



Effects of handle size and shape on measured grip strength

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ARTICLE INFO

Article history:

Received 5 October 2010

Received in revised form

29 July 2011

Accepted 20 January 2012

Available online xxx

Keywords:

Grip force

Handle size

Jamar dynamometer

Tool handle

ABSTRACT

The Jamar handle dynamometer is the most commonly used instrument for measuring grip strength. However, the grip strength applied on a cylindrical handle may not exhibit the same handle size relationship as that observed with the Jamar handle. Direct comparison studies are required to clearly identify the major differences between the two dynamometer styles. This study utilized a recent grip dynamometer design along with the Jamar dynamometer to further examine these relationships. The objective of this study was to compare how changes in grip size affects grip strength measured with each dynamometer style. Results confirm that handle size significantly affects the applied grip strength measured with both types of grip dynamometer. The handle size effect is more pronounced with the Jamar handle, especially at the small handle diameter/span. The highest grip force components observed with the cylindrical handles were found at the fingertips. The Jamar grip dynamometer may not adequately reflect the fingertip forces at the low and middle spans because the fingertips are not applied in the force measurement plane of the Jamar handle. Therefore, the Jamar dynamometer may not adequately capture changes in the fingertip forces under different grip spans.

Relevance to Industry: It is important to properly characterize grip strength used in occupational settings in order to optimize tool and machine handle designs. The Jamar dynamometer may not be appropriate for assessing cylindrical or near-cylindrical handles that are found on the majority of tools and machines. The grip strength measured with the cylindrical dynamometer used in this study can be used to help optimize handle designs.

Published by Elsevier B.V.

1. Introduction

Prolonged, forceful grip exertions have been strongly associated with tenosynovitis, tendinitis, carpal tunnel syndrome, and other upper extremity musculoskeletal disorders (MSDs) (NIOSH, 1997). High grip forces are also considered to be a contributing factor in the development of hand-arm vibration syndrome (HAVS) (Griffin, 1990; Muggleton et al., 1999). Therefore, it follows that factors influencing maximum voluntary contraction (MVC) grip force or grip strength should be evaluated as a part of overall strategies for preventing these upper extremity MSDs. Furthermore, it is important to properly characterize grip strength used in occupational settings in order to optimize tool and machine handle designs.

Since the introduction of the Jamar handle dynamometer more than 50 years ago (see Bechtol, 1954), it has become a popular instrument for measuring grip strength. This is partially because of its convenience, but also because the instrument provides

a reasonable simulation of the handle shapes of many widely used two-piece handled tools such as pliers, shears, or crimping tools. The Jamar dynamometer and similar models typically feature a two-pole design with four or five fixed grasp span settings ranging from approximately 25–75 mm. The grip strength measured with such a handle generally exhibits an approximate inverted-U relationship with the grasp span; the grip strength is highest at the middle span settings (Petrofsky et al., 1980; Oh and Radwin, 1993; Blackwell et al., 1999; Ruiz-Ruiz et al., 2002; Lee et al., 2009).

However, the grip strength applied on a cylindrical handle may not exhibit the same handle size relationship as that observed with the Jamar grip dynamometer. For example, in a study of grasping forces using cylindrical handle dynamometers with diameters ranging from 31 to 116 mm, Amis (1987) concluded that grip strength generally decreases with the increase in handle size. In a more recent study, Kong and Lowe (2005) measured MVC grip force exertion (grip strength) using six cylindrical handles with diameters ranging from 25 to 50 mm and came to a similar conclusion. In their recent studies, Seo et al. (2006, 2007) concluded that dissimilar grip force trends exhibited by Jamar and split-cylinder dynamometers might be due to the difference in

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grip postures imposed by the different handle shapes. Radwin (1999) noted that the Jamar dynamometer exhibits a curved surface at the grip center, while nearly all cylindrical handles are straight. These observations suggest the measured grip strength depends on the handle shape as well as size. This further suggests that Jamar grip strength measurements may not be useful for the optimization of cylindrical handle designs. Direct comparison studies are required to clearly identify the major differences between the grip strengths measured with Jamar-style dynamometers and cylindrical handle dynamometers.

There are also some inconsistencies among reported effects of cylindrical handle size on grip strength. The Edgren et al. (2004) study evaluated grip strength using split-cylindrical handles with five diameters ranging from 25 to 76 mm. They observed the greatest mean grip strength on a handle with a diameter of 38 mm. In a more recent study using three cylindrical handle diameters, McGorry et al. (2009) reported that grip strength measurements were significantly higher using 30 and 40 mm cylindrical handles than with 50 mm handles. However, neither of these two studies replicated the near-linear inverse relationship between cylindrical handle size and grip strength reported by Amis (1987) and Kong and Lowe (2005). Therefore, further studies are also required to clarify the relationship between grip strength and cylindrical handle size.

Based on the improved understanding of grip forces applied on cylindrical handles (Dong et al., 2008), an accurate and reliable cylindrical handle grip dynamometer has been recently developed to measure the total grip force applied on cylindrical handles (Wimer et al., 2009). This study will utilize this new dynamometer design along with the Jamar dynamometer to further examine fundamental characteristics of the handle size-grip strength relationships. The objective of this study is to compare how changes in grip size affects grip strength measured with cylindrical handles and with Jamar handles. There are two hypotheses:

- The MVC grip force (or grip strength) will vary with handle size.
- The handle size effect on grip strength will be different for the Jamar handle than with the cylindrical handles.

2. Methods and materials

This laboratory study employed twelve subjects (six male; six female) recruited from local university students. Table 1 presents subject anthropometry. The subjects followed a protocol that was

reviewed and approved by the National Institute for Occupational Safety & Health (NIOSH) Human Subjects Review Board.

2.1. Grip dynamometers

Two grip dynamometer types were used to measure MVC grip force or grip strength in this study. The first type of grip dynamometer, shown in Fig. 1, was the six-arm cylindrical handle recently developed by Wimer et al. (2009). Three diameters of this handle style – 30, 40, and 50 mm – were developed and evaluated in this study. Each of the cylindrical grip dynamometer bodies consists of six arms machined from 7075 aluminum. Each arm has a full length of 155 mm and an effective measuring length of 120 mm. The six measuring arms are attached to a common aluminum base via two machine screws. There is a 1-mm gap between each pair of arms to prevent arm-to-arm contact during maximal loading. The grip force on each arm is measured using a pair of shear strain gauges installed in pockets near the base of the measuring arm using the method previously proposed by Pronk and Niesing (1981). The strain gauge signals were acquired and processed using a conditioning board (National Instruments SC-2043-SG). The processed signals from the conditioning board were transmitted to a data acquisition card (National Instruments PCI-MIO-16XE-10) installed in a computer. The display and data recording program was developed in house using LabVIEW software (National Instruments, Version 7.1). Each of the six arms on each handle was calibrated individually as described by Wimer et al. (2009). As in the previous study, the calibration results verified that the load measurements were essentially independent of the point of application along the effective length of the measurement arm.

The second type of grip dynamometer was a regular Jamar model 5030J1 (Sammons Preston, USA). The Jamar dynamometer is shown in Fig. 2. The Jamar dynamometer measures the applied force in a single plane using a sealed hydraulic system with an analog dial gauge. The span of the Jamar handle can be adjusted by positioning the finger side of the gripping area to one of five settings. For this study, the Jamar handle was evaluated at its three shortest grip spans – 34, 47, and 60 mm as measured at the mid-point of the gripping area.

2.2. Experimental procedures

During a test session, the subject completed four MVC grip efforts with each hand on each of the six dynamometer configurations for

Table 1
Anthropometry of the twelve study participants.

	Subject	Stature (m)	Weight (kg)	Right Hand Length(mm)	Left Hand Length (mm)	Right Hand Breadth (mm)	Left Hand Breadth (mm)	Right Hand Volume (ml)	Left Hand Volume (ml)	Dominant Hand (R or L)
Females	F1	1.63	68.0	181	180	77	75	280	272	R
	F2	1.70	59.0	178	180	79	79	290	280	R
	F3	1.68	52.2	169	169	75	76	230	225	R
	F4	1.68	63.5	177	175	78	76	270	260	R
	F5	1.61	53.5	173	171	73	73	240	245	R
	F6	1.63	61.2	180	178	77	76	290	270	R
	Mean (SD)	1.65 (0.04)	59.6 (6.0)	176 (5)	176 (5)	77 (2)	76 (2)	267 (26)	259 (20)	
Males	M1	1.85	83.9	203	202	91	91	450	445	R
	M2	1.78	79.4	192	190	89	89	430	415	R
	M3	1.78	86.2	196	196	91	90	440	450	R
	M4	1.88	90.7	194	195	97	95	445	450	R
	M5	1.85	88.5	191	190	87	87	420	415	R
	M6	1.88	122.5	206	203	93	92	510	508	R
	Mean (SD)	1.84 (0.04)	91.9 (6.0)	197 (5)	196 (5)	91 (2)	91 (2)	449 (26)	447 (20)	
Combined	Mean (SD)	1.75 (0.10)	75.7 (20.2)	187 (12)	186 (12)	84 (8)	83 (8)	358 (99)	353 (102)	

Notes: Hand Length = tip of 3rd finger to crease at wrist; Hand Breadth at distal end of metacarpals.
Hand Volume = water displaced by hand submerged to crease at wrist.

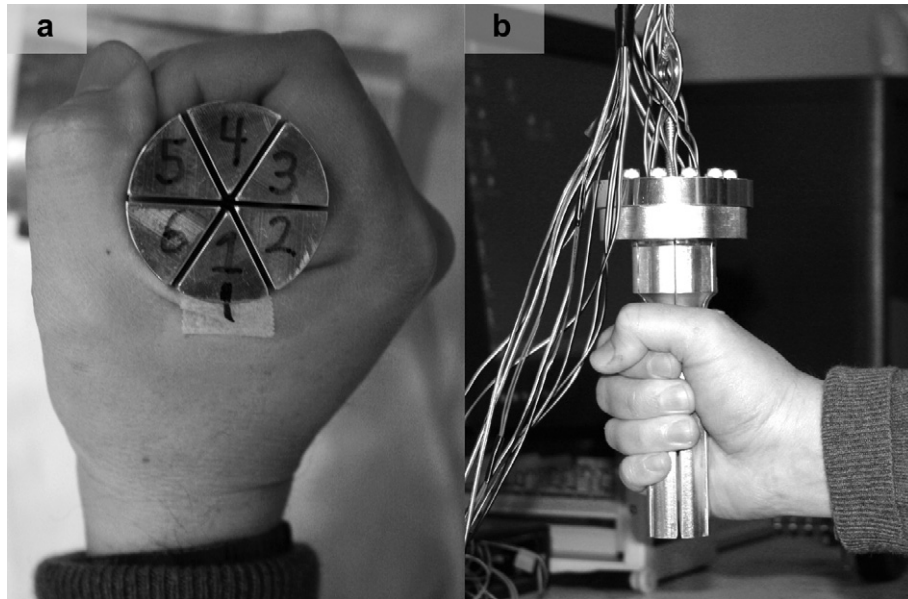


Fig. 1. (a) The 40 mm diameter six-arm cylindrical handle dynamometer with the individual arms numbered. During the test, the subject's forearm was aligned with the plane bisecting arms 1 and 4. (b) The 30 mm diameter handle suspended from string. A 50 mm diameter handle was also evaluated in the study.

a total of 48 trials per session ($4 \times 2 \times 6$). The test sessions were divided into four segments; each segment consisted of paired trials (left and right hands) with each of the six dynamometers. The order of the dynamometers was randomized within each twelve-trial segment. Test sessions lasted about two and one-half hours per subject.

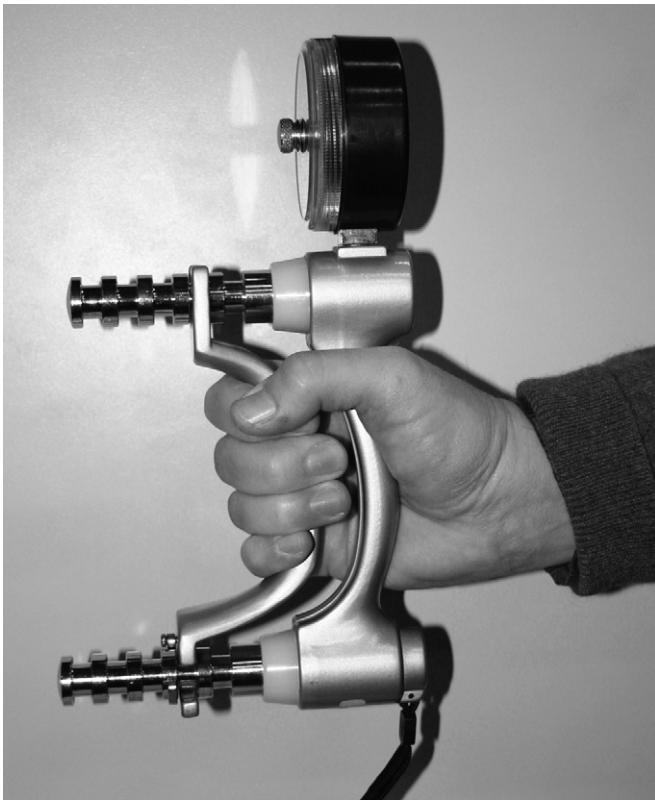


Fig. 2. The Jamar handle dynamometer set to its next-to-smallest grip span (47 mm). During the test, the subject's forearm was aligned with the plane bisecting the two parts of the handle. The Jamar handle was also evaluated at its smallest (34 mm) and middle (60 mm) span settings.

Each dynamometer was suspended from an overhead fixture so that no push, pull, or torque forces could be applied to the handle during the gripping actions. This arrangement is shown in Fig. 1b. Each handle's elevation was adjusted so that a maximum grip effort could be applied to the handle with the subject in a standing posture with the wrist in a neutral position, the elbow bent at 90° , and the forearm parallel to the floor. Markers were used to indicate the centerline of the first measuring arm of a six-piece handle, as well as on the thenar region of the subject's hand. (Refer to Fig. 1a.) The subject aligned these markers before applying a grip effort to help standardize the trial-to-trial hand direction and position. These posture and hand-alignment techniques were also employed with the Jamar handle.

Each subject was asked to apply his/her maximum grip effort with the right hand for 5 s per trial. The data collection started once the subject nodded their head to indicate maximum grip. The sampling rate was 5 Hz. Only the middle 3 s of each five-second trial were used to calculate the mean value of the maximum grip strength. This process was then repeated for the left hand on the same dynamometer. The subjects rested for at least 3 min before repeating this process on a different grip dynamometer. Once a subject had completed a twelve-trial segment, the order of the six handles was re-arranged in a random fashion, and the subject completed another six-handle, twelve-trial segment, and so on until the 48-trial matrix was completed.

2.3. Data analysis

Each arm of the six-arm cylindrical handle dynamometer produces a force output during a gripping action. These six outputs are summed to provide a measure of total grip strength. In contrast, the Jamar dynamometer provides a force output for a single plane. Thus, the magnitudes of the force outputs of the two dynamometer types are not directly comparable. To overcome this difficulty, the data were transformed to a common metric to evaluate the effect of varying the grip sizes of the cylindrical and Jamar handles. Specifically, the four-trial average force measured at the smallest grip span (34 mm) of the Jamar handle was computed for each hand for each subject. These left- and right-hand averages became the

Table 2

The mean ratios of the force measured with each of the six handle dynamometer configurations as compared to the Jamar dynamometer set to a grip span of 34 mm along with the subsets identified via Tukey HSD tests. Means within a common subset are not significantly different ($p > 0.05$).

Type	Span (mm)	Ratio	Subsets
Jamar	34	1.000	a
	47	1.369	b
	60	1.302	b
Cylindrical	30	2.055	c,d
	40	2.136	d
	50	1.987	c

baseline values for each individual subject. The measured grip force for each trial was then compared to that subject's corresponding baseline value, and a Force Ratio was then computed for each trial using the following formula:

$$\text{Force Ratio} = \text{Measured Force} / \text{Baseline Value} \quad (1)$$

Thus, Force Ratio became the dependent variable in the subsequent data analyses; a three-factor analysis of variance (ANOVA) for Force Ratio was conducted using hand, gender, and handle size as fixed factors. Post hoc Tukey Honestly Significant Difference (HSD) tests were performed to further evaluate the effect of handle size on the Force Ratio. The ANOVA and post hoc tests were performed using SPSS statistical software (SPSS Inc., ver. 15.0). Pearson correlation analyses were also conducted to examine the relationship between the subject's hand length and Force Ratio. Analysis results were considered to be significant at the $p < 0.05$ level.

3. Results

3.1. Force ratios by Handle size

As described above, the dependent variable evaluated in this study's analyses was the ratio of the force measured by one of the six grip dynamometers to the four-trial average force for each individual subject with the Jamar handle set to a span of 34 mm. Table 2 and Fig. 3 present the mean ratios for the six grip dynamometer configurations. The ANOVA for Force Ratio revealed that handle size and gender were both significant factors ($p < 0.001$). There was no significant difference between the left- and right-hand results ($p = 0.354$). The post hoc Tukey test results are presented in Table 2. For the Jamar dynamometer, the 47 and 60 mm grip strength means were both significantly higher than that at the

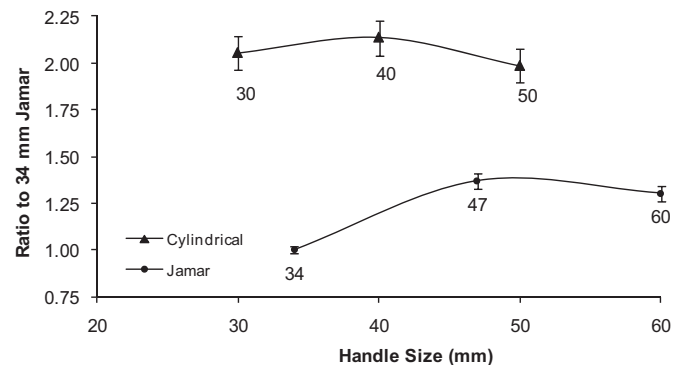


Fig. 3. The mean ratios of the force measured with the three cylindrical handle dynamometers and the Jamar dynamometer set to its three smallest grip spans as compared to the Jamar dynamometer set to a grip span of 34 mm (The y-error bars indicate the 95% confidence intervals for each mean.)

Table 3

The twelve study participants sorted by hand length along with the handle sizes with which they were able to produce their greatest grip force.

Subject	Hand Length (mm)	Optimum Size (mm)	
		Cylindrical	Jamar
F3	169	30	47
F5	173	30	47
F4	177	30	47
F2	178	40	47
F6	180	40	47
F1	181	40	47
M5	191	40	47
M2	192	40	47
M4	194	40	47
M3	196	40	47
M1	203	50	60
M6	206	40	47

34 mm span setting. For the cylindrical handles, the highest forces were measured with the 40 mm diameter handle. The 40 mm grip strength mean was significantly higher than the 50 mm mean, but was not significantly higher than the 30 mm mean. The 30 mm and 50 mm means were not significantly different.

3.2. Optimum handle size by test subject

Table 3 presents the optimum size for each type of grip dynamometer for each of the twelve study participants. That is, the handle sizes listed in the table are those at which each subject produced their greatest grip force for each type of handle. The data are sorted from low to high according to the subjects' hand lengths. With the Jamar dynamometer, all but one of the subjects produced his/her highest grip effort with the span set at 47 mm; the lone exception was the male subject with next-to-longest hands who produced his greatest mean grip strength with the Jamar handle set to a span of 60 mm. For the cylindrical handles, the three females with the smallest hands produced their greatest grip strength values with the 30 mm handle; the other three females produced their maximum grip values on the 40 mm handle. The male subject with next-to-longest hands produced his greatest grip strength measurements with the 50 mm handle. All the other males produced their highest grip strength measurements on the 40 mm handle.

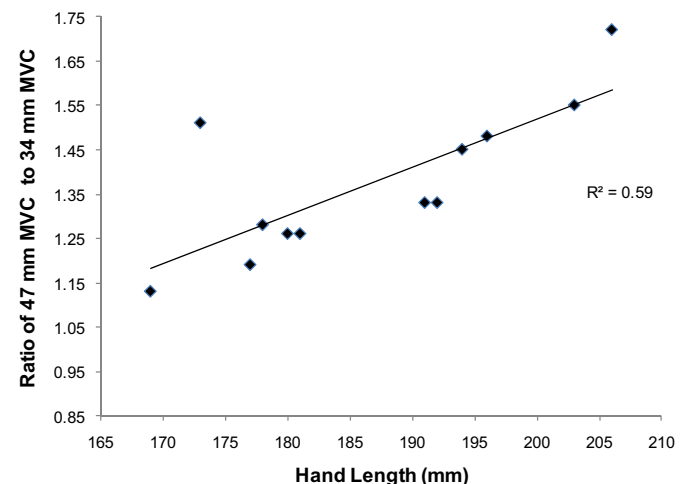


Fig. 4. The correlation between subject hand length and the ratio of the maximum grip strength measured with the Jamar handle set at 47 mm and that at 34 mm.

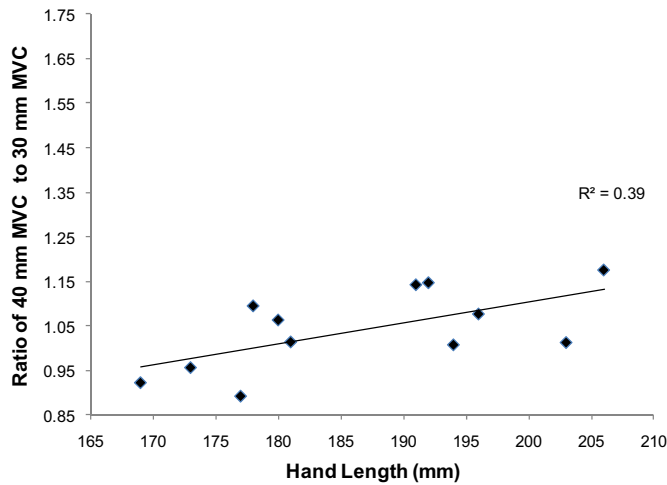


Fig. 5. The correlation between subject hand length and the ratio of the maximum grip strength measured with the 40 mm cylindrical handle and that with the 30 mm cylindrical handle.

3.3. Correlations between force ratio and hand length

Fig. 4 illustrates the correlation between subject hand length and the ratios of the 47 mm Jamar mean grip strength to the 34 mm Jamar grip strength for each subject. In general, the ratio increased with an increase in hand length (Pearson correlation = 0.766, $p = 0.004$). In similar fashion, the hand length/force ratio correlation for the 40 and 30 mm cylindrical handles is shown in Fig. 5. As was the case for the Jamar handle, the force ratios increase with hand length. However, the correlation, while also significant, is not as strong (Pearson correlation = 0.626, $p = 0.030$), and the ratios are considerably lower than those with the Jamar handle.

3.4. Force distribution around the cylindrical handles

The distribution of force around the six arms of the cylindrical handle changed with handle diameter. The average percentage distributions for the right hand for each of the three handle diameters are presented in Table 4. As indicated, the greatest percentage force was measured on Arm 5 for the 30 and 40 mm diameter handles. The greatest percentage force shifted to Arm 4 for the 50 mm handle. While not presented here, these patterns were effectively repeated with the left hand, except, of course, the percentages for Arms 5 and 6 were reflected by Arms 3 and 2, respectively.

3.5. Maximum torque factors

Some powered hand tools such as grinders and in-line nut runners could generate significant dynamic torque around the centerlines of their cylindrical handles. The amount of grip force

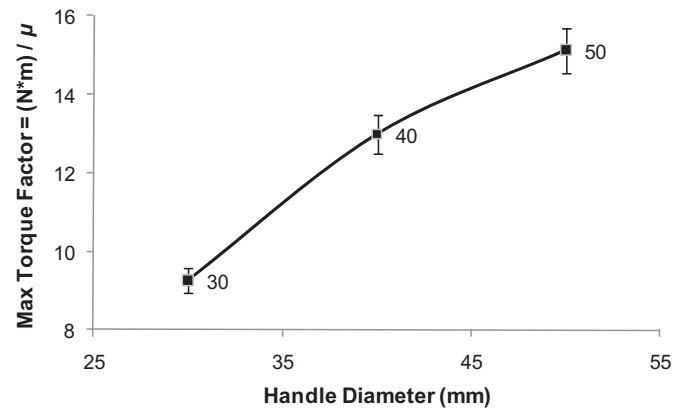


Fig. 6. The relationship between cylindrical handle diameter and the calculated theoretical maximum torque factors for the cylindrical handle dynamometers employed in this study. (The y-error bars indicate $\pm$ SEM.)

applied during the operation of such tools is largely attributed to the build up of sufficient friction force to counteract the torque (Radwin et al., 1989; Armstrong et al., 1999). Therefore, the maximum torque-reaction force (T_{Max}) is also an important parameter for optimizing the design of tool handles for these and other torque-producing tools. The maximum torque-reaction force can be estimated as follows:

$$T_{\text{Max}} = \mu \times F_G \times R, \quad (2)$$

where μ is the coefficient of friction, F_G is the total grip force, and R is the radius of the cylindrical handle. Because the determination of μ is beyond the scope of this study, the maximum torque can be normalized with respect to μ , which is termed as the maximum torque factor and expressed as follows:

$$T_{\text{Max}}/\mu = F_G \times R. \quad (3)$$

Fig. 6 shows the relationship between the maximum torque factor and handle diameter for the cylindrical handle dynamometers. As can be seen, the maximum torque factor increases with handle diameter in a near-linear fashion from 30 to 50 mm.

4. Discussion and conclusions

As was hypothesized, the ANOVA results of the present study confirm that handle size significantly affects the applied grip strength measured with both types of grip dynamometer. The handle size effect differs somewhat between the two grip dynamometers. As can be seen in Figs. 3–5, the handle size effect is more pronounced with the Jamar handle than with the cylindrical handles, especially at the small handle diameter/span. This is mainly due to differences in the handle shape and force measurement technique. Consistent with earlier studies (Seo et al., 2006; Wimer et al., 2009), the highest grip force components observed with the cylindrical handles were found at the fingertips. For most subjects grasping the six-arm cylindrical handle with the right hand, the fingertip forces are measured with Arm 5 (see Fig. 1a). Increasing the handle diameter moves the fingertips closer to Arm 4, as is reflected in the force distribution data presented in Table 4.

Due to their design and measurement approach, Jamar grip dynamometers and similar two-pole designs may not adequately reflect the fingertip forces at the low and middle spans because the fingertips are not applied in the force measurement plane of the dynamometer, as can be clearly observed in Fig. 2. Therefore, such dynamometers may not adequately capture changes in the

Table 4

The average percentage force distribution around the six arms of the cylindrical handle dynamometers for the right hands of the twelve study participants. (Refer to Fig. 1(a) for the arm numbering sequence.).

Handle	Arm 1	Arm 2	Arm 3	Arm 4	Arm 5	Arm 6
30 mm	16.0	20.6	14.9	14.0	24.7	9.8
40 mm	19.9	19.5	13.4	18.2	21.6	7.4
50 mm	22.0	17.4	15.1	22.1	15.4	8.0

finger tip forces under different grip spans. Whereas the grip strength measured with the Jamar dynamometer can be used to guide the design of tool handles with shapes similar to its two-pole configuration, the grip strength measured with a cylindrical dynamometer is better for optimizing designs of cylindrical or near-cylindrical handles that are found on many tools and machines.

This study's cylindrical handle results differ from the near-linear inverse relationship between handle diameter and grip strength observed in the Kong and Lowe (2005) and Amis (1987) studies; no such linear relationship was observed in this study. This may be because the grip dynamometer used in the present study provides a reasonable measure of total grip force, while the Amis study only measured the forces at the phalanges, and Kong and Lowe's study only measured forces at the middle of each phalange and at the metacarpal heads. This observation also suggests that partial force/pressure measurements may not be suitable to fully and accurately characterize the total grip force applied to a cylindrical handle.

The results of this study are more consistent with the results of the McGorry et al. (2009) study. This is likely because they used a similar measurement approach and an identical set of cylindrical handle diameters. Different from the six-arm dynamometer used in the current study, the McGorry group used a dynamometer with a core of three measurement beams. Theoretically, the six-arm dynamometer can take into account approximately 95% of the contact pressure, while the three-beam approach can take into account 83% of the pressure in the measurement (see Wimer et al., 2009 for a detailed explanation). Therefore, the basic trends of the McGorry et al. measurements should be similar to those in the present study, but the six-arm approach is theoretically more reliable and accurate. Further reducing the measuring arms to two could only take into account 64% of the contact pressure; as a result, the measurement will depend more heavily on the grip orientation (Edgren et al., 2004; Dong et al., 2008). If a fixed hand grip orientation is used, like that specified in ISO 15230 (2007), the grip strength applied on a small handle (≤ 30 mm) may be greatly underestimated because the fingertips may not be well-aligned with the single measurement axis, similar to the phenomenon observed with the Jamar handle.

The results of this study have implications on the design of cylindrical and near-cylindrical tool handles. The results indicate that handle diameter does not have a huge influence on total grip forces applied to cylindrical within the range of handle sizes used in this study (see Fig. 3). Therefore, if total grip force is the only design concern, handle size is not a critical factor. However, if torque reaction forces are of importance, the results of this study, as shown in Fig. 6, indicate that handle size would be a key design aspect.

The present study reaffirms that hand size may be an important factor influencing handle design. However, the relationship between hand size and optimal handle diameter requires further clarification. The study reported by Boadella et al. (2005) concluded that hand anthropometry was not good for predicting which Jamar handle span would provide optimal grip strength for a given subject, and that other factors should be considered for standardizing handle span. On the other hand, they did find that hand length had the strongest relationship with optimal handle span compared to other hand anthropometrical measures. The Ruiz-Ruiz et al. (2002) study used a six-position handle dynamometer with a configuration similar to a Jamar dynamometer and found that hand size (defined as maximum distance separating distal extremes of the first and fifth digits) influences optimal handle span for females, but the influence was not significant for males. Kong and Lowe (2005) found that when subjective comfort ratings are considered, hand length is a good predictor for optimum cylindrical handle diameter. They also found that handle span

differentially-affected individual finger forces, and thus they recommended that both handle shape and size should be considered in handle optimization. Seo and Armstrong (2008) reported that the interaction between cylindrical handle diameter and hand length explained 62% of the variance in grip strength for handle diameters ranging from 38 to 83 mm. The results of the current study corroborate the existence of a relationship between the subject's hand length and handle size for producing the highest grip force, but further studies are obviously required to better characterize the relationship between hand anthropometry and tool handle size.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety & Health. The mention of trade names, commercial products, or organizations does not imply endorsement by the US Government.

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