Applied Ergonomics 41 (2010) 141–145

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Psychophysically determined forces of dynamic pushing for female industrial workers: Comparison of two apparatuses

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ARTICLE INFO

Article history:
Received 18 February 2008
Accepted 9 June 2009

Keywords:
Psychophysics
Cart pushing
Manual materials handling

ABSTRACT

Using psychophysics, the maximum acceptable forces for pushing have been previously developed using a magnetic particle brake (MPB) treadmill at the Liberty Mutual Research Institute for Safety. The objective of this study was to investigate the reproducibility of maximum acceptable initial and sustained forces while performing a pushing task at a frequency of 1 min^{-1} both on a MPB treadmill and on a high-inertia pushcart. This is important because our pushing guidelines are used extensively as a ergonomic redesign strategy and we would like the information to be as applicable as possible to cart pushing. On two separate days, nineteen female industrial workers performed a 40-min MPB treadmill pushing task and a 2-hr pushcart task, in the context of a larger experiment. During pushing, the subjects were asked to select a workload they could sustain for 8 h without "straining themselves or without becoming unusually tired, weakened, overheated or out of breath." The results demonstrated that maximum acceptable initial and sustained forces of pushing determined on the high inertia pushcart were 0.8% and 2.5% lower than the MPB treadmill. The results also show that the maximum acceptable sustained force of the MPB treadmill task was 0.5% higher than the maximum acceptable sustained force of Snook and Ciriello (1991). Overall, the findings confirm that the existing pushing data developed by the Liberty Mutual Research Institute for Safety still provides an accurate estimate of maximal acceptable forces for the selected combination of distance and frequency of push for female industrial workers.

1. Introduction

The discipline of psychophysics was instrumental in developing maximal acceptable weights and forces during a variety of manual materials handling (MMH) activities (Snook and Ciriello, 1991). In simple terms, the psychophysical technique consists of subjects choosing weights and forces that can be maintained over an 8-hour shift without workers "straining themselves or without becoming unusually tired, weakened, overheated or out of breath." For example, MMH tables developed at the Liberty Mutual Research Institute for Safety are still widely utilized by many industries for (re)designing their job activities so as to prevent injuries and increase productivity at their workplace (Snook et al., 1978; Benson, 1986, 1987; Snook, 1987; Ciriello and Snook, 1999; Ciriello et al., 1999b). Redesign of manual materials handling (MMH) tasks using sound ergonomic principles has the two-fold advantage of accommodating the work place to a high percentage of the industrial population with and without low back disability. This strategy is important due to: (1) the most frequent (36% of all claims) and costly (35% of total cost) category of workers' compensation losses is MMH (Leamon and Murphy, 1994; Murphy et al., 1996; Dempsey and Hashemi, 1999) and (2) MMH claims are also associated with the largest proportion (63% to 70%) of compensable low back disability (Snook et al., 1978; Bigos et al., 1986; Murphy and Courtney, 2000).

Ergonomic redesign strategies sometimes call for changing lifting, lowering, and carrying tasks to pushing and pulling tasks. A well-designed cart can transfer heavy weights with forces that are acceptable to a high percentage of males and females. In establishing the criterion for dynamic pushing, experiments were initially conducted on a magnetic particle brake (MPB) treadmill to derive maximum acceptable forces (Snook and Ciriello, 1991), and were later compared to pushing forces obtained on a high inertia push cart (Ciriello et al., 1999a, 2007) for men. Results from these studies demonstrated that there were significant differences between pushing on the MPB treadmill versus a pushcart, with higher forces derived during cart pushing. However, it was not clear if women would respond in the similar way when they push the same distance at the same frequency on both the MPB treadmill

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0003-6870/$ – see front matter
doi:10.1016/j.apergo.2009.06.001

and the high inertia push cart. Ciriello (2004) demonstrated that for female industrial workers, the maximum acceptable forces on the pushcart were not significantly different than MPB treadmill values. The purpose of this study was to replicate the methodology of Ciriello (2004) with a larger number of subjects, and establish if the relationship between the two methods remains similar. The argument for replication lies not only in the scientific community but also in the ergonomic world which uses the "Snook and Ciriello" tables quite extensively since the guidelines provide the most complete data on pushing and pulling in the world. Extensions to the "Snook and Ciriello" tables, e.g. Liberty Mutual Tables and CompuTaskII (Liberty Mutual's computerized task analysis program) are also used by our own loss prevention specialists and other large company safety personnel to perform job redesign. Therefore, it is of the utmost importance that the initial comparison in our 2004 study with eleven subjects be verified with at least a doubling of the population. The present study reports the verification of the first study. We also conducted the study within the background of a larger study that was different from the 2004 study. This added more confidence to the reporting of the study's results.

2. Method

2.1. Subjects

Nineteen female industrial workers were recruited from local industries to participate in this study which was approved by our institutional review committee. Candidates were excluded from the experiment if they had experienced previous significant low back pain or musculoskeletal problems of the extremities. Following initial screening and upon giving written informed consent, the subjects were examined by a nurse practitioner to ensure that they had no serious cardiovascular problems or musculoskeletal conditions. Several anthropometric measurements were taken to set the handle of the push cart midway between knuckle and elbow height (Table 1). These measurements along with height and weight were compared with military and industrial populations to ensure similarity with our subjects (Snook and Ciriello, 1974; Ciriello et al., 1990; Eastman Kodak Co., 1986; Gordon et al., 1989; Marras and Kim, 1993; Ciriello, 2004). The comparison to the above studies yielded a median difference of 1.4%, 2.4%, 2.0%, and 8.9% respectively for stature, elbow height, knuckle height and weight. All subjects were dressed in surgical type "scrub suits" to control for heat dissipation. They were provided with commercial slip-resistant shoes that had similar sole and heel material to ensure consistent coefficients of friction across subjects on the treadmill belt and the runway for the push cart.

2.2. Apparatuses

The following describes the two apparatuses used in this experiment. The first dynamic pushing task was performed on a specially constructed MPB treadmill. During pushing, the MPB treadmill was powered by the subject while pushing against a stationary bar. The bar was 3.2 cm in diameter and was set midway between knuckle and elbow height for each subject. Knuckle and elbow height were determined by the vertical distances from the standing surface to the tip of the third metacarpal (at the metacarpo-phalangeal joint) and to the most proximal edge of the radius, respectively. Both measurements were taken while the subjects stood erect with their arms hanging naturally by their sides. A load cell on the stationary bar measured the horizontal force being exerted. Subjects controlled the resistance of the treadmill belt by varying the amount of electric current flowing into the MPB linked to the treadmill belt. The control was devoid of positional cues and located within arm's length of the subject. Subjects turned the control knob clockwise to increase the resistance and counterclockwise to decrease resistance. The control knob could be adjusted before, during, or after each push. Pushing tasks were performed for a distance of 7.6 m and at a frequency of 1 task min^{-1}. This system has been used in all the previous manual handling experiments performed in our laboratory to establish criteria for pushing (Ciriello and Snook, 1978; Ciriello and Snook, 1983; Ciriello et al., 1990; Ciriello et al., 1993; Snook et al., 1978; Snook, 1971; Snook and Ciriello, 1974; Snook and Ciriello, 1991).

Table 1
Subject Characteristics ($n = 19$).

	$\bar{X}$	SD
Age (yrs)	38.74	9.57
Weight (kg)	72.41	14.35
Stature (cm)	164.55	6.64
Elbow height (cm)	105.08	4.39
Knuckle height (cm)	73.51	3.76

The second dynamic pushing task was performed with a specially constructed push-cart which was designed with an 'on demand' water loading system. This system was described and illustrated in a previous publication (Ciriello et al., 1999a). In summary, the push cart was a wooden framed box, covered in plywood, and mounted on four 20 cm diameter tubeless rubber wheels. The dimensions of the box were 117 cm high, 142 cm wide and 206 cm deep. A 610 L polyethylene tank, baffled with a motion suppressing open cell foam, was mounted in the box and had empty and full weights of 262 kg and 780 kg, respectively. The rubber wheels, at a inflation level of 207 kPa, minimized rolling of the cart after the push task and thus did not require the test subject to exert any force to stop the cart. Since the laboratory was only 15 m long, the subjects pushed 7.6 m in one direction and immediately walked around to the other side of the cart to wait for the next 1-min signal to push 7.6 m in the opposite direction. Therefore, two horizontally mounted push bars, 93 cm long and 4.3 cm in diameter, were located at each end of the cart. Each push bar was mounted to the cart by two 2225 N rated load cells, configured to measure the total horizontal forces applied by the subjects. Similar to the MPB treadmill, the bar was adjustable and set midway between knuckle and elbow height for each subject.

The pneumatically actuated diaphragm pump delivered a minimum of 145 kg/min. of water to and from the cart through the single hose via a manifold containing four electronically actuated solenoid valves. Water was off-loaded from the cart to a reservoir by opening and closing the appropriate valves. The cart weight was adjusted by depressing buttons on the cart labeled "More" or "Less". The button selection sent a signal to a personal computer which in turn activated the pump and appropriate solenoids. Computer control of this process also allowed the experimenter to change the cart weight when required by the protocol.

The reservoir was mounted on a base resting on top of two 454 kg rated load cells. The outputs of the two load cells provided a measure of the water weight contained in the reservoir. In this closed system, the cart weight was determined by the amount of water entering or exiting the reservoir during the pumping.

The outputs of the push bars and the two reservoir load cells were transmitted to the personal computer equipped with an analog-to-digital converter, and were sampled at a minimum rate of 100 Hz. In-house custom software was written to control data acquisition during the experimental sessions and to perform data analysis functions. The statistics reported on a per trial basis were: initial and sustained horizontal forces, time period of the pushing