMG. The ratio of force to coactivity was also found to be significant.

Descriptive statistics showing peak grip force as a function of glove type are shown in Figure 3. The average maximum grip force of 29.92 kg (SD = 11.70) was produced by the barehanded condition. The least amount of grip force was produced by the leather glove condition with an average force of 22.82 kg (SD = 9.73). This range of observations shows that there can be as much as a 23.7% drop in grip strength when wearing gloves.

The corresponding letters above the error bars represent the LSD groupings found for glove type. Glove types with the same letter groupings were not found to be significantly different. There are three distinct groupings observed from the LSD analysis. The first group includes the barehanded and surgical glove types, indicating no difference in strength between these types. In the second group jersey, oversized jersey, and oversized surgical glove conditions were found to be significantly different from the other two groupings, but not different from each other. The last group contains PVC, cotton, neoprene, and leather, as well as oversized leather. These groupings also demonstrate a significance difference between the surgical and oversized surgical conditions, demonstrating that glove fit is an important consideration.

The anthropometric measurements taken for each subject were compared with corresponding glove measurements to find a percentage of glove fit for each subject. However, these results did not prove to be significant.

Figure 4 shows the relationship of normalized peak EMG and glove type. This graph represents the internal input according to glove type. As mentioned previously, only the force-to-flexor muscle activity ratio was found to be significant at the $p < 0.05$ level. The lowest value for percentage maximum for flexor EMG (60.6%) was found during the oversized surgical condition. The

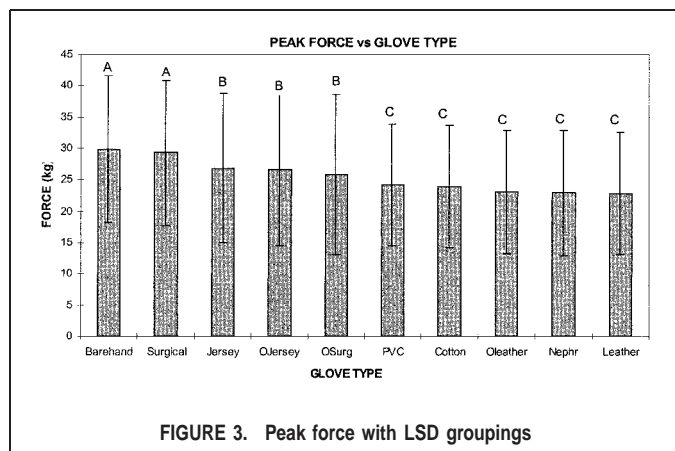


FIGURE 3. Peak force with LSD groupings

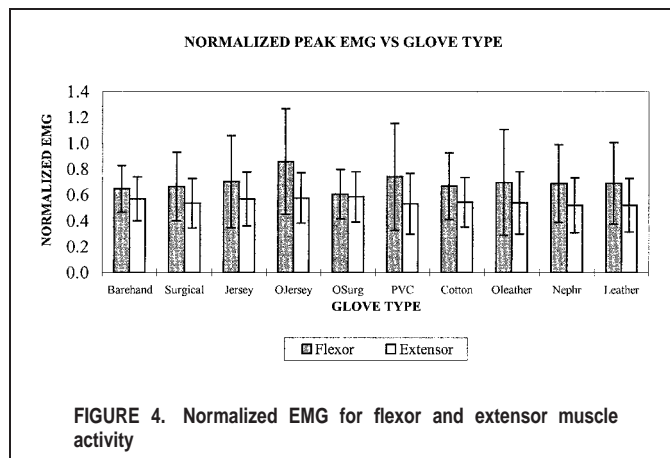


FIGURE 4. Normalized EMG for flexor and extensor muscle activity

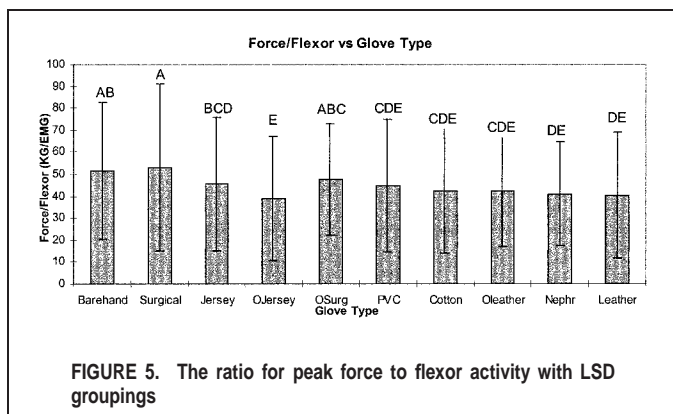


FIGURE 5. The ratio for peak force to flexor activity with LSD groupings

highest value for percentage maximum for flexor EMG (85.8%) was found in the oversized jersey condition.

The ANOVA analysis for the ratio of force to flexor muscle activity proved to be significant ($p \leq 0.0015$). Figure 5 provides an illustration of how force/flexor activity relates to the various glove conditions. The mean magnitude and standard deviations are given with corresponding LSD groupings. The LSD groupings did not identify the same groups, as was the case for peak force.

Figure 6 shows the relationship of external force output (grip) to internal force input (muscle EMG). More specifically, it indicates the transfer function of external force to coactivity in relation to glove type. The corresponding LSD groupings are shown in Figure 6. There is a good amount of separation in the groupings, demonstrating a significant difference between oversized leather, leather, oversized jersey, PVC, neoprene, and the barehanded and oversized surgical.

DISCUSSION

Previous studies have compared hand forces for barehanded exertions with gloved exertions. These studies typically compared being barehanded with wearing gloves or layers of gloves and investigated differences between them. However, they did not address the range of gloves commonly found in the workplace. The present study investigates potential differences among different types of gloves and glove fits.

Significant differences were observed between the peak forces of different glove types. Results of the data analysis suggest that characteristic aspects of different gloves such as material and size can affect the peak grip force of the wearer. Additionally, results of the ANOVA model of the normalized peak EMG activity of

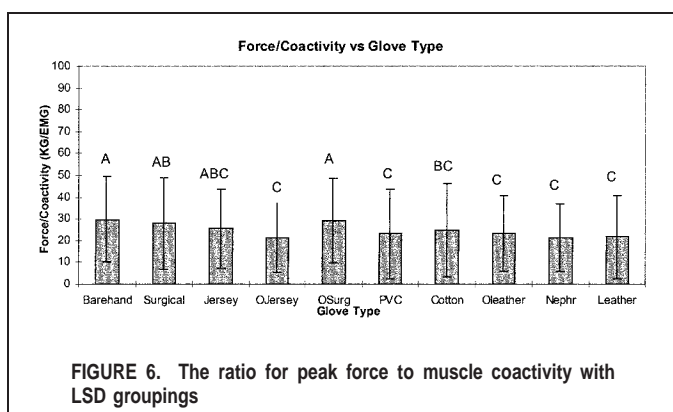


FIGURE 6. The ratio for peak force to muscle coactivity with LSD groupings

the forearm flexor and extensor muscles did not show a significant effect of glove type. This was not surprising because subjects were asked to provide maximum grips under all conditions. This finding indicates a high level of subject compliance to the experimental task. These results also agree with those found by Sudhakar et al.⁽²⁾ indicating that subjects generated maximum exertions in each condition. The ratio of normalized flexor to extensor EMG showed no significant effects due to glove type, indicating that glove type did not significantly affect coactivity. This indicates that the glove-hand or glove-handle interface reduces force transmission between muscle and handle rather than through increased coactivity patterns.

The lack of a significant effect of glove type on EMG activity combined with the significant effect of glove type on peak force indicates that gloves have an effect on the transfer of energy from internal muscle activity to external grip force. Although the internal activity levels remained at a maximal level, the force output was significantly reduced with the addition of gloves. Since all gloves except surgical resulted in significantly reduced grip force when compared with the barehanded condition, this effect could be characterized as a general reduction of force transmission due to the glove. These results indicate that gloves can be chosen or designed for a job so as to maximize the grip force the wearer can exert.

The data indicate that different glove types have significantly different effects on peak grip force. Observed trends in the LSD groupings suggest that thicker, less elastic glove types cause a greater decrease in peak grip force than thinner, more elastic glove types. Thus, the "thinnest," elastic gloves—surgical glove and barehanded—allow for the most force output, followed by the thin, elastic gloves: jersey, oversized jersey, and oversized surgical.

The transfer function of output (grip force) per unit of input (normalized EMG activity) is more closely examined by considering the ratio of peak force to normalized EMG activity. For this ratio (peak force-to-flexor EMG activity) glove type was shown to have a significant effect. The barehanded and surgical glove conditions provided the greatest transfer of muscle activity to grip force. Based on this relationship, the bare hand and surgical glove conditions were significantly different from all except the oversized surgical and jersey glove conditions. This emphasizes the importance of both the fit and material of the glove. Larger, less flexible gloves inhibited the ability to produce force outputs compatible to that seen with the bare hand and surgical glove conditions. Because the internal force was not seen to differ between the various glove types, it is evident that grip force transmission is reduced due to the glove itself, either at the hand-glove or the glove-handle interface.

Additionally, the jersey glove type produced significantly higher transfer than the oversized jersey glove type. Since the oversized jersey gloves were two sizes larger than the jersey gloves, these results suggest that glove fit may have a significant effect on the transfer of flexor muscle activity to grip force when gloves worn are more than one size larger than a properly fitting glove. The larger glove size may increase the grip diameter used during the exertion, or permit a slight wrist extension (within the 6° window), thereby changing the length-strength relationship of the flexor and extensor muscles. Despite similar EMG activity between the different glove conditions, compatible force outputs may become unattainable.

An increase in muscle coactivity indicates that the overall muscular force and joint stiffness required to produce a given output force is also increased. While the data do not show significant

interactions between coactivity alone and glove type, they do indicate significant glove type effects on the ratio of peak force to coactivity. Because coactivity alone was not significant, the significance found for the peak force to coactivity ratio is driven by the fact that peak force is significant due to glove type.

Two glove characteristics have been shown to have an effect on grip force output: glove material and glove fit. It was shown that neither of these factors affected the EMG activity by itself in each condition; therefore, any force transmission reductions must be explainable by the external factors. Glove material may influence the force output due to the elasticity and flexibility of the material. Some reduction in force transmission may be caused by stiffer, less elastic gloves or by friction between the glove and gripping surface.

Another likely explanation for the effects seen due to glove fit is the length-strength relationship of the muscle. Larger gloves create slipping between the glove-handle interface, which creates a slight extension of the wrist. This extension then forces the grip to occur at a less optimal muscle length.

From an applications standpoint this investigation suggests that gloves reduce the amount of grip force that may be exerted, and that this loss of gripping ability will then result in a lowered efficiency. A mismatched glove (i.e., one with the incorrect material and/or size) causes the required force level to be higher than expected. Consequently, the muscles used to produce the grip are still working at their maximum level; however, a lower grip force results. To maintain productivity, more repetitions may be used as well as more forceful exertions. Both of these factors have been linked to increased risk of CTDs.⁽⁴⁾ Practically, these results suggest that gloves that fit the worker well can maximize transfer of muscular force to grip force and can reduce the amount of overgripping needed to maintain a desired grip force. These reductions can benefit the wearer by reducing the chances of acute or cumulative trauma. In addition to the proper glove selection, workers may benefit from additional rest between exertions. However, further investigations are needed to more fully explore this area.

Limitations

Several factors must be considered that may have affected the results seen from this study. First, the results of regressions using the anthropometric and percentage fit data did not find any notable correlations between any of the anthropometric and percentage fit variables and peak force output. As these variables were continuous, the sample size for the levels of each variable was relatively small. Thus, conclusions regarding the effects of fit on peak grip force are limited to the previously mentioned observations.

Second, radial and ulnar deviation were not measured during each trial, which could have allowed small deviations (within $\pm 6^\circ$) from the neutral position. Although it was primarily controlled for, it may have allowed wrist extension sufficient to alter the length-strength relation of the flexor muscle. Future studies should attempt to control this to a greater degree.

Finally, this study measured the activity of only two muscle groups in the forearm using surface electrodes. Future studies could observe alternative muscle groups or additional muscle groups to provide additional data.

The authors believe these findings have identified trends that would occur regardless of the effects of the limitations. This study emphasizes the biomechanical risk associated with glove use and the importance of well-fitting gloves.

CONCLUSIONS

In general, the results of this study provide insight into the effects of different types of gloves on peak grip force and muscle activity.

- Generally, gloves reduced peak grip strength.
- Different glove types have different effects on peak grip strength. Thinner, more elastic materials such as jersey and surgical gloves allowed for the greatest external force output.
- Barehanded exertions, and exertions performed wearing surgical and oversized surgical gloves, provided greater transfer of flexor muscle activity to grip force than many of the other glove types. Better-fitting gloves resulted in better transmission of muscular force to measured grip force.
- Significant differences exist between the ratios of force to coactivity between different glove types.

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