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Effect of an on-hip load-carrying belt on physiological and perceptual responses during bimanual anterior load carriage

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ABSTRACT

Manual load carriage continues to be a major contributor of musculoskeletal injury. This study investigates the physiological and subjective effects of an on-hip load-carrying belt (HLCB) during bimanual anterior load carriage. Fifteen healthy male participants walked on a level ground treadmill at 4.5 km/h for 5 min carrying 5, 10 and 15 kg loads with hands and arms in front of the body, with and without using the HLCB (WD and ND). Heart rate, normalized oxygen uptake, minute ventilation and, central and peripheral ratings of perceived exertion were the dependent variables. The mean heart rate, normalized oxygen uptake, minute ventilation and peripheral rating of perceived exertion increased significantly with load under both WD and ND conditions. At a load of 15 kg, the mean heart rate, normalized oxygen uptake, minute ventilation and peripheral rating of perceived exertion were significantly lower by 6.6%, 8.0%, 11.8% and 13.9% respectively in WD condition when compared to the ND condition. There was no significant difference between WD and ND conditions with 5 or 10 kg load. It can be concluded that the HLCB could reduce a person's physiological and peripheral perceptual responses when walking on a level ground treadmill at 4.5 km/h with a load of 15 kg. Using a HLCB or similar device is therefore recommended for bimanual anterior load carriage for loads of 15 kg or probably larger.

1. Introduction

Load carrying is a well-known risk factor of back pain, musculoskeletal disorders and fall injuries (Chow et al., 2014; Kelsey et al., 1984; Pietri et al., 1992; Kuiper et al., 1999; and Myung and Smith, 1997; Kim and Chai, 2015). Over the years, research has examined the physiological and biomechanical implications of load carrying for risk prevention, energy reduction, mobility improvement, and enhancement of comfort (Datta and Ramanathan, 1971; Legg, 1985; and Haisman, 1988; Wang et al., 2013).

Several studies have shown that factors affecting load carriage performance are the method of carrying, placement of load, the magnitude of the load, speed of locomotion, terrain type and so on (Bastien et al., 2005; Browning et al., 2007; Soule and Goldman, 1969; Stuempfle et al., 2004). It has been reported that metabolic expenditure increases linearly with the increase of load magnitude and walking speed in some (Bastien et al., 2005; Browning et al., 2007; and Keren et al., 1981), but not all studies (Griffin et al., 2003; Bastien et al., 2005; and Abe et al., 2004). Other findings have shown that a well-distributed load using a harness or trunk vest could reduce the physiological responses during long term walking (Datta and Ramanathan, 1971; Lloyd and Cooke, 2000; Knapik et al., 1996). Legg and Mahanty (1985), after comparing the metabolic effect of five different load carrying methods, concluded that the front/backpack (also called doublepack) method produced the least metabolic strain and suggested that the optimum way to carry loads would be stable as that brings the center of gravity of the load as close to the body to make use of the large mass muscles, thereby reducing the metabolic strain.

In contrast, anterior load carriage (i.e. carrying objects with hands and forearms) was considered as one of the least efficient physiologically, as it increases energy expenditure on shoulder muscles (Malhotra and Gupta, 1965; Knapik et al., 1996). When compared with backpack carrying, anterior carrying consumed 34% more oxygen (Malhotra and Gupta, 1965), and required more muscular effort in the contralateral muscles (Cook and Neumann,

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1987; Malhotra and Gupta, 1965). Other studies also reported a higher energy cost and a greater cardiovascular strain in hand carriage compared to torso carriage (Knapik et al., 2000; Lind and McNicol, 1968). A significant increase in anterior/posterior shear loading of the spine as compared with other methods of carrying has been reported as well (Rose et al., 2013). The primary disadvantage of anterior load carriage is presumably as a result of extra torque on the smaller groups of muscles of forearms and hands as well as the relatively large loads imposed on the low back muscles and the spine. Nevertheless, many occupations (e.g. military, emergency medical, moving and delivery) require anterior load carrying frequently. Besides, delivery workers tend to adopt this carrying mode over short distances for convenience.

To overcome the various issues, considerable research has focused on determining the transfer of some load from hands to shoulders and the hip (Knapik et al., 2000; Holewun and Lotens, 1992; Smallman et al., 2013). In this regard, Knapik et al. (2000) found that moving a stretcher load from the hands and placing that load on the shoulders and/or hip resulted in improved performance, reduced cardiorespiratory stress and improved the subjective ratings. Holewun and Lotens (1992) observed that when the load was carried primarily on the waist with a hip belt, there was less discomfort compared to shoulder load carriage. Smallman et al. (2013) also generated an on-body assistive device for professional movers in Canada, which could reduce perceived discomfort and flexor digitorum activity, with greater in-phase coordination between the trunk-pelvis. Unfortunately, that device was designed for carrying large objects, and it is too big for delivery workers on full-day shifts. Its effect on metabolic expenditure is unknown as well.

Most previous studies have focused on the physiological effects of backpack carriage and manual material handling that involves lifting, carrying, and lowering of large and heavy objects. There is limited understanding of the physiological responses of bimanual anterior load carriage of boxes that are frequently carried by delivery personnel. Even though previous studies have shown the disadvantages of hand carrying as compared to carrying objects close to the trunk (e.g. backpack) (Cook and Neumann, 1987; Knapik et al., 2000), the research related to physiological changes of transferring load from the hands to the waist is rather limited.

In view of the above, the research reported here is aimed at investigating an on-hip load carrying belt (HLCB) for two-handed anterior load carriage for delivery personnel. The basic needs of a HLCB ought to be lightweight, swift to load and unload, and easy to be used with a waist belt that most men wear. Physiological and subjective responses were measured to assess the effect of the HLCB when walking (Paul et al., 2015). It was hypothesized that the HLCB would reduce energy expenditure and reduce the discomfort of carrying loads.

2. Methods

2.1. Participants

Fifteen male college students aged from 18 to 30 years old voluntarily participated in this study (Table 1). The sample size was estimated based on the results of a pilot study. Their demographics were recorded prior to the experiment. Each participant completed an informed consent, and a health history questionnaire prior to testing. All participants reported being in good health and free of any musculoskeletal injuries or disorders. They all participated regularly in physical activities, but were not used to carrying loads on a regular basis. The study was approved by the ethics committee of the Hong Kong Institute of Education.

Table 1
Demographic data of the participants; values expressed as mean ± standard deviation (range).

Age (years)	Height (cm)	Mass (kg)	BMI (kg/m2)	HRrest (beats/min)
24.0 ± 3.2 (21–30)	174.2 ± 4.8 (169.2–183.0)	67.3 ± 5.4 (55.9–73.4)	22.3 ± 2.5 (17.4–24.7)	69.5 ± 6.7 (60–80)

Note: BMI = body mass index; HRrest = resting heart rate.

2.2. Configuration of the purpose-built belt

A prototype HLCB (Fig. 1) was designed to transfer load from the hands to the waist. It consisted of a modified lifting belt, a leather belly protector, and a support of size 10 × 14 cm. The belt and the belly protector were hand made of cowhide. The support was designed using Rhino for Mac (Rhino 5, Robert McNeel & Associates, USA) and 3D printed with ABS on a UP Plus 2 (PP2DP, USA). The total weight of the HLCB was 476 g and it could fit a person having a waist of 72–90 cm. Shoulder straps were not used in order to minimize weight and convenience.

2.3. The load

A standard cardboard box of size 36 × 30 × 25 cm used in the delivery industry (sf-express.com, SF Express, China) was used. Sand bags of weight 5 kg (low), 10 kg (medium), and 15 kg (heavy) weight (equivalent to about 7.5%, 15% and 22% of participants' body weight) comprised the load (Bhambhani et al., 1997). The sand bags were positioned in the box with foam of negligible weight, placed in all directions to ensure even distribution of the load. The participants were asked to wear the LCB, then grasp the load at the front bottom edge furthest from the body with both hands (Morrissey and Liou, 1984). The "back" bottom edge of the box was placed on the load support for the with-device (WD) condition of the experiment. In the without- or no-device (ND) condition, the LCB was also worn to make sure the total mass was the same, but the load support was moved to the back when carrying the load.

2.4. Experimental procedure

There were six sessions in total, including 5, 10 and 15 kg loads in WD as well as 5, 10 and 15 kg loads in ND. The experiment was conducted on two separate days. A balanced order experimental design was used in which eight participants began with WD first with the remaining seven participants being exposed to the WD condition in reverse order. The order of presentation of the three loaded conditions was based on a Latin square design. In each

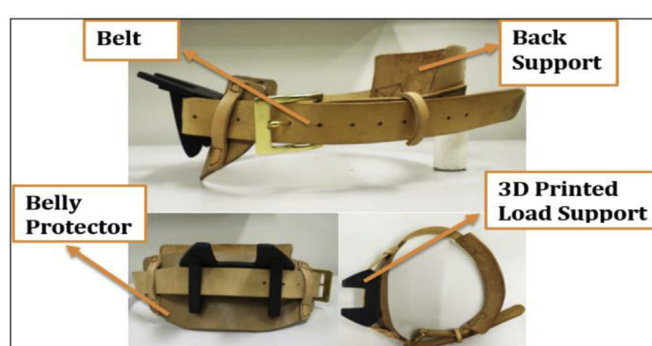

Fig. 1. Prototype of the hip load-carrying belt (HLCB); side view (top); front view (bottom left), top view (bottom right).