Evaluation of Various Handle Grip Spans for Optimizing Finger Specific Force Based on the Users' Hand Sizes

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Evaluation of various handle grip spans for optimizing finger specific force based on the users' hand sizes

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Abstract

This study evaluated the effects of handle grip span and user's hand size on maximum grip strength and individual finger force using a computerized digital dynamometer with five various grip spans (45, 50, 55, 60, and 65mm). Forty-six males participated and were assigned into three hand size groups (small, middle, large) according to their hand lengths. Results showed that generally 55 and 50mm grip spans had the highest grip strength (433.6N and 430.8N, respectively), whereas 65mm grip span had the least grip strength. With respect to the interaction effect of grip span and hand size, small hand sized participants produced the highest grip forces at the 45mm grip span, followed by 50 and 55mm, middle hand size participants provided the highest grip force at the 55mm followed by 50 and 45mm, whereas large hand size participants exerted the highest grip force at the 55mm followed by 60mm. In the analysis of individual finger force, the middle finger force was the strongest and the highest contribution (37.5%) to the total finger force, followed by ring (28.7%), index (20.2%) and little (13.6%) fingers. In addition, it was noted that each finger had a different optimal grip span for exerting maximum force, resulting in a bowed contoured shaped handle (i.e., the grip span of the handle at the center is larger than that of the handle at the end) for two-handle hand tools.

1. INTRODUCTION

Grip span is an important factor in the design of hand tools to maximize grip performance and minimize stress on the digit flexor tendons, first metacarpal ulnar collateral and carpometacarpal ligaments (Meagher, 1987). It can also influence force exertion in manual work during hand tool use (Grant et al., 1992; Blackwell et al., 1999).

A few investigators have tried to obtain the optimal grip span of two-handle tools for maximum grip strength resulting in the wide ranges from 45mm to 66.3mm (Petrofsky, 1980; Pheasant and Scriven, 1983; Härkönen et al., 1993; Oh and Radwin, 1993; Talsania and Kozin, 1998; Eksioglu, 2004). Some researchers have also shown the trend of decreasing grip strength above and below the optimal grip span (Ohtsuki, 1981; Pheasant and Scriven, 1983; Härkönen et al., 1993; Talsania and Kozin, 1998). However, there is a discrepancy between findings of these studies in terms of the effects of users' hand size on optimal grip span. Pheasant and Scriven (1983) and Härkönen et al. (1993) reported that hand size did not affect grip strength, while Oh and Radwin (1993) and Eksioglu (2004) reported that the optimal grip span was dependent on user's hand size.

Although many researchers have studied grip spans for two-handle tools, it is noted that there are relatively few studies that have considered the relationship between handle grip span and users' hand anthropometry for defining the best handle grip span in two-handle tools. Therefore, the purposes of this study were to: (1) investigate the effects of handle grip span and user's hand size on maximum grip strength and individual finger force;

(2) investigate the finger specific contribution to the total hand grip force using a specialized digital hand grip dynamometer with individual force sensors under each finger.

2. METHODS

2.1. Subjects

Forty-six male subjects between the ages from 20 and 39 years (mean = 25.9 ± 4.9) were participated. Participants were all healthy volunteers and free of known musculoskeletal injuries. At the beginning of the experiment, informed consent was obtained and hand lengths (the distance from the crease of the wrist to the tip of the middle finger with the hand held straight and stiff) were measured. The average hand length was 187.1mm (range: 173.5~208.0mm). Based on the hand length, each participant was assigned into one of the following three hand size groups, [(1) Small hand: up to 30th percentile (186.0mm); (2) Middle hand: 30~70th percentile (186.0~196.3mm); (3) Large hand: over 70th percentile (over 196.3mm)].

2.2. Instrumentation

The NK DIGITS-grip measurement system (NK Biotechnical Corp., Minneapolis, MN, USA) which contains four sensors was used to accurately measure each individual finger force as well as total grip force. Custom fabricated slip-on adapters were constructed to test five grip spans from 45mm to 65mm, in 5mm increments. NK measurement system and custom-made adapters are presented in Figure 1. The data acquisition program recorded the force created by each individual finger and the total grip force.

2.3. Experimental Design

To evaluate the effects of grip span and user's hand size on the grip finger forces, five grip spans and three levels of hand size groups (small, middle and large hand size) were evaluated. Based on the hand size criteria, 25, 12, and 9 subjects were assigned into small, middle, and large hand size groups, respectively. Subjects were nested in the hand size factor. Subjects were considered as a random effects variable and all others were considered as fixed effects variables. This was an unbalanced design and all grip spans were assigned in a random order for each subject.

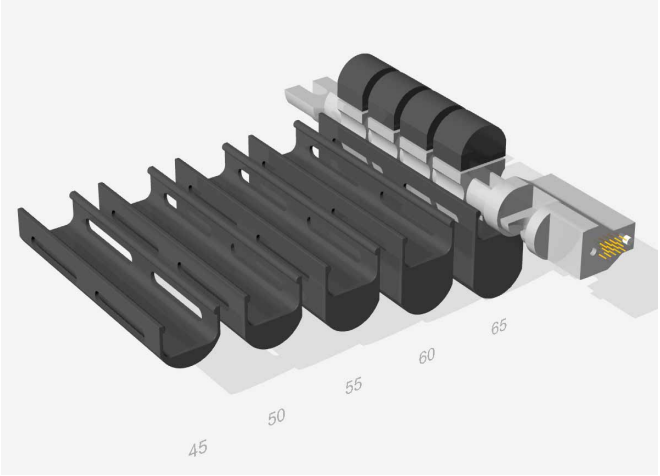

Figure 1. Five custom-made handles and NK system

2.4. Experimental Procedures

Each subject was seated upright in a chair with the arm adducted to the side, elbow at 90°, wrist and forearm in neutral position. Subjects were instructed to perform a maximum isometric grip exertion for four seconds duration. Visual feedback about performance was not allowed. Five different grip spans were tested: 45, 50, 55, 60 and 65mm by placing the appropriate slip-on adapter on the device. Three trials for each grip span were performed with two minutes of resting time between trials to avoid muscle fatigue.

3. RESULTS

3.1. Total Grip Force

Statistical analysis of total grip force showed that the main effect of grip span ($p<0.0001$) and the interaction effect of grip span*hand size ($p=0.003$) were statistically significant on the total grip force. Overall participants produced high grip force at 55 and 50mm grip spans (433.6N and 430.8N, respectively), followed by 45mm and 60mm. Grip span 65mm showed the least grip force (378N) over the other grip spans.

In the analysis of interaction effect of grip span and hand size, the highest total grip forces were obtained at the 45mm grip span, followed by 50 and 55mm for the small hand group, at the 55mm followed by 50 and 45mm for the middle

hand size group, and at the 55mm followed by 60mm for the large hand size group, respectively. The 65mm grip span had the least total grip force for all three hand size groups. Table 1 shows the summary of total grip force for hand size and grip span.

The average total grip force of the large hand size group (470.3N) was 11.0% and 19.2% higher than the middle hand size group (423.6N) and small hand size group (394.5N), respectively. The average total grip force of the middle hand size group was 7.4% higher than that of the small hand size group.

Table 1. Total grip force for hand size and grip span (unit: N)

	45mm	50mm	55mm	60mm	65mm
Overall	427.9	430.8	433.6	414.6	378.0
Small	411.2	410.9	404.8	391.2	354.6
Middle	438.9	442.4	447.1	411.7	378.1
Large	459.3	470.5	495.6	483.3	443.0

3.2. Individual Finger Force

Table 2 summarizes individual and total finger forces with contributions of finger force to the total finger force as a function of grip spans. As expected, the highest contribution to the total force was from the middle finger (average force 156N, contribution 37.5%), followed by the ring (119.6N, 28.7%) and index (84.1N, 20.2%) fingers. The average force and percent contribution to total finger force of the little finger were 56.9N and 13.6%.

It is noted that the individual finger forces were related with grip span. Based on the Tukey test, the middle finger force was the largest at the 55mm grip span and decreased when grip span decreased or increased, whereas the little finger force showed significantly decreasing trend as the grip span increased. In both index and ring finger forces, the least finger forces were also obtained at a grip span of 65mm.

The analysis of the interaction effects of hand size and grip span for each finger are shown in Table 3. Results indicated that the interaction effects were significant on the middle and ring fingers (p=0.0049 and p=0.0061, respectively). With respect to the middle finger, small and middle hand participants exerted their maximum finger force at 50 and 55mm, whereas large hand participants produced their maximum finger force at 55 and 60mm. For the ring finger, the small hand group exerted maximum force at 45 and 50mm, and the middle hand group exerted maximum force from 45~55mm, whereas large hand participants exerted their maximum force at 55 and 60mm grip spans.

In light of the present data, two-handle hand tools might be designed with a specific grip span for each finger, i.e., the grip spans for the index, middle, and ring fingers would be greater than that for the little finger and grip span for the middle finger would be slightly greater than that for the index or ring finger. Table 4 shows the recommended finger-specific grip spans based on the users' hand sizes.

Table 2. The total/individual finger forces and contributions [unit: N (%)]

Grip span	Total force	Mean forces of individual fingers and percentage contributions			
		Index	Middle	Ring	Little
45mm	427.9	84.8^{A} (19.83)	154.3^{B} (36.06)	124.4^{A} (29.08)	64.3^{A} (15.04)
50mm	430.8	86.9^{A} (20.18)	160.7^{AB} (37.29)	123.3^{A} (28.63)	59.9^{B} (13.90)
55mm	433.6	$87.8N^{A}$ (20.26)	163.8^{A} (37.77)	123.8^{A} (28.54)	58.2^{B} (13.43)
60mm	414.5	$83.4N^{A}$ (20.11)	156.6^{B} (37.77)	120.7^{A} (29.11)	54.0^{C} (13.02)
65mm	378.0	$77.5N^{B}$ (20.51)	146.7^{C} (38.79)	106.0^{B} (28.03)	47.9^{D} (12.67)
Mean	417.0	84.1N (20.18)	156.4 (37.54)	119.6 (28.68)	56.9 (13.61)

(alphabetic letters mean Tukey multiple test results, i.e., same letters are not significantly different)

Table 3. Interaction effects of hand size and grip span for finger (unit: N)

Finger	Hand Size	45mm	50mm	55mm	60mm	65mm
Index	Small	80.9^{A}	80.5^{A}	81.2^{A}	77.2^{AB}	73.1^{B}
	Middle	88.2^{A}	91.4^{A}	91.9^{A}	86.2^{A}	77.2^{B}
	Large	91.1^{B}	98.9^{A}	100.8^{A}	96.6^{AB}	90.3^{B}
Middle*	Small	152.9^{AB}	158.5^{A}	157.6^{A}	151.7^{B}	140.6^{B}
	Middle	154.3^{B}	161.9^{AB}	165.2^{A}	155.3^{B}	143.0^{C}
	Large	157.9^{C}	164.7^{B}	179.1^{A}	171.6^{AB}	168.3^{B}
Ring*	Small	119.3^{A}	118.1^{AB}	115.2^{AB}	114.0^{B}	98.5^{C}
	Middle	127.2^{A}	124.4^{A}	125.4^{A}	115.5^{B}	106.2^{C}
	Large	135.1^{B}	136.5^{B}	145.3^{A}	145.9^{A}	126.4^{C}
Little	Small	58.0^{A}	53.8^{B}	50.8^{BC}	48.2^{C}	42.5^{D}
	Middle	69.3^{A}	64.6^{B}	64.7^{B}	54.6^{C}	51.6^{C}
	Large	75.3^{A}	70.4^{AB}	70.5^{AB}	69.1^{B}	58.0^{C}

(: statistically significant)*

Table 4. Recommended grip spans for each finger according to the hand size group (unit: mm)

Finger	Small Hand	Middle Hand	Large Hand
Index	45-50	50-55	50-55
Middle	50-55	50-55	55-60
Ring	45-50	45-55	55-60
Little	45	45	45

4. DISCUSSION

Individual finger force and contribution to the total grip force in a maximal hand dynamometer grip exertion were investigated in this study. The traditional hand grip dynamometer exertion involves finger contact that is distributed mostly on the middle phalangeal segments. This is a different pattern of hand contact force from the grip of handles that are more cylindrical in shape in which the distal phalanges create a larger percentage of the contact force. However, in terms of finger specific contribution of each finger to total hand force the findings of the present study are in agreement with those of previous studies (Hazelton et al., 1974; Ohtsuki, 1981; Amis, 1987; Talsania and Kozin, 1998). The contribution by the middle finger to total grip force was the largest (37.5% in this study, ranges from 33-36.2% in previous studies) and the contribution by the little finger to total grip force was the least (13.6% in this study, ranges from 14%-18% in previous studies). The results of contributions of index (20.2%) and ring (28.7%) fingers were also similar to the results reported in other grip force studies. In addition to the traditional hand grip dynamometer study, there are a few

previous studies in which thin profile force sensors were attached over the phalangeal segments and metacarpals of the hand for maximum grip and maximum vertical torque tasks (Kong and Lowe, 2005a; Kong and Lowe, 2005b). The findings from these studies also exhibit patterns in finger specific contribution to the total grip force similar to that measured in the present study (24.7~24.9%, 34.8~35.7%, 26.5~28.3%, and 11.3~13.8% for index, middle, ring, and little finger, respectively). The thin profile force sensors attached to an athletic grip glove can be used to quantify grip force distribution on a wide range of tools or the hand coupling force on other objects. Conversely, the NK Digits-grip system is limited to the assessment of finger specific grip strength and hand function in conventional evaluations performed with a hand grip dynamometer.

Customization of grip spans to users' hand size has been investigated by several researchers (Petrofsky, 1980; Pheasant and Scriven, 1983; Härkönen et al., 1993; Oh and Radwin, 1993; Talsania and Kozin, 1998; Eksioglu, 2004). These results, however, have typically been made in terms

of broad ranges from 45 to 66mm. In the analysis of grip force in this study, total grip force capability was greatest for the 50~55mm grip spans. In addition, there was an interaction effect between hand size and grip span. The small and middle hand size users exerted the highest grip force at 45~55mm grip spans whereas the large hand size group showed the highest grip force at 55~60mm grip spans, and the lowest grip force at 65mm in all hand sizes.

The relationship between grip span and individual finger force showed that the middle finger force was decreased when grip span decreased or increased from the 55mm grip span, whereas the little finger force was apparently decreased when grip span increased from 45mm to 65mm. All four fingers exerted the least finger force at the largest grip span (65mm). The analysis of the interactions of users' hand size and grip span for individual finger force capability showed that the middle and ring fingers had the optimal finger spans in the 45-65 mm range where subjects could provide maximum finger force. For small and middle hand sized users, the optimal finger spans for middle and ring fingers were 50-55mm and 45~50mm, respectively. For the large hand users, the optimal finger spans for middle and ring fingers were 55-60mm grip spans. For users of all hand sizes, the optimal finger spans for little finger to provide maximum finger force was less than 45mm.

Based on the results, it is noted that there are possibly different optimal grip spans for each finger and each hand size. This is consistent with the findings of previous studies, Lewis and Narayan (1993) and Lindstrom (1991). Therefore, it appears that a bowed contour handle profile, which has a different span for each finger, may be a better design than the traditional straight handle "A-shaped" design which has the widest span at the end closest to the gripping point of the little finger.

Note: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

REFERENCES

Amis A.A., 1987. Variation of finger forces in maximal isometric grasp tests on a range of cylinder diameters. Journal of Biomedical Engineering 9, 313-320.

Blackwell J.R., Kornatz K.W. and Heath E.M., 1999. Effect of grip span on maximal grip force and fatigue of flexor digitorum superficialis. Applied Ergonomics 30, 401-405.

Eksioglu M., 2004. Relative optimum grip span as a function of hand anthropometry. International Journal of Industrial Ergonomics 34, 1-12.

Grant K.A., Habes D.J. and Steward L.L., 1992. An analysis of handle designs for reducing manual effort: The influence of grip diameter. International Journal of Industrial Ergonomics 10, 199-206.

Härkönen R., Piirtomaa M. and Alaranta H., 1993. Grip strength and hand position of the dynamometer in 204 Finnish adults. Journal of Hand Surgery 18B, 129-132.

Hazelton F.T., Smidt G.L., Flatt A.E. and Stephens R.I., 1975. The influence of wrist position on the force produced by the finger flexors. Journal of Biomechanics 8, 30-306.

Kong Y.K and Lowe B.D., 2005a. Optimal cylindrical handle diameter for grip force tasks. International Journal of Industrial Ergonomics 35, 495-507.

Kong Y.K and Lowe B.D., 2005b. Evaluation of handle diameters and orientations in a maximum torque task. International Journal of Industrial Ergonomics 35, 1073-1084.

Lewis W.G. and Narayan C.V., 1993. Design and sizing of ergonomic handles for hand tools. Applied Ergonomics 24 (5), 351-356.

Lindstrom F.E., 1991. Pliers jaws for cutting materials with different hardness and dimensions. US Patent number 5033195.

Meagher S.W., 1987. Tool design for prevention of hand and wrist injuries. Journal of Hand Surgery 12 (A), 855-857.

Oh S. and Radwin R.G., 1993. Pistol grip power tool handle and trigger size effects on grip exertions and operator preference. Human Factors 35 (3), 551-569.

Ohtsuki T., 1981. Inhibition of individual fingers during grip strength exertion. Ergonomics 24 (1), 21-36.

Petrofsky J.S., Williams C., Kamen G. and Lind A.R., 1980. The effect of handgrip span on isometric exercise performance. Ergonomics 23 (12), 1129-1135.

Pheasant S.T. and Scriven J.G., 1983. Sex differences in strength: Some implications for the design of handtools. Proceedings of the Ergonomics Society's Annual Conference 9-13.

Talsania J.S. and Kozin S.H., 1998. Normal digital contribution to grip strength assessed by a computerized digital dynamometer. The Journal of Hand Surgery 23 B (2), 162-166.