

Use of Normalized Hand Size for Subjective Rating and Performance of Handle Diameter in a Maximum Horizontal Torque Task

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Abstract

An experiment was performed to evaluate the effect of handle diameter on handle comfort, finger force capability, and torque, and to predict the optimal handle diameter based on a 'Normalized Hand Size (NHS)' in a maximum horizontal torque task. Subjective ratings, a force glove and LIDO WorkSET were used to assess comfort, finger force capability, and torque output on six experimental handles (from 25 to 50 mm). Analysis of subjective ratings showed that the 45 mm handle diameter was the most comfortable followed by the 50 mm handle. These two handles (50 and 45 mm) showed significantly larger torque, and lower finger forces than the other handles. The ratio of handle circumference to hand length, the NHS, was applied and resulted in 86.3% and 90.7% as the ratios to obtain maximum comfort and torque, respectively. From these data the optimal handle diameters can be recommended according to users' hand sizes in horizontal torque tasks. More sophisticated methods are being used to represent mathematically the relationships between handle diameter, finger force capability, and maximum torque output.

1. INTRODUCTION

Torque exertion depends upon the normal grip force, the friction between hand/gloves and handle, and the handle diameter. Handle diameter is one of the important factors of torque exertion as well as handle design. The relationship between handle diameter and torque has been evaluated in previous studies (e.g. Pheasant and O'Neill, 1975; Pheasant and Scriven, 1983; Replogle, 1983; Magill and Konz, 1986; Strasser, 1991; Shih and Wang, 1996; Habes and Grant, 1997). The objective of this study was to evaluate the effect of handle diameter on handle comfort, finger force capability, and maximum torque in a horizontal torque task. Normalized hand size (NHS) was also applied to define the optimal ratio of handle circumference to user's hand size. The results from this study will provide information that can

lead to design improvements of torque-generating hand tools.

2. METHODS

2.1. Subjects

Seven subjects between the ages of 20 and 35 yrs (mean: 28 yrs) were recruited to participate in this experiment. Participants were healthy and free of known musculoskeletal impairments. At the beginning of the experiment, informed consent was obtained and hand length was measured. Hand length was defined as the distance from the most distal wrist crease to the tip of the middle finger with the hand held straight and stiff.

2.2. Experimental design

A full factorial design was employed in this study. The independent variables involved

subject and handle diameter. Six handle diameters (25, 30, 35, 40, 45, and 50 mm) were tested. All handles had a length of 130mm. Subject was considered as a random effect and the handle diameter was considered as a fixed effect. A total of 18 maximum horizontal torque tasks (6 handles * 3 replicates) were performed in a randomized order for each participant.

2.3. Experimental procedure

Participants were asked to wear the force glove and to perform a maximum isometric torque exertion in a clockwise direction, which simulates the use of a screwdriver. The long axis of the handle/actuator of LIDO WorkSET was positioned parallel to the floor (See Figure 1). The height of the handle /actuator was adjusted according to the participant's hand position to keep participant's arm straight during the task. Maximum torque was exerted for 5 seconds and recorded through the torque spindle of the LIDO WorkSET II. During maximum torque exertions, the finger force data were measured by the force glove system. Each participant was provided 2 minutes resting time between trials. At the end of each task, the participant was asked to rate overall handle comfort on a 7-point scale.

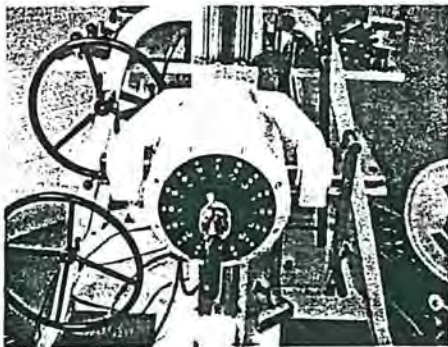


Figure 1. LIDO set up for horizontal torque

2.4. Dependent variables

Maximum torque was measured through the LIDO WorkSET II system. The average torque of the three maximum exertions was calculated. Individual finger force capabilities were measured by the force glove system (FSA, Vista Medical, Winnipeg, Manitoba, Canada).

The total finger force capability was obtained by summing all 16 force sensors, which are attached on the positions of the middle of each phalange and the head of each metacarpal bone on the palmar side of a thin cotton glove (See Figure 2). The thumb sensors were not included in this study.

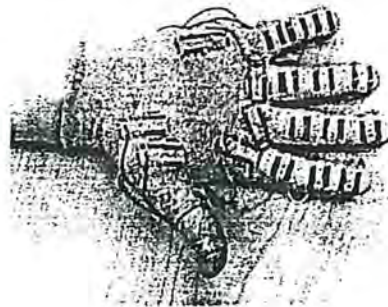


Figure 2. Force glove

Participants were asked to provide subjective ratings of overall finger and hand comfort for each handle while performing the maximum torque task. Ratings were obtained using the semantic differential method with the following numerical values used as indices of the degree of comfort: very comfortable, 7; moderately comfortable, 6; somewhat comfortable, 5; neutral, 4; somewhat uncomfortable, 3; moderately uncomfortable, 2; and very uncomfortable, 1.

2.5. Normalized hand size

Normalized hand size (NHS), defined as the ratio of the handle circumference to the user's hand length, was calculated to determine the optimum handle diameter. NHS was defined by the following equation for any handle.

$$NHS_{ij} = \frac{HC_j}{HL_i} * 100$$

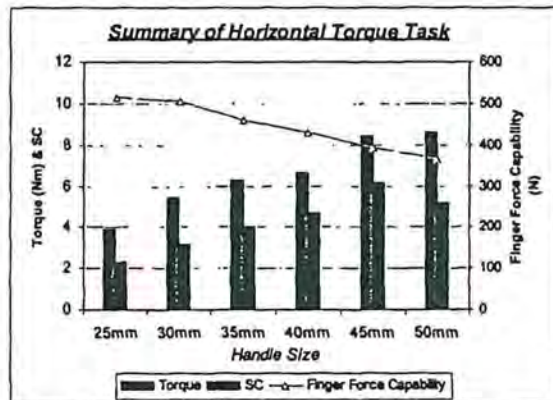
where, HC_j : Circumference of handle j , HL_i : Hand length of subject i .

To predict the optimal NHSs models regressing subjective comfort ratings and maximum torque against normalized hand size were generated.

3. RESULTS

3.1. Subjective comfort ratings

Statistical analysis on subjective comfort ratings showed the handle diameter was significant ($p = 0.0001$). Generally, participants preferred larger handle diameters than smaller ones (Table 1). The 45 mm and 50 mm handles were rated as the most comfortable followed by the 40 mm, 35 mm, and 30 mm. The 25 mm handle was rated as the least comfortable handle.



* SC: Subjective rating of Comfort
Figure 3. Summary of horizontal torque task

3.2. Torque output

ANOVA results showed that the handle diameter had a significant effect on the torque output. Table 1 presents the results for torque output. The relationship between torque and handle diameter was similar to that between subjective comfort ratings and handle diameter i.e., the larger the handle diameter, the larger the torque output. The 50 mm and 45 mm handle diameters showed the largest torque output (8.64 Nm and 8.39 Nm, respectively). The lowest torque was obtained by the 25mm handle (3.92 Nm).

3.3. Finger force capability

Finger force capability was calculated by summing the forces registered on all 16 sensors and identifying the maximum sum of finger forces. Figure 3 showed that as handle diameter increased, the finger force capability decreased. Thus, the relationship between

handle diameter and maximum torque is complicated by the fact that increasing handle diameter is disadvantageous for finger force capability while advantageous for torque production. The largest handle was associated with a finger force capability (364.8 N) of only 70% of the finger force capability associated with the smallest handle (516.2 N), yet maximum torque was 2.14-2.2 times greater with the large handles compared to the smallest (8.39 Nm and 8.64 Nm vs. 3.92 Nm).

3.4. Normalized hand size for subjective comfort rating and torque output

Two quadratic regression equations were obtained in this study. The following Equations (1 and 2) represent the relationships between NHS and subjective comfort (SR), and NHS and maximum horizontal torque (MHT), respectively.

$$SR = -.0017*(NHS)^2 + .2935*(NHS) - 7.34 \quad \text{--- (Eq.1)}$$

$$MHT = -.0019*(NHS)^2 + .3448*(NHS) - 7.22 \quad \text{--- (Eq.2)}$$

Based on the first derivative of these equations, 86.3%, $[NHS\% = .2935/(2*.0017)]$ and 90.7%, $[NHS\% = .3448/(2*.0019)]$ were derived as optimal NHS ratios in terms of maximizing comfort ratings and torque performance, respectively, in the horizontal torque task. These preliminary findings can be used to derive handle diameters for maximizing comfort or torque output based on the user's hand size [i.e., handle diameter = user's hand length * NHS / π].

Table 1. Handle diameters for optimal comfort and torque output (preliminary results).

	Percentile	Hand Length (mm)	Handle diameter (mm)
Small	5 th ~ 25 th	167 ~ 178	46 ~ 49*
			48 ~ 51**
Medium	25 th ~ 50 th	178 ~ 183	49 ~ 50*
			51 ~ 53**
Large	50 th ~ 75 th	183 ~ 188	50 ~ 52*
			53 ~ 54**
X-large	75 th ~ 95 th	188 ~ 199	52 ~ 55*
			54 ~ 57**

(*: handle diameter for optimal subjective comfort; **: handle diameter for optimal torque output)

Hand sizes can be classified into four groups based on the 25th, 50th, and 75th %tile combined male and female population of US adults (Source: Pheasant, 1986). For these groups, handle diameters were recommended to maximize comfort and torque performance based on the NHS ratios (86.3% and 90.7%) in the maximum horizontal torque task (Table 1).

4. DISCUSSION

The effect of handle diameter of cylindrical handles on maximum horizontal torque output was evaluated in this study. The relationship between handle diameter and maximum torque showed that the larger the handle diameter (50 mm and 45 mm), the greater the horizontal torque output. These findings are consistent with other studies (Pheasant and O'Neill, 1975; Shih and Wang, 1996). However, the relationship between handle diameter and torque is not simply linear. The increase in torque output levels off as handle diameter gets larger (Replogle, 1983; Shih and Wang, 1996). This non-linear relationship can be explained by the decrement in finger force capability as handle diameter increases. Torque (T) is a function of the shear force (the total normal grip force (G) * the coefficient of friction (μ) between glove and handle surface) and the radius of the handle (R) i.e., $T = G * R * \mu$. In this study, total finger force capability (G) decreased from 516.2 N to 364.8 N as the handle diameter (R) increased from 25 mm to 50 mm. Therefore, torque output, which is a function of G and R, increased between the groupings of handles according to 25 mm, 30 mm, 35/40 mm, and 45/50 mm. There was no significant increase in torque between 35 and 40 mm handles, and between 45 and 50 mm handles (i.e., the relationship between handle diameter and maximum torque output is non-linear).

Subjective ratings of comfort showed that the participants conclusively preferred the larger size handles (45 mm and 50 mm) over the smaller size handles. It has been noted by Strasser (1991), however, that subjective ratings can be dominated by impression of task performance (i.e., torque output). Thus, it is hard to entirely separate the subjective rating of

comfort from these transfer effects, which is the effect of task performance on subjective ratings, although the ratings were requested for handle comfort only in this study.

The effect of handle diameter on external finger force distributions, preferences of the handles, and task performances were evaluated and handle diameters were suggested based on the user's hand size (Table 1) from these preliminary findings to achieve the maximum subjective comfort and the maximum horizontal torque output, respectively. The results of this study can be applied to design of handle diameters for non-powered hand tools which require torque, such as screwdrivers.

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