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Effects of the resting time associated with the number of trials on the total and individual finger forces in a maximum grasping task

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ABSTRACT

The repetitive and excessive workload accompanying grip strength- or hand-intensive tasks are often considered to be common causes of work-related upper limb musculoskeletal disorders. For this reason, numerous experimental studies have been performed on maximum grip strength. However, due to an absence of standard guidelines, researchers have adopted different resting times and number of trials suited for their particular research purposes. The effects of resting time and the number of trials on the maximum total grip strength and individual finger forces of 24 participants over 20 trials were investigated. Results showed that the total grip strength and individual finger strengths differed significantly according to the resting time and the number of trials ($p < 0.05$). Overall, grip strength tended to increase with a reduction in resting time (% reduction: 7.8%, 9.1%, 11.1%, and 13.0% for 3 min, 2 min, 1 min, and 30 s resting time, respectively) as well as with an increase in the number of trials (% reduction: 8%, 10%, 13%, and 16% for 5th, 10th, 15th, and 20th trials). The effects of resting time and the number of trials also showed statistically significant effects on individual finger forces. Regression equations of total grip strength and finger forces with resting time and number of trials were established. These equations were then applied to formulate guidelines for appropriate resting times in experiments based on the number of trials and acceptable reductions in grip strength. Data from this and future studies regarding decreasing grip strength and the contribution of each finger are expected to form the groundwork for ergonomic hand tool design and development.

1. Introduction

Work-related musculoskeletal disorders (WMSDs), which most often occur in industries such as production assembly and auto-repair, have recently drawn considerable attention. According to previous researches, many WMSDs have been reported in industry workers due to tasks that involve high risk activities such as the lifting and carrying of heavy objects, repetitive motions and exertions, insufficient resting time, awkward body postures, and vibrations (Putz-Anderson, 1988; Armstrong et al., 1990; Punnett et al., 1991; Bernard, 1997). Researchers have sought to lower the incidence rate of WMSDs, but it has remained stubbornly high. The incidence rate of WMSDs is greater in the upper limbs than in the lower limbs (Baker, 1995; Macleod, 1999). According to data from the Industrial Accident Examination (KOSHA, 2008), the incidence rate of upper limb WMSDs, relative to occurrences of all WMSDs, has gradually increased from 29.9% in 2005 to 37.6% in 2006 and 42.9% in 2007. Generally, WMSDs affect the upper limbs because workers repeatedly use tools or carry heavy items, often employing their upper limb joints such as the wrist, elbow, shoulder, and neck. Workers can succumb to WMSDs due to unsuitable work environments, for example where workers are required to contort their limbs in unnatural ways (Macleod, 1999). Grip force is used in general tasks and is also needed for repeated handling (Gurram et al., 1993; Dubrowski and Carnahan, 2004). Generally, over-exertion and repetitive grip forces are required in maintenance, fastening and repair activities in which hand tools are used. When using hand tools, WMSDs can be caused by excessive radial or ulnar deviation or bent wrists (Armstrong et al., 1990). It has been reported that the generation of excessive forces, improper posture, extreme temperatures, vibrations, and other variables can also lead to losses of grip force (Kattle et al., 1996). It has been suggested that WMSDs could be reduced if hand tools were ergonomically designed with a focus on the comfort and safety of the tool users (Lewis and Narayan, 1993).

The provision of adequate resting time and limitation of repetitions between rest periods are important factors in preventing WMSDs and improving operational efficiency and

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Table 1
Summary of resting times and number of trials in previous research.

Resting time	Author (year)	Trial
15 s	Trossman and Li (1989)	5
	Mathiowetz (1990)	3
	Montazer and Thomas (1991, 1992)	30
30 s	Reddon et al. (1985)	10
	Trossman and Li (1989)	5
	Desrosiers et al. (1995a,b)	3
	Shechtman et al. (2001, 2007)	12,26
	Mandalidis and O'Brien (2010)	3
1 min	Trossman and Li (1989)	5
	Spijkerman et al. (1991)	3
	Beaton et al. (1995)	3
	Ruiz-Ruiz et al. (2002)	11
	Kundson and Noffal (2005)	14
	Fink et al. (2010)	2
2 min	Fransson and Winkel (1991)	7
	Richards et al. (1995)	9
	Hager-Ross and Rosblad (2002)	3
	Kaya et al. (2005)	3
	Kwak et al. (2010)	15
3 min	Pryce (1980)	18
	Kim et al. (1995)	24
	Wimer et al. (2010)	24
5 min	Teraoka (1979)	6
	Balogun et al. (1991)	8
	Cho et al. (2007)	3
	Lee et al. (2011)	3

comfort. However, relatively few studies have investigated the effects of resting time and repetition of force exertions on the total grip strength and individual finger forces in a maximum grasping task. Mathiowetz (1990) and Shechtman et al. (2007) only showed that grip force is reduced as the gripping task is repeated. Caldwell et al. (1974), Trossman and Li (1989), Garg et al. (2005), and Chow and Dickerson (2009) analyzed the reduction of grip force with 1–3 min of resting time, which is advised to minimize the consequences of fatigue.

There is a lack of research findings addressing the sufficiency of resting times relative to the number of trials in a grasping task. Some researchers have applied different resting times and number of grasping task trials for each set of experiments (Caldwell et al., 1974; Trossman and Li, 1989; Montazer and Thomas, 1992; Shechtman et al., 2007; Kwak et al., 2010). Table 1 indicates resting times and the number of trials researchers used for their grip strength measurement experiments, which of course have varying results due to the different lengths of resting time.

Accordingly, the objectives of this study were to: (1) analyze the effects of resting time and the number of trials on the total grip strength and individual finger force in a maximum grasping task and, based on the study, (2) provide suggestions on the proper amount of resting time associated with the number of gripping measurement tasks and trials.

2. Methods

2.1. Participants

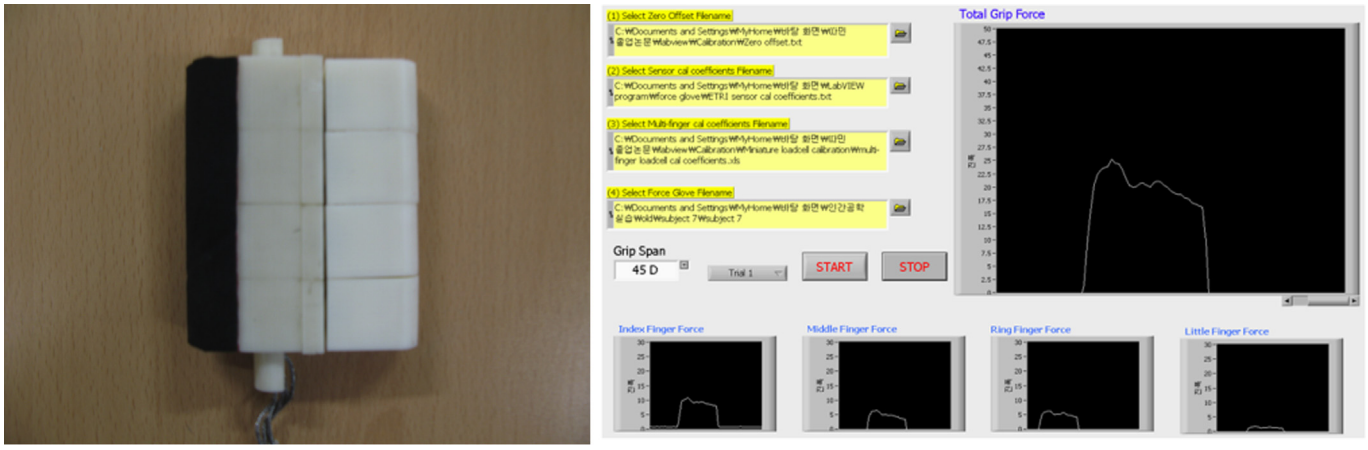
Twenty-four males (age: 24.7 ± 1.3 yrs, weight: 70.2 ± 8.6 kg, height: 176.6 ± 5.3 mm) were recruited via advertisements within the University community. All participants were right handed and free of known upper-limb musculoskeletal injuries. At the beginning of the experiment, signed informed consent forms were obtained, and basic anthropometric data such as hand length and width were collected.

2.2. Apparatus

The Multi-Finger Force Measurement (MFFM) system, which was developed by Kim and Kong (2008) to measure individual finger forces and total grip strength, was used in this study. The system consists of four sub-miniature load cells (Honeywell Model 13, force ranges from 0 to 0.49 N, 9.5 mm in diameter, 2.75 mm in thickness) placed where the fingers were bent. The grip span and grip length of the MFFM system were 55 and 80 mm, respectively (Fig. 1a). When measuring grip force, output signals were collected by an NI DAQmx-6259 system and presented on the screen by custom-made software written in the LabVIEW Program widely used for computer control and measurement, as shown in Fig. 1b.

2.3. Procedure

Participants were provided with a brief description of the purpose and procedures of the experiment. Posture during the measurement experiment was adopted from the ASHT (American Society of Hand Therapists, 1981). All participants were asked to



(a) Grip span (b) MFFM System

Fig. 1. Components of the MFFM system.