Measurements of Grip Strength Applied to Cylindrical Handles and the Effect of Gloves

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This paper introduces a new dynamometer for measuring grip force/strength applied on a cylindrical handle and briefly describes its application to investigate the effect of wearing gloves on grip strength. Sixteen subjects participated in the glove experiment. Six types of gloves were used in the test. Whereas the gloved-hand grip strength applied to cylindrical handles is well correlated with bare-hand grip strength, all gloves reduced the grip strength, especially those designed for isolating hand-transmitted vibration, regardless of the handle sizes (30 and 40 mm in diameter) used in this study.

INTRODUCTION

Repeated forceful hand and/or fingers exertions are associated with several musculoskeletal disorders (MSDs) such as hand tendonitis, strained muscles, and carpal tunnel syndrome. The hand force is also one of the important factors that can influence the development of hand-arm vibration syndrome. The forcefulness can be quantified using the percent of the maximal grip force or grip strength resulting from the maximum voluntary contraction of muscles. As one of the major hand force components, grip strength is required for tool and task designs and for risk assessments of MSDs. Grip strength can also be used to help diagnose MSDs, to examine the effectiveness of their treatments, and to evaluate the functional capacity of workers. Handgrip strength is also frequently measured as a total fitness parameter of the population or in sports practice. Although many studies on this subject have been reported, the measurements of grip force and grip strength applied to cylindrical handles and their associated musculoskeletal loading remain important issues for further studies.

A series of theoretical and experimental studies on this subject have been carried out by NIOSH investigators (Welcome et al., 2004; Dong et al., 2005; 2008; McDowell et al., 2007; Wimer et al., 2008). They have also developed finger models for predicting the musculoskeletal loading inside a finger (Wu et al., 2008; 2009). To help study hand biomechanics, a new dynamometer for measuring grip force/strength applied on a cylindrical handle has been developed. Detailed information on the development has previously been published (Wimer et al., 2009); further information on this new dynamometer and some experimental results are briefly introduced in the current article.

Various types of gloves are widely used in the operation of many tools and machines. These work gloves are designed to protect workers from chemical exposures, electrical hazards, biohazards, mechanical cuts, abrasive trauma, thermal burns, and/or hand-transmitted vibration. However, gloves can also reduce dexterity, tactile perception, and range of motion. Gloves have also been shown to reduce grip strength, when measured with Jamar handles or similar devices (Riley et al., 1985; Wang et al., 1987; Chang and Shih, 2007). A large glove-induced reduction in grip strength could require a higher grip effort when using tools or operating machines. Increasing the grip effort could increase the risk of hand-arm MSDs such as hand tendonitis, strained muscles, and carpal tunnel syndrome (Silverstein et al., 1987; Moore and Garg, 1995; NIOSH, 1997). A comprehensive understanding of this adverse glove effect may help improve the design of gloves. Knowledge of the effects of gloves on grip strength can also help workers, managers, and safety professionals make informed decisions about glove selection and use in the workplace.

As an application of the NIOSH-developed dynamometer, the effect of wearing a glove on grip strength applied on two cylindrical handles (30 and 40 mm) was investigated. The major findings are briefly presented in this paper.

A NEW DYNAMOMETER

For the same grip action, the grip force applied on a cylindrical handle measured in different hand orientations could vary significantly (Edgren et al., 2004; Dong et al., 2008). The vast majority of the reported hand dynamometers measure the grip force or strength only in one orientation at a time (e.g., Welcome et al., 2004; Radwin et al., 1991). According to Dong et al. (2008), the grip force should be measured in at least three orientations to sufficiently characterize it. A cylindrical handle wrapped with a flexible pressure sensor can be used to conduct the multi-orientation measurement (Dong et al., 2008). Because this approach is technically demanding and its reliability and accuracy have been questioned by some researchers, it is desired to develop a convenient and robust device to conduct the multi-orientation measurement.

Fig. 1: A 40 mm dynamometer and the hand grip posture used in the grip force/strength measurement.

Fig. 2: The orientation of the six measuring arm and the alignment of the hand and arm in the grip force/strength measurement.

The multi-arm handle structure proposed by Chadwick and Nicol (2001) provides a solution for the measurement of the grip force in three orientations. However, it is questionable whether the measurement with their hand dynamometer could vary with the hand grip position along the handle length. This potential problem can be minimized by measuring the grip force using a pair of shear strain gauges installed in a pocket near the foot of the cantilevered arm fixed on a base (Pronk and Niesing, 1981; Radwin et al., 1991). This technique was applied to develop the NIOSH hand dynamometer. Specifically, it consists of a cylindrical handle with integral shear strain gauges (Vishay, CEA 06-062UV-350/P2), and is configured in three sizes—30, 40, 50 mm—to accommodate variation in hand size. As an example, the one with a 40 mm diameter is shown in Fig. 1. Each dynamometer is composed of six uniform measuring arms, each of which covers a 60° range of the handle circumference, as shown in Fig. 2. Such a dynamometer structure makes it possible to simultaneously quantify the force values in three orientations.

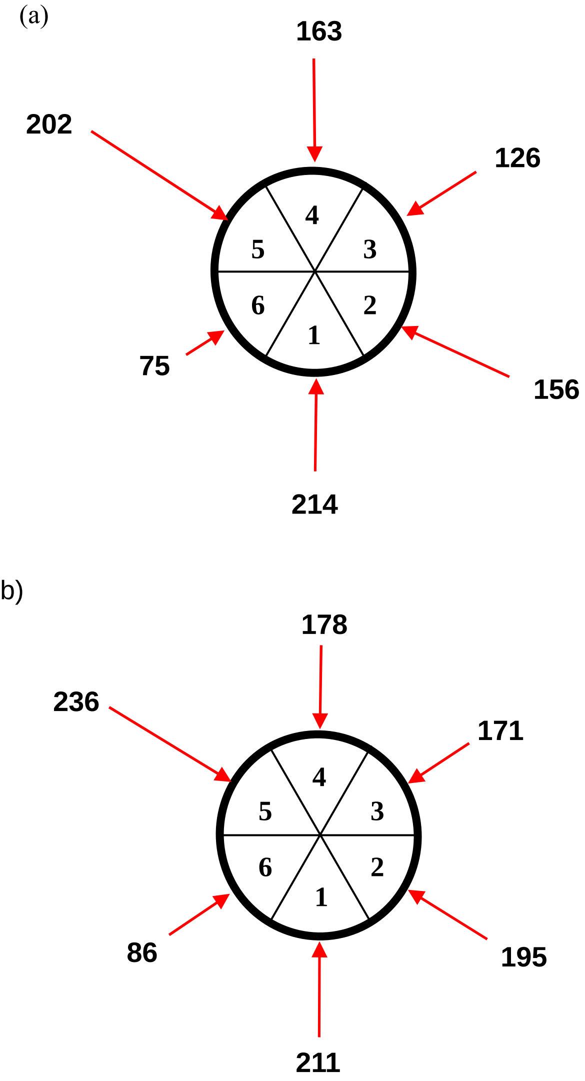

Fig. 3: Examples of the grip force components measured with the same subject on the 40 mm dynamometer under two different hand conditions: (a) with oil lubricant; and (b) without lubricant.

The experimental results reported by Amis (1987) indicate that the friction force in the grip-only action on a cylindrical handle with a diameter less than 50 mm is much smaller than the normal force. Therefore, it is not necessary to measure the friction-induced tangential force in the grip-only action for quantifying the grip effort for many applications. The dynamometer was thus designed to measure the normal force resulting from the contact pressure and assigned as a point value at the center of each arm. Theoretically, if the grip pressure is uniformly distributed around the circumference of the handle, the summed force measured on the six-arm dynamometer would be 95.5% of the total grip force acting on the handle (Wimer et al., 2009). This suggests that it is reasonable to use the summation of the distributed force components measured on the six arms to represent the grip strength applied on the cylindrical handle, and this assumption is applied in this study.

Each dynamometer was calibrated and examined using a dead weight method (Wimer et al., 2009). The maximum error was less than 4% of the applied load.

Six subjects participated in an experiment to test the NIOSH-developed dynamometers. To minimize any push or pull force that could be applied to the dynamometer during the experiment, the dynamometer was suspended by a string, as shown in Fig. 1. To minimize the dynamic force that could result from the acceleration of the handle, the subjects were advised to keep their hand steady while gripping the dynamometer.

Fig. 3 shows an example of the normal force distribution measured on the six arms when a subject applied the maximum grip force with a bare hand with the postures and dynamometer orientation shown in Fig. 1 and 2. The highest force is on Arm 5 where the fingertips are positioned (see Fig. 2), which is consistent with the findings reported by Amis (1987) and Dong et al. (2008).

Interestingly, the vector summation of any three forces on three neighboring arms (e.g., 1-2-3, 2-3-4, or 3-4-5) is very similar to that of the opposite three forces (e.g., 4-5-6, 5-6-1, or 6-1-2) when oil was used to lubricate the hand contact surface, as is demonstrated by the data shown in Fig. 3(a). This phenomenon was observed in the data measured with each of the six subjects who participated in the test. Theoretically, this is because the vector summation of all the normal force components on the handle in any direction should be close to zero for the designed testing conditions. The friction force was likely to be negligible because of the lubrication.

However, the force balance did not generally exist when the hand was not lubricated, as is demonstrated by the data shown in Fig. 3(b). The grip strength or the arithmetical summation of all six force components measured without hand lubrication is marginally (15%) larger than that with the hand lubricated ($p < 0.001$). This suggests some friction does exist in the grip-only action, and it helps stabilize the grip action. This also suggests that the friction force can be at least partially taken into account in the measurement using the NIOSH-developed dynamometer. This also suggests that a tool or machine handle should be kept clean and dry for optimal control.

EFFECT OF GLOVES ON GRIP STRENGTH

Glove Testing Method

The 40 mm dynamometer was used in the experiment to examine the effects of gloves on the measured grip strength. Because the 30 mm and 50 mm dynamometers were not available when the experiment was conducted, a 30 mm cylindrical handle instrumented with a flexible resistive pressure sensor matrix (TekScan Model 5101; 100 psi range) used in a previous study (Dong et al., 2008) was also used in the glove experiment. A following-up experiment was performed to compare the grip strength measured with this handle and that measured with the six-arm 30 mm dynamometer developed after the glove testing. Twelve subjects participated in the comparison testing. The grip strength values measured with these two dynamometers are highly correlated ($r = 0.93$, $p < 0.001$). This suggests that the handle equipped with the pressure sensor matrix is acceptable for the grip strength measurement. However, the grip strength measured on the pressure sensor-equipped handle is greater than that measured with the six-arm dynamometer. Their linear relationship factor (1.23) was applied to adjust the glove testing data so that the grip strength values measured with the 40 mm dynamometer and that measured with the 30 mm pressure sensor-equipped handle could be directly compared.

The glove study tested six commercially-available gloves: Glove 1- Mechanix Wear automotive; Glove 2 - leather/cotton construction; Glove 3 - Decade gel padded, anti-vibration; Glove 4 - Impacto leather, air pocket, anti-vibration; Glove 5 - Impacto mesh, air pocket, anti-vibration; and Glove 6 - ErgoAir pump, air pocket, anti-vibration. Four of the selected gloves were marketed as anti-vibration gloves. The other two were standard work gloves. Various sizes of each glove type were purchased in order to provide the best fitting gloves for each study participant.

Ten male subjects recruited from a local university participated in the glove experiment. The experiment was divided into two segments. One segment featured trials using the 40 mm dynamometer, the other utilized the 30 mm handle. During a segment, the subject completed three grip efforts on the cylindrical handle with each of the six gloves as well as in the bare-handed condition for a total of 21 cylindrical handle trials per segment. The postures of the measurements were as shown in Fig. 1 and 2. Each 21-trial sequence was fully randomized for each subject. Each of the ten subjects completed both segments; the two segments were completed on separate days.

The subjects were asked to apply maximum grip force efforts with the right hand for five seconds per trial. Data collection started once the grip exertion of the subject was stable. The force data sampling rate was 5 Hz. To discount initiation and termination effects, only the middle three seconds of each five-second trial were used to calculate the mean value of the maximum grip effort. The subjects rested for at least three minutes between trials.

Glove Testing Results

The 10-subject means and coefficients of variation (CV) for the grip strength applied to each of the two cylindrical handles are listed in Table 1. As expected, the grip strengths measured with these two handles are highly correlated ($r = 0.996$, $p < 0.001$). The grip strength of the gloved hand is correlated with the bare hand grip strength ($r \geq 0.854$, $p < 0.001$). The gloved grip strengths are also correlated to each other ($r \geq 0.797$, $p < 0.001$).

Each of the gloves produced a significant reduction in grip strength on both handles as compared to the bare-hand conditions ($p < 0.001$). No statistical differences were found among the four anti-vibration gloves (Gloves 3 through 6). Each of the anti-vibration gloves as well as the generic cotton/leather glove (Glove 2) caused significantly greater reductions in measured grip strength than the Mechanix glove (Glove 1). There was no significant handle/glove interaction ($F = 0.2$, $p = 0.980$). By and large, the glove effects observed with the 40 mm handle were duplicated on the 30 mm handle.

Table 1: The ten-subject means, coefficients of variation (CV), and percent reductions in grip strength for each glove condition for both cylindrical handles

Condition	40 mm handle			30 mm handle		
	Grip Strength (N)	CV	% Strength Reduction	Grip Strength (N)	CV	% Strength Reduction
Bare hand	905.8	0.17	–	870.3	0.17	
Glove 1	825.2	0.21	8.9	813.7	0.17	6.5
Glove 2	644.5	0.17	28.8	649.9	0.17	25.3
Glove 3	585.3	0.18	35.4	618.0	0.18	29.0
Glove 4	570.1	0.13	37.1	570.4	0.19	34.5
Glove 5	600.3	0.16	33.7	613.0	0.16	29.6
Glove 6	607.6	0.22	32.9	616.3	0.17	29.2

DISCUSSION AND CONCLUSION

The glove testing results clearly indicate that glove use generally reduces the grip strength applied to cylindrical handles. In other words, to achieve the same operational grip force needed to effectively and safely control a handled tool, a worker must apply additional grip effort when wearing gloves. This explains why wearing gloves during tool operations—especially thick gloves—could increase fatigue of the hand, wrist, and arms. It is anticipated that substantial increases in gripping efforts could also lead to long-term adverse health effects (NIOSH, 1997).

Our observations suggest that at least two different mechanisms could be involved in the glove effect on measured grip strength. One of them should be related to the glove stiffness under the constrained conditions of a gripping action. Thicker gloves generally exhibit increased bending stiffness. This may explain why the anti-vibration gloves caused more strength reduction. This mechanism suggests that the stiffness of the glove material should be minimized in order to minimize grip strength reduction. Better designs of the glove structures may also help reduce the glove stiffness and its effect.

Another possible mechanism related to glove effect is the glove material's effect on the effective handle diameter. It has been shown that hand grip strength generally changes with the handle size, which has also been confirmed in our follow-up study with three handle sizes (30, 40, and 50 mm). Thick gloves increase the effective handle size more than do thin gloves, and this mechanism should cause some interaction between handle size and glove type. For example, the effect of the glove on grip strength measured with the 30 mm handle should be reduced if the grip strength increases with handle size in the range of 30 to 40 mm. However, this prediction was not observed in the current study. This may be because the effect of the increased handle size could be cancelled by the increased glove reaction force resulting from increased glove bending on the smaller handle.

In summary, the NIOSH-developed dynamometer provides an alternative approach to existing dynamometers to measure the grip force/strength and its components distributed around the circumference of a cylindrical handle. The measured data can be used to estimate the principal grip direction and force. Its estimated maximum error is less than 4%, which should be sufficient for human subject testing. In principle, the NIOSH-developed dynamometer can also be used to measure the push or pull force or the hand forces involved in the combined grip and push/pull action. The dynamometer can also be used to calibrate or verify the hand contact force that can be measured using a flexible sensor appropriately wrapped on the dynamometer. The distributed force components and pressure can be used as inputs to a finger or hand model for predicting the musculoskeletal loading inside the fingers or hand. This study also concluded that gloves generally reduce grip strength; the degree of which depends on the specific glove or the glove material and structure. This suggests that it is possible to minimize the grip strength reduction effect by appropriately designing the gloves.

DISCLAMERS

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