Evaluation of Pliers in a Maximum Gripping Task

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Abstract

The objective of this study is evaluation of pliers associated with a hand grip span in the maximum grip force study. In order to understand the best design criteria for pliers, a custom-made device which can measure individual finger force, total finger force while maximum gripping task was developed in this study. 19 males were participated to test 5 different hand grip spans (45mm, 50mm, 65mm, 70mm, and 80mm) with both dominant and non-dominant hands. Individual finger force, total grip strength, and subjective discomfort were measured as dependent variables in this study. Results showed that all dependent variables, total grip strength, individual finger force, and subjective discomfort, were statistically significant for hand grip spans and dominances (all p-values < 0.001). Also, the middle finger force was the strongest, followed by ring and index fingers. Little finger force showed that the least gripping force in the maximum gripping task. The best grip span of pliers that exerting maximum gripping force was 50 and 60mm based on this study.

Keywords
A-type hand tools, pliers, grip span, maximum grip, subjective discomfort

1. Introduction

Despite mechanized and automated working environment, most of workers has been exposed an improper working environment such as lifting heavy load and repeating the same task. Repetitive simple task induced intensive load on particular body part of the worker (Onishi et al., 1976; Aoyama et al., 1979). Also, WMSDs could be occurred by frequent use of hand tools, inappropriate wrist position, excessive strength, and continuous vibration (Groenesteijn, 2004). To prevent hand-related WMSDs, many studies about designing optimal hand tools are being conducted with a focusing on grip strength.

Grip strength related to grasp object is important factor for preventing hand-related WMSDs. Therefore, the research of grip strength has been conducted in various aspects such as grip span, handle shape, and dominance of the hand.

Grip span is an important factor of designing hand tools for reducing the applied stress to the hand (Meagher, 1987; Grant et al., 1992; Blackwell et al., 1999). Therefore, proper grip span of hand tools is important for increasing working efficiency and reducing industrial diseases. Research about optimal grip span for exerting maximum grip strength has been studied (Petrofsky et al., 1980; Fransson and Winkel, 1991; Talsania and Kozin, 1998; Eksioglu, 2004). Especially, individual finger force has been affected by grip span. In other words, each finger showed different grip span for exerting maximum finger force (Kim and Kong, 2008).

Grip strength would be different according to shape of handle because each finger has its optimal grip span for maximum finger force. Kong et al. (2009) categorized handle shape in four types (A, D, I and V) according to difference of grip span of index finger and little finger. Fransson and Winkel (1991) divided handle shape of plier in two types (traditional grip and reversed grip), also.

Hand tools generally can be divided into two types of handle shape; the one is I-type whose grip span is the same by all fingers, such as hammer, a spanner, and a wrench, and the other is A-type grip span whose lower part of handle is wider than the upper part, like nippers, rivet gun, and pliers.

Previous research has been focused on I-type handle (Grant et al., 1992; Talsania and Kozin, 1998; Kong and Freivalds, 2003), but the studies of A-type handle were few (Fransson and Winkel, 1991; Greenberg and Chaffin, 1977; Kong et al., 2009; Kong et al., 2011).

Contribution of individual finger force in maximum gripping task, the highest finger force was obtained from the middle finger, followed by the index and ring fingers, and the little finger was the lowest (Hazelton et al., 1975; Fransson and Winkel, 1991; Farris B.A. et al., 1997). Kong et al. (2011) have showed different contribution and optimal grip span of A-type handle compared to I-type apparatus, MFFM system (Kong et al., 2008).

Dominance of the hand is the important factor of grip strength. Dominant hand exerts more force than non-dominant hand about 10% (Bechtol, 1954; Petersen, 1989). This result has shown in generally but not always the same. Difference of grip strength could not assure in each finger force showed the same tendency, however.

The purpose of this study is to induce an optimal grip span of A-type plier. Grip strength, finger force and subjective discomfort rating were used for evaluating optimal condition of plier. Experimental apparatus was renovated existing hand tools and could measure each finger force.

2. Methods

2.1 Subjects

A total of 19 adult male subjects participated in the study. They had no history of upper extremity MSDs or other disorders. The averages of their age, height, weight, hand length and hand width were 25.7±2.5 years, 176.0±3.6cm, 69.7±8.2kg, 18.8±0.9cm, 8.2±0.5cm, respectively

2.2 Equipment

A plier with adjustable grip span had been developed by replacing head-handle joints of a plier used in the field with a gear. For measuring individual finger force, four load cells had been inserted into the handle of the plier (Figure 1). Five grip spans were chosen using the middle finger's gripping part of the handle as the standard. The data from the load cells were collected and recorded by Lab VIEW.

Figure 1: Remodel plier

2.3 Experimental design

The independent variables were five levels of grip spans (45, 50, 60, 70, and 80mm), dominant and non-dominant hand, and four levels of finger (index, middle, ring, and little finger). Total grip strength, individual finger force and subjective discomfort rating (10 point VAS scale) were chosen as dependent variable. ANOVA was performed for analyzing the collected data by SPSS (ver. 18.0) with a significance level of 0.05 and Tukey HSD was followed for significant results

2.4 Experimental procedures

Before the experiments, participants filled up a questionnaire about illnesses or injuries in their upper extremities that could affect the results. Anthropometric measurements of the subjects were assessed and other information about the subjects was collected. All participants were provided with a description of the experiment postures and procedures, and thoroughly familiarized with the gripping task prior to the experiments.

For each trial, participants exerted maximum grip force for 5 seconds by gripping the handle of the plier. Gripping tasks were performed with both dominant and non-dominant hands. It was repeated two times for each grip span, so a total of 20 trials were performed for every single subject. After performing each gripping task, participants evaluated subjective discomfort using 10 point VAS scale. Between each trial about 3 minutes resting time was provided in order to minimize the muscle fatigue. The trials were performed in a random sequence.

3. Result

3.1 Grip strength

3.1.1. Grip span

In statistical analysis, main effect of grip span in total grip strength was statistically significant ($p<0.001$). Subjects exerted the highest grip strength at 60mm grip spans (345N) and decreased their grip strength at smaller or larger grip spans (Table 1).

Table 1: Grip strength over grip span

	Grip span				
	45mm	50mm	60mm	70mm	80mm
Grip Strength (N)	295 ± 82^{C}	334 ± 78^{AB}	345 ± 85^{A}	319 ± 66^{B}	261 ± 75^{D}
Ratio (%)	85.5	96.8	100	92.4	75.7

3.1.2. Individual finger force

Individual finger force was statistically different ($p<0.001$). The force of middle finger was the highest, followed by the ring and index fingers. The little finger was the lowest finger force (Table 2).

Table 2: Individual finger force and contribution of grip strength

	Finger			
	Index	Middle	Ring	Little
Finger Force (N)	73 ± 31^{C}	109 ± 32^{A}	84 ± 24^{B}	45 ± 23^{D}
Contribution of grip strength (%)	23.5	35.0	27.0	14.5
Ratio (%)	67.0	100	77.1	41.3

3.1.3. Dominant and non-dominant hand

In analysis of dominant and non-dominant hand associated with grip strength, dominant hand (323N) showed higher grip strength than non-dominant hand (299N) ($p<0.001$). The grip strength ratio of non-dominant hand over dominant hand was 92.6%.

3.1.4. Interaction

The interaction of grip span and individual finger force was statistically significant ($p<0.001$). As shown in table 3, force of index and middle finger were decreased statistically as grip span was decreased while force of ring and little finger were statistically increased.

Table 3: Interaction of grip span and individual finger force

		Grip span				
		45mm	50mm	60mm	70mm	80mm
Finger	Index	87±34^{A}	82±28^{A}	78±28^{AB}	67±26^{B}	50±22^{C}
	Middle	118±35^{a}	116±30^{a}	113±31^{a}	108±28^{a}	90±30^{b}
	Ring	67±21$^{\gamma}$	92±24$^{\alpha}$	94±25$^{\alpha}$	87±20$^{\alpha\beta}$	79±22$^{\beta}$
	Little	22±13$^{\underline{C}}$	44±19$^{\underline{B}}$	60±24$^{\underline{A}}$	57±22$^{\underline{A}}$	42±15$^{\underline{B}}$

In table 4, the interaction of individual finger force and dominant was statistically significant (p=0.005), although individual finger force of dominant hand always had larger than non-dominant hand. The ratio of non-dominant over dominant finger was different for fingers. Ration of index finger was 95.9% and little finger was 87.5%.

Table 4: Interaction of individual finger force and dominance of hand

		Finger			
		Index	Middle	Ring	Little
Dominance	Dominant (N)	74±28	113±31	87±25	48±24
	Non-dominant (N)	71±34	105±33	80±24	42±22
Ratio (%)		95.9	92.9	92.0	87.5

3.2 Subjective discomfort rating

Subjective discomfort rating of maximum gripping task was measured by using VAS scale (10 score). It showed statistically different rating score according to grip span as a main effect factor (p<0.001). In figure 2, the least subjective discomfort rating was obtained at the grip span of 50 and 60mm whereas the most discomfort rating was measured at the grip span of 80mm.

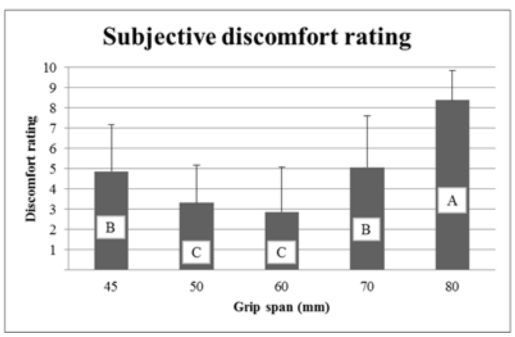

Figure 2: Subjective discomfort rating over grip spans

4. Discussion

The study involved measurement and analysis of the grip strength, individual finger force (index, middle, ring, and little fingers) and subjective discomfort rating regarding various grip span of plier. Experimental apparatus used in this study was specially remodeled version of normal pliers used in every working environment. It was modified to have an adjustable grip span and to measure grip strength and individual finger force for each finger associated with real working conditions. The result of grip strength in respect to grip span corresponds to previous studies. Grip strength showed the largest at 50 and 60mm grip span with 334 and 345N, and the least at 80mm grip span with 261N. In the range of grip span between 45 and 60mm, grip strength increased as the grip span increased. On the other hand, grip strength and grip span had an inverse relationship in the range from 60mm to 80mm. The results illustrated that an optimal grip span range of maximum gripping task is exist. This result was consistent with previous research for the optimal grip span of real pliers as 55~65mm for male (Fransson and Winkel, 1991). Also, this results were different from previous research finding (75~80mm) by Greenberg and Chaffin (1977). However, in terms of similarity and relevancy of experimental apparatus with real tool, the finding of Fransson and Winkel (1991) had a similar tendency of real plier rather than laboratory apparatus.

Next, individual finger forces and contribution for grip strength showed that the 109N (35.0%) for middle finger, 84N (27.0%) for ring finger, 73N (23.5%) for index finger, and 45N (14.5%) for little finger. In previous research, contribution of middle finger force to the grip strength was significant higher than other fingers and the little finger is the lowest. In case of studies, contribution of index and ring finger force showed the same or little difference, statistically. The finding of this study showed contribution of ring finger was higher than index finger, which was corresponds to the result of plier study (Fransson and Winkel, 1991).

Grip strength difference of dominant hand and non-dominant hand was 7.4%. In case of individual finger, index finger force ratio of non-dominant hand over dominant hand was 95.9%, and little finger was 87.5%. The ratio of non-dominant over dominant finger was different for fingers. The interaction of individual finger force and dominant was statistically significant (p=0.005). Ratio of index finger was 95.9% and little finger is 87.5%. It means difference of dominant hand and non-dominant hand in index finger was small, while in little finger was the largest. In addition, weaker finger of non-dominant hand had a tendency of exerting much lower force than other finger of dominant hand.

Subjective discomfort rating in maximum gripping task showed statistically different rating score according to grip span. The most discomfort grip span was 80mm, and 50 and 60mm were more comfort grip spans than others. In relation of grip strength and discomfort rating accordance with grip span, participants exerted more force in comfort grip condition, and vice versa (Figure 3). Or, comfort feeling of grip span made participants exert more force than discomfort feeling condition.

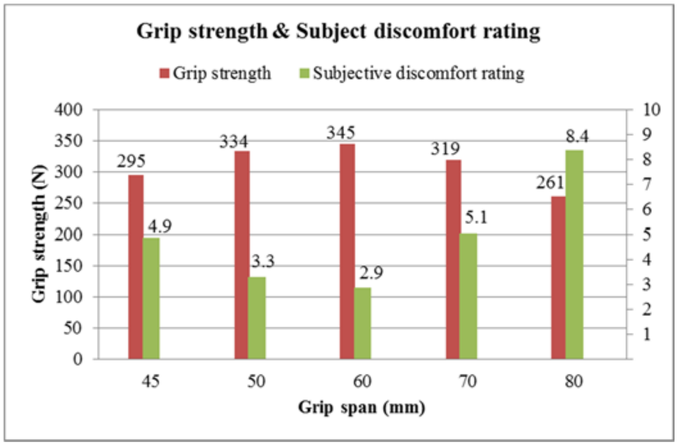

Figure 3: Grip strength & Subjective discomfort rating

5. Conclusion

The effects of grip strength, individual finger force, and subjective discomfort rating in condition of various grip spans and dominance of the hand were investigated by using remodeled general plier. Grip strength of pliers was the largest at 50 and 60mm grip spans, which had much lower subjective discomfort rating than other grip spans. Dominant hand showed more force than non-dominant force about 7.4%. Individual finger force, which is contribute to grip strength, was decreased in order of middle finger, ring finger, index finger, and little finger. As a limitation, it is obvious that difference of dominant and non-dominant hand in grip strength is not the same between right-handed and left-handed. So, right-handed and left-handed subjects have to separate in order to acquire more precise experiment result in further study.

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Biography

Yong-Ku Kong is an Associate Professor in Industrial Engineering in the Department of Industrial Engineering at the Sungkyunkwan University, KOREA. He earned B.S. in Industrial Engineering from Sungkyunkwan University, Masters and PhD degrees in Industrial Engineering from The Pennsylvania State University, University Park, USA. He is a Certified Professional Ergonomist (CPE) with ergonomics experience in working with many companies and research centers. His research interests include WMSDs (work-related musculoskeletal disorders), Biomechanics, Anthropometrics, and Human Simulation Modeling.

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