

OPTIMIZING HANDLE SIZE BASED ON NORMALIZED HAND SIZE IN A MAXIMUM GRIPPING TASK

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Six cylindrical handles were evaluated for the effect of handle size (diameter) on handle comfort, finger force capability and muscle activity in a maximum gripping task. Optimal handle size was calculated based on a 'normalized hand size, NHS', which was defined as the ratio of handle circumference to a user's hand length. A pressure sensitive glove was used to measure finger force capability and surface electromyography was recorded from flexor digitorum superficialis and extensor digitorum to analyze muscle activity while participants performed maximum isometric grip exertions. The 35mm handle was rated as the most comfortable handle size followed by the 40mm. The 30 and 25 mm handles were associated with the highest finger force capability followed by the 35 and 40mm handles. The muscle activity of the flexor showed that 25, 30, and 35mm handles had high flexor muscle activities, whereas 45mm and 50mm handles represented low flexor muscle activities in this study. A 64% NHS ratio was applied to obtain recommended handle sizes for comfort as a function of users' hand size in a maximum gripping task.

1. INTRODUCTION

Much research has been focused on handle size because handle size is one important tool design factor to minimize stresses on the muscles and tendons, and optimize force exertion in manual work (Amis, 1987; Meagher, 1987; Radhakrishnan and Nagaravindra, 1993). A few studies have focused on the relationship between handle size and user's hand size and the effect of this relationship on task performance and subjective ratings of handle comfort. These studies suggested that handles should be designed to vary in size to obtain maximum performance and handle comfort (Grant et al., 1992; Oh and Radwin, 1993; Yakou et al., 1997; Blackwell et al., 1999).

The purpose of this study was to evaluate the effect of cylindrical handle sizes on handle comfort and grip finger force capability in a maximum gripping task. Normalized hand size (NHS) was also calculated to define the optimal ratio of handle circumference to users' hand size.

2. METHODS

2.1. Subjects

Seven participants (1 female and 6 males; ages 20 through 35 yrs) were recruited from a local university. All participants were healthy and free of known musculoskeletal disorders. Hand length, the distance from the crease of the wrist to the tip of the middle finger, was measured for each participant.

2.2. Experimental design

Six cylindrical handles (from 25mm to 50mm, in a 5mm increment, Figure 1) were tested in a full factorial design. Subjects were considered as random effects and the handle size was considered as a fixed effect. Gender factor was not considered as a main effect in this study. All participants performed maximum gripping tasks with a total of 18 treatments (6 handles*3 trials) in a random order.



Figure 1. Cylindrical handles. Handle diameters are (1-6) 25, 30, 35, 40, 45, and 50 mm.

2.3. Experimental procedure

Participants were provided with a description of the purposes and procedures of the experiment and provided informed consent. Surface electrodes were positioned over the bellies of the flexor digitorum superficialis (FDS) and the extensor digitorum (ED),

parallel to the longitudinal axis of these muscle fibers. Each participant was instructed to stand and grip the handles while wearing a cotton pressure sensitive glove (Force Sensing Array; Vista Medical, Winnipeg, Manitoba, Canada) with sensors attached to the positions of the middle of each phalangeal segment and the head of each metacarpal bone on the palmar side (Figure 2). The thumb sensors were not included in the analysis of finger force capability. The height of the handle was adjusted for each participant to keep the elbow angle at approximately 90°. All participants were asked to perform a maximum grip exertion for five seconds.

2.4. Dependent variables

(1) *Subjective comfort rating (SCR)*: all participants used a seven point scale to provide a subjective rating of overall comfort for the hand while performing the maximum isometric gripping task. The scale was as follows: very comfortable, 7; moderately comfortable, 6; somewhat comfortable, 5; can not determine, 4; somewhat uncomfortable, 3; moderately uncomfortable, 2; and very uncomfortable, 1.

(2) *Finger force capability (FFC)*: was defined as the total force imposed by all individual phalangeal and metacarpal head segments of the four fingers (measured by summing the forces registered on all 16 sensors of the glove).

(3) *Muscle activity*: EMG activity of the FDS and ED were recorded during the maximum exertion. The EMG signals were acquired at a sampling frequency of 1000 Hz with 12 bit A/D resolution. The raw signal was digitally filtered (10-350 Hz passband) and expressed as the RMS EMG (50 ms TC).

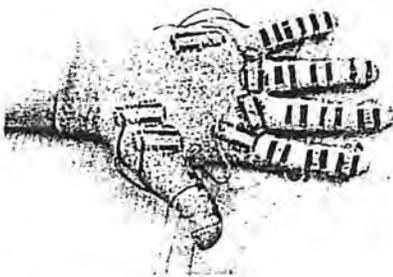


Figure 2. Pressure glove.

2.5. Normalized hand size (NHS)

Normalized hand size (NHS) was calculated to determine the optimum handle size based on a user's hand size. The ratio of handle circumference to user's

hand length was defined as follows:

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

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

To predict the optimal NHS ratio based on subjective comfort ratings, a quadratic regression model was employed.

3. RESULTS

3.1. Subjective comfort ratings (SCR)

Statistical analysis showed that the handle size had a significant effect on subjective comfort ratings ($p = .0032$). Figure 3 shows that the 35mm and 40mm handles (5.57 and 5.0) were rated as the best comfortable handles, whereas 25mm and 50mm handles were rated as the least comfortable handles (3.143 for both).

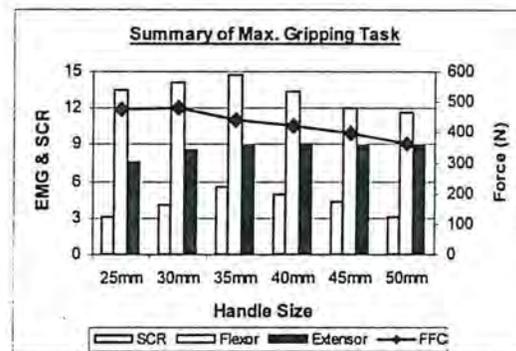


Figure 3. Summary of max. gripping task

3.2. Finger force capability (FCC) and flexor/extensor muscle activity

Handle size also had a significant effect on finger force capability ($p = .0021$) and muscle activity ($p = .02$ and $.03$ for flexor and extensor, respectively). Figure 3 shows that the finger force capabilities of smaller handles (473.9N for 25mm and 482.2N for 30mm) were higher than those of larger handles (398.5N for 45mm and 363.1N for 50mm). That is, small handles showed about 1.19~1.33 times higher finger force capability than large handle sizes.

The pattern of flexor muscle activities according to the handle was similar to the finger force capabilities, whereas the extensor muscle activities were increased as the handle size increased. Figure 3 indicates that the flexor muscle had a more prominent

role in the maximum gripping task, rather than the extensor muscle.

3.3. Normalized hand size (NHS) for subjective comfort rating (SCR)

A quadratic regression was obtained based on the relationships between NHS and SCR (Figure 4 and Eq.1).

$$SCR = -.0048*(NHS)^2 + .619*(NHS) - 14.57 \quad (Eq.1)$$

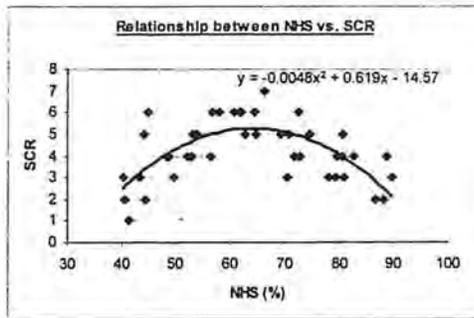


Figure 4. NHS vs. Subjective comfort rating

From the first derivative of Equation 1, 64% [NHS% = .619/(2*.0048)] was obtained as the optimal NHS ratio, in terms of maximizing comfort ratings in the maximum gripping task.

This NHS ratio can be used to recommend handle sizes to maximize comfort based on the user's hand size [i.e., handle diameter = user's hand length*(0.64)/π]. 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, the recommended handle sizes that provide optimal comfort based on the NHS ratio (64.5%) in the maximum gripping task are shown in Table 1.

Table 1. Handle sizes for optimal comfort (preliminary results).

	Percentile	Hand Length (mm)	Handle Size (mm)
Small	5 th ~ 25 th	167.1 ~ 178.2	34 ~ 36
Medium	25 th ~ 50 th	178.3 ~ 183.0	36 ~ 37
Large	50 th ~ 75 th	183.1 ~ 187.8	37 ~ 38
X-large	75 th ~ 95 th	187.9 ~ 198.9	38 ~ 41

4. DISCUSSION

Finger force capability showed a decreasing trend as the fingers were extended to grasp larger handles. One plausible explanation for this finding is that the smaller handles place the extrinsic finger flexor muscles nearer to the length where the number of cross-bridges between the thick and thin filaments is optimal. Thus, active muscle tension of the small handles would be at a maximum. In contrast, the larger diameter handles lengthen the extrinsic finger flexors resulting in a reduction in the number of cross-bridges and in the active tension.

Another possible explanation for the reduced finger force capability with the larger handles involves a compromise in the inability to create equal opposing forces in the power grip (e.g. Replegle, 1983) if the hand can not adequately encircle the larger handle. In this case there is an area on which no opposing force can be exerted. In the present study, the analyses of individual finger forces indicated that as the handle size increased from 25mm to 50mm, the finger forces measured on the heads of the metacarpal bones decreased dramatically (from 33.8N to 17.8N). This may have been a result of inadequate encircling of the hand around the larger handle and an inadequacy of opposing forces involving the metacarpal area.

In evaluations of handle comfort in torque tasks subjective ratings have been shown to be influenced by impressions of torque performance (Magill and Konz, 1986; Strasser, 1991). This was not the case in the present study as subjective ratings of comfort indicated that participants preferred larger handles (i.e., 35mm and 40mm) over the smaller handles which were associated with higher finger force capability. In this maximum gripping task subjective ratings did not appear to be heavily influenced by impressions of gripping performance.

Although the subjective ratings indicated that medium sized handles were the most comfortable, participants exhibited large variation in their ratings for each handle. Thus, all participants were categorized based on the NHS to predict the most comfortable handle size based on hand size. An NHS ratio of 64% was calculated as the optimal NHS and was applied to make the handle size recommendations in Table 1. Customization of handle size to user's hand size has been suggested by other researchers (Grant et al., 1992; Yakou et al., 1997; Blackwell et al., 1999) however, these recommendations have typically been made in terms of broad ranges. The findings of this study can serve as a guideline for determining the handle size best suited for an individual user's hand size and can be applied in the design of hand tools.

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