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Comparison of psychophysiological responses in healthy men and women workers during cart pushing on two walkways of high and low coefficient of friction

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ABSTRACT

The purpose of this study was to compare psychophysiological responses between healthy men and women workers during dynamic pushing on two frictional floor surfaces. First, using a psychophysical approach 27 participants chose a cart weight that they could push for 8 h "without strain or becoming unusually tired, weakened, overheated or out of breath" on Plywood (coefficient of friction = 0.68) and Teflon (coefficient of friction = 0.26) walkways. Second, cardiopulmonary and muscle metabolic measurements were collected simultaneously on two separate days while participants pushed the high-inertia cart over a 7.6 m distance at a frequency of 1 push/min at the psychophysically chosen workload for 2 h on each walkway. Muscle responses, Tissue Hemoglobin Index (THI) and Tissue Oxygenation Index (TOI), from the right and left gastrocnemius medialis, were obtained using near-infrared spectroscopy.

Statistical analysis showed that cart weight chosen by both men and women on the Plywood walkway was 27% higher than that on the Teflon walkway ($P < 0.001$), with women able to push 9% (on Teflon) and 27% (on Plywood) less than men ($P < 0.005$). The resultant force exerted on the instrumented cart handle by both men and women on the Plywood walkway was 33% higher than that on the Teflon walkway ($P < 0.001$), with women exerting 21% (on Teflon) and 35% (on Plywood) less force than men ($P < 0.001$). The lower resultant forces exerted while pushing on the Teflon walkway produced lower oxygen uptake responses than that on the Plywood walkway, with women displaying 20% (on Teflon) and 22% (on Plywood) less than men. Women had 35% less hemoglobin concentration (i.e., THI) in calf muscles compared to men during cart pushing, but this gender difference in THI responses was nullified after adjustment for the resultant force. The net saturation of hemoglobin represented by TOI was not influenced by walkway, implying that an increase in oxygen extraction is matched by the increased blood flow to the calf muscles in both men and women irrespective of the walkway. However, the influence of the force of exertion on oxygen saturation in women was 31% more than men, suggesting the importance of investigating gender-specific physiological differences in skeletal muscles during dynamic pushing.

Relevance to industry: Using a combination of methodologies from psychophysics and physiology, the present study evaluated functional abilities of both men and women during cart pushing. Psychophysiological findings from the present study clearly demonstrate the need for further understanding of gender differences during a variety of repetitive manual materials-handling activities at the workplace.

1. Introduction

Based on the Liberty Mutual Workplace Safety Index (2007), *overexertion* (involving materials-handling activities such as excessive lifting, pushing, pulling, holding, carrying, or throwing) and *same level falls* are the first and second leading causes of workplace injuries, respectively. Pushing, a manual materials-handling activity, is defined as the application of one- or two-handed force on an object or person, with feet either stationary (i.e., static) or moving (i.e., dynamic). Cart pushing is an example of applying a two-handed force with feet moving. Such dynamic pushing on various walkways is not only associated with localized muscle fatigue (Hoozemans et al., 1998; van der Beek et al., 2000), but also with occurrence of slips and falls in the workplace (Haslam et al., 2002; Gronqvist et al., 2001). A slip-induced fall leading to an injury might occur when the friction required to push a loaded cart

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by a worker exceeds the available friction at the shoe–walkway interface.

A review of Treaster and Burr (2004) reported that women have higher prevalence rates of work-related musculoskeletal disorders than men. Anatomically, women have smaller upper body muscle mass with lower strength for upper body muscle groups as compared to men (Miller et al., 1993). Also, women have greater percentages of slow twitch fibers, but have 10–14% less hemoglobin than men, resulting in lower oxygen-carrying capacity (Wells, 1991). It has been demonstrated that, in selected occupational tasks, significant differences exist between genders in their energy expenditure per unit amount of work done (e.g., Esmail et al., 1995; Maikala and Bhambhani, 2005). However, gender-specific physiological differences in cart pushing are not yet known. To this effect, a physiologic approach in combination with psychophysics (Snook, 1978) is one means of investigating gender differences so that the physical demands associated with occupational activities can be evaluated within the physiologic capabilities of the majority of workers (e.g., Straker et al., 1996; Dempsey et al., 2008).

Usually, the whole body (viz. arms, back, and legs) is involved in the pushing of carts at the workplace, hence workers tend to expend considerable amounts of force and energy while starting and maneuvering a cart in motion (Hoozemans et al., 1998). While measurements such as pulmonary oxygen uptake and heart rate are used to assess whole-body physiological responses during a task performance, these measurements do not provide information on the effort from specific muscles. In terms of the lower-extremity region, the gastrocnemius muscle provides vertical support of the body weight, forward locomotion, and swing initiation of the lower limbs, whereas the medial region of the gastrocnemius facilitates the swing phase of the leg (Neptune et al., 2001). However, it is not clear how this specific muscle region responds during cart pushing. Therefore, the goal of this study was to compare whole-body and localized physiologic responses between healthy men and women workers during cart pushing of psychophysically selected workloads on walkways with high (Plywood) and low (Teflon) coefficient of friction (COF).

We hypothesized that the greater the COF of the walkway, the higher the chosen workload and cardiopulmonary and localized muscle responses. Metabolic responses from bilateral gastrocnemius medialis regions were monitored using near-infrared spectroscopy. Since there is no literature that supports the presence of either symmetry or asymmetry in the lower limbs during dynamic pushing, we hypothesized an equal contribution from both left and right calf muscle regions in terms of metabolic responses.

2. Methods

Written informed consent from 27 healthy industrial workers (12 men and 15 women) from local industries with experience in various manual materials-handling activities were obtained. Demographics in mean $\pm$ SD were: men – age: 39 ± 13 years; height: 178 ± 6 cm, and body mass: 91.5 ± 16 kg; and women – age: 42 ± 7 years; height: 169 ± 10 cm, and body mass: 73.5 ± 15 kg). The Institutional Review Board of the research institute approved the experimental protocols.

2.1. High-inertia pushcart

Dynamic pushing on the Plywood and Teflon walkways was simulated using a high-inertia pushcart (Ciriello et al., 1999). The configuration of the four-wheeled customized cart is as follows: 117 cm (height) $\times$ 142 cm (width) $\times$ 206 cm (depth). The diameter of each wheel was 20 cm, and was inflated to a pressure of 207 kPa. At this inflation pressure, the rubber wheels minimized the rolling of the cart after each push, and thus did not require the participant to exert any force to stop the cart (Ciriello et al., 2001; Ciriello, 2005). Instrumented handles that can be adjusted between 66 and 127 cm in height were attached to both ends of the cart (Fig. 1a). For this experiment, the instrumented handle on the cart was adjusted to midway between knuckle and elbow height for each participant (women: 91.5 ± 4.2 *versus* men: 99.5 ± 5.0 cm). Each handle was instrumented with four load cells (Omega Engineering, Inc., Stamford, CT, USA) of 2225 N capacity in order to measure horizontal and vertical forces applied by the participant during pushing.

The weight of the cart was regulated with an 'on demand' water loading system (Ciriello et al., 1999), in such a way that when empty, the cart weighed 262 kg and with full weight of water it approximated to 780 kg. The water was contained in a 610 l polyethylene tank, baffled with a motion-suppressing open cell foam. The water tank was mounted on a wooden frame. A pneumatically actuated diaphragm pump delivered a minimum volume of 145 kg/min of water to and from the cart through a single hose via a manifold containing four electronically actuated solenoid valves. This high-pressure hose of 3.8 cm diameter connected the cart tank to the pump–manifold assembly, and was mounted to an overhead carriage which travels with the cart to minimize drag. Water was off-loaded from the cart to the reservoir and vice versa by opening and closing of the valves (Ciriello et al., 1999). The reservoir was mounted on a base resting on top of two 454 kg rated load cells. The outputs of these two load cells indicated a measure of the water weight contained in the reservoir. Since it was a closed system, the full cart weight measured during the calibration mode was deducted by the water weight in the reservoir to determine the latest cart weight. The reservoir and pump–manifold assembly were contained in an acoustically insulated housing to minimize noise. The output leads of the handle and the two reservoir load cells were interfaced with a personal computer and a 16-channel analog-to-digital converter (Ciriello et al., 1999). Data were sampled in real time at a minimum rate of 100 Hz.

2.2. Walkway

A 15 m walkway for cart pushing was constructed in the Work Physiology Laboratory at the institute (Fig. 1b). This walkway consisted of six untreated Plywood panels (each 244 cm length $\times$ 86 cm width $\times$ 2 cm thick) with surface treatments providing the desired COF or Teflon sheets glued to a Plywood base, thereby simulating floors with different COF. A U-shaped aluminum channel adjacent to the walkway guided two of the cart wheels, thus eliminating the need for steering.

Two points (START and STOP) were marked above the walkway at a distance of 7.6 m. Participants were asked to stand at the START marker to initiate the push (Fig. 1b). Upon hearing an audio signal (beep), participants began the pushing effort on the walkway by grasping the instrumented handle on the cart and moving forward until reaching the STOP marker at a 7.6 m distance. Participants then walked to the other side of the cart and waited for the beep. After hearing the audible signal at 1 min, the pushing effort continued by grasping a second instrumented handle and pushing the cart back to the START position.

2.3. Psychophysical protocol

Each participant underwent a psychophysical protocol that consisted of choosing a cart weight one could push without strain for a typical 8-h shift to identify his/her maximum acceptable workload on the Plywood and Teflon walkways (Ciriello et al., 2001). The protocol on each walkway was 2 h long and contained