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Study on the grip spans of combination pliers in a maximum gripping task

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ABSTRACT

A newly developed system was applied in this study to evaluate the effects of the grip spans (45–80 mm) of combination pliers on the total grip strength, individual finger force, resultant force, and subjective discomfort. A total of twenty-six males participated and were asked to exert their maximum grip strength with two repetitions. The highest and the lowest total grip strength and resultant force (311.8 N and 737.9 N vs. 210.1 N and 501.7 N) were obtained at a 60 mm and 80 mm grip spans, respectively. In general, the participants considered the 50 and 60 mm grip spans as being the least discomfort, whereas the 80 mm grip span was considered as the most discomfort grip span in a maximum grasping task. The results can be utilized as basic data for the manufacturing and design industries of two-handle hand tools, such as pliers and wrenches.

Practitioners summary: Custom-made combination pliers were applied in this study to evaluate grip strength, resultant force, and subjective discomfort, relative to five grip spans. The authors expect that the results of the present study will provide valuable information for the designers and users of pliers.

1. Introduction

Despite the automation of production facilities and the development of efficient motor-driven tools, many jobs performed by workers required the use of hand tools (Cochran and Riley, 1986; Hakkanen et al., 1997; Lin et al., 2007). In most manufacturing or assembling processes, workers hold or manipulate various machine parts using hand tools (Mital and Kumar, 1998; Dianat et al., 2012). When workers use non-ergonomic hand tools, they tend to apply unnecessary force or adopt awkward postures for hands, wrists, and shoulders. In particular, if the upper extremities are repeatedly applied for the use of hand tools, an increase occurs in the risk of upper extremity musculoskeletal disorders (MSDs) such as tendinitis, stenosing tenosynovitis (trigger finger or trigger thumb), carpal tunnel syndrome, and shoulder tendinitis (Brickbeck and Beer, 1975; Masear et al., 1986; Silverstein et al., 1987; Kim, 2012; Fernandez and Marley, 2014). Thus, designing the appropriate hand tools suitable for users is very important to reduce the risk of work-related MSDs (WMSDs).

Tool users experience discomfort resulting in body stress, according to the studies conducted by Fellows and Freivalds (1991) and Aldien et al. (2005a,b). Along with repetition, awkward postures, vibrations, and forceful exertion were considered critical factors that caused MSDs resulting from the use of hand tools (Armstrong et al., 1990; Nazari et al., 2012; Dianat and Salimi, 2014). Furthermore, researchers have noted that most tasks that require the use of hand tools included one or more of these factors (Chang and Wang, 2000; Aldien et al., 2005a,b; Das, 2007).

To prevent hand-related MSDs resulting from the use of hand tools, researchers have attempted to design appropriate handles by considering such characteristics as size, shape, surface material, and texture (Cochran and Riley, 1982; Fraser, 1983; Fellows and Freivalds, 1991; Grant et al., 1992; Kong and Freivalds, 2003; Eksioglu, 2004; Kong and Lowe, 2005; Jung et al., 2007; Lowndes et al., 2012; McDowell et al., 2012; Dianat et al., 2016). Numerous studies have shown that the handle grip span is an important hand tool design factor to maximize grip strength, reduce stress on the digit flexor tendons, and avoid stress to the first metacarpal ulnar collateral and carpometacarpal ligaments (Chaffin and Anderson, 1984; Meagher, 1987; Grant et al., 1992; Blackwell et al., 1999).

Only a few studies have examined hand tools with angulated

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handles, such as various types of pliers and nippers associated with grip spans, although hand tools with one-handle grips such as drivers, hammers, and meat hooks have often been studied (Pheasant and Scriven, 1983; Grant et al., 1992; Talsania and Kozin, 1998; Kong and Freivalds, 2003; Eksioglu, 2004; Penzkofer et al., 2015). Of the results of hand tool studies related to angulated handles, Fransson and Winkle (1991) evaluated the traditional grip and reversed grip for slip joint pliers and suggested an optimum grip span (the highest resultant force) for males of 55–65 mm and for females of 50–60 mm. Greenberg and Chaffin (1977) recommended 64–89 mm as the optimum grip span for adult males, while Kong et al. (2014) suggested the most recommended grip spans were 45–50 mm, in terms of the strength of maximum exertion according to the A-handle force measurement (AFM) system. However, the AFM system relies on A-shape mock-ups, which were custom-made by a rapid prototype machine (3D printer). Hence, these handles were not associated with real hand tools. Thus, Kong et al. 2011 finding may not be suitable for its application to the design of real commercially available hand tools.

In general, many types of pliers have been used mainly for cutting electrical wires, tying different parts together, holding materials during assembly, and fastening and unfastening components (Li, 2003) in many occupational areas such as construction (Anton et al., 2001; Li, 2002; Vi, 2006; Husain et al., 2013), electrical assembly (Groenesteijn et al., 2004), and telecommunications (Paivinen, 2006). Combination pliers have not yet been studied, to our knowledge, in spite of the wide use in many industry sites of combination (lineman's) pliers that have a snub nose, short-round handles, and a multi-function head.

Thus, the objectives of this study include: (1) to evaluate the effects of grip span on total grip strength, individual finger force, resultant force, and subjective discomfort rating; (2) to investigate the contribution of individual finger forces to the total grip strength associated with the grip span; and (3) to suggest guidelines, based on this study, for the grip spans of combination pliers to hand tool users or designers, or both.

2. Methods

2.1. Participants

A total of 26 males, with no history of upper extremity MSDs, volunteered for this study. At the beginning of the experiment, each participant was given an informed consent form and a brief description of the goals and procedures of the experiment. The means and standard deviations (SDs) of the participants' age, height, and weight were 25.8 ± 1.5 years, 173.8 ± 5.4 cm, and 74.0 ± 12.9 kg, respectively. The average hand length, hand width, and hand thickness were 18.5 ± 0.7 cm, 8.1 ± 0.3 cm, and 2.9 ± 0.2 cm, respectively. Further details about the characteristics of the participants are summarized in Table 1.

2.2. Measurement system

Combination pliers with an adjustable grip span were developed for this experiment. An adjustable mechanism was applied to the region between the hinge and the front part of the combination pliers handles so that the grip spans could be changed in a 45–80 mm range. Four load cells (Model 13 subminiature load cell, ranging from 0 to 50 lb., 3/8″ diameter; Honeywell) were also mounted in the handles of combination pliers and one load cell (Model 13 subminiature load cell) was inserted into the jaws of the pliers to measure individual finger force and resultant force, respectively, with a sampling rate of 10 Hz (Fig. 1, top). All five load cells were calibrated by known weights (1–5 kg) on a custom-made calibration fixture due to their large linearity of ±0.5% full scale. The output data (voltage) from the load cells were measured using a NI USB-6259 DAQ board and analyzed using a data acquisition program written in LabVIEW software (National Instrument; Austin, TX, USA). The correlation (R^2) between the output voltage data and applied known weights was more than 0.998 for all load cells. The display of the data acquisition program was composed of two large windows for the total grip strength and resultant force and there were four small windows for each finger force (Fig. 1, bottom).

The combination pliers were modified to change the grip span from 45 to 80 mm when there was no object between the jaws of the pliers. Five grip spans were chosen for this experiment (45 mm, 50 mm, 60 mm, 70 mm, and 80 mm), and the grip span was defined as the distance between the middle finger-side handle and the palm-side handle. More details about the specifications of the combination pliers are summarized in Table 2.

2.3. Experimental procedures

Before the experiments, the participants completed a questionnaire about upper extremity MSDs. The anthropometric data of each participant were assessed. Then, prior to the experiments, all participants were provided with a brief description of the experimental procedure and performed a practice test for familiarization with the grasping task.

For this study, the participants exerted their maximum grip force by gripping the handles of the pliers. All participants were instructed to apply exertion as fast as possible (about 1 s) to reach their maximum from an initial state of relaxation and then to maintain their maximum grip exertion for 4 s. After applying their maximum exertion, they were asked to relax. The average of maximum exertion force during the last 4 s was measured. The participants were given three minutes to rest between each trial in order to minimize muscle fatigue. The maximum grasping task was repeated twice for each grip span (45 mm, 50 mm, 60 mm, 70 mm, and 80 mm) hence, each participant performed ten exertions. The trials were selected in a random order. After performing a grasping

Table 1
Characteristics of participants.

	Mean ± SD	Range		Mean ± SD	Range
Age (yr)	25.8 ± 1.5	23.0–30.0	Wrist circumference (cm)	16.0 ± 0.7	14.8–17.9
Weight (kg)	74.0 ± 12.9	56.7–113.2	Hand length (cm)	18.5 ± 0.7	17.4–19.8
Height (cm)	173.8 ± 5.4	156.4–184.5	Hand width (cm)	8.1 ± 0.3	7.6–8.6
Sitting height (cm)	79.3 ± 8.6	41.4–87.2	Hand thickness (cm)	2.9 ± 0.2	2.6–3.2
Arm length (cm)	54.1 ± 4.5	35.0–59.4	Palm length (cm)	10.7 ± 0.5	10.0–12.0
Upper arm length (cm)	34.8 ± 5.3	30.1–59.8	Index finger length (cm)	7.1 ± 0.4	6.4–8.0
Lower arm length (cm)	26.4 ± 1.6	23.1–30.3	Middle finger length (cm)	7.8 ± 0.4	7.2–8.5
Upper arm circumference (cm)	31.2 ± 3.4	25.2–38.4	Ring finger length (cm)	7.3 ± 0.4	6.7–8.1
Lower arm circumference (cm)	25.5 ± 1.6	22.8–29.3	Little finger length (cm)	6.0 ± 0.3	5.5–6.7