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Does load position affect gait and subjective responses of females during load carriage?

Katrina M. Simpson, Bridget J. Munro*, Julie R. Steele

Biomechanics Research Laboratory, University of Wollongong, New South Wales 2522, Australia

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ABSTRACT

Recreational hikers carry heavy loads while often walking long distances over uneven terrain. Previous studies have suggested that not only the load mass but also the position of the load may influence load carriage. The purpose of this study was to determine the effect of vertical load position on gait and subjective responses of female recreational hikers. Fifteen experienced female hikers walked for 2 km over a simulated hiking trail carrying 30% BW in three vertical load positions (high, medium and low). Lower limb and trunk kinematic, electromyography (EMG) and ground reaction force (GRF) data were collected together with heart rate (HR), ratings of perceived exertion (RPE) and discomfort measures. Although HR, RPE and discomfort measures were not able to discern statistical differences between load positions, the high load position was the most preferred by participants. The high load position also resulted in a more upright posture ($p < 0.001$), decreased gastrocnemius integrated EMG compared to the medium ($p = 0.005$) and low load positions ($p = 0.02$) and a higher first peak deceleration vertical GRF compared to the low load position ($p = 0.011$). However, the absolute differences were small and unlikely to be functionally relevant in load carriage studies. Based on the findings of this study, a high, medium or low load position cannot be preferentially recommended for healthy, experienced, female hikers carrying 30% BW.

1. Introduction

The backpack is a versatile and common form of manual load carriage often used by recreational hikers, school students and the military, and is possibly the most fundamental piece of equipment for those seeking an outdoor experience. Determining safe and efficient methods of load carriage has been the subject of investigation for many years with researchers examining physiological (Sagiv et al., 1994; Quesada et al., 2000; Abe et al., 2008), postural (Kinoshita, 1985; Attwells et al., 2006), gait (Harman et al., 2000; Birrell and Haslam 2009a; 2010) and subjective responses (Legg et al., 2003; Birrell and Haslam, 2009b; Lloyd et al., 2010). Not surprisingly, the most knowledge about load carriage comes from military-related studies (Knapik et al., 2004), the findings of which may not be applicable to other load carrying populations such as recreational hikers, who differ in age, gender, fitness, experience and loads carried (Bentley et al., 2004; Lobb, 2004) to military personnel.

Load carriage has been associated with an increased risk of musculoskeletal disorders in the back and upper and lower limbs in recreational hikers (Twombly and Schussman, 1995; Bentley et al., 2004) with females suffering significantly higher injury rates than males when participating in the same hiking activities in outdoor education (Twombly and Schussman 1995; Leemon and Schimelpfenig, 2003). Reducing backpack weight has been suggested as one prevention strategy to reduce hiking-related injury (McIntosh et al., 2007) with previous research recommending 30% body weight (BW) as the maximum load for healthy adult males (Haisman, 1988). Altering the position of the centre of mass (COM) of the load within the backpack is another strategy that has been suggested as a way of influencing energy expenditure, body mechanics and minimising the physical stress of load carriage (Stuempfle et al., 2004).

Although there is a general recommendation for a high positioning of the load (Stuempfle et al., 2004), the effect of changing the vertical position of load has received limited attention and the results of available studies are inconsistent. For example, Stuempfle et al. (2004), Obusek et al. (1997) and Bobet and Norman (1984) found that metabolic, cardiorespiratory and subjective variables, together with muscle activity of the erector spinae and trapezius, were lowest when load was placed in a high position (approximately level with thoracic vertebrae 1–6). In contrast, Johnson et al. (2000) found no significant differences in oxygen consumption

* Corresponding author. Tel.: +61 2 4221 5140; fax: +61 2 4221 5945.
E-mail address: bmunro@uow.edu.au (B.J. Munro).

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with three load positions (high, medium and low) and Devroey et al. (2007) found no significant differences in heart rate or erector spinae, trapezius or rectus abdominis muscle activity between loads concentrated at a lumbar compared to a thoracic-level position. Results of these studies have been difficult to interpret, however, given differences in subject populations (e.g., male military populations or inexperienced hikers), the use of differing absolute and relative load mass, type of backpack, variations in load positioning, and having subjects walk at a fixed or self-selected speed. Irrespective of these study variations, both high and low load positions have been found to induce forward flexion of the trunk, with greater flexion found when the load is placed in a low compared to a high position (Bloom and Woodhull-McNeal, 1987; Harman et al., 1999; Johnson et al., 2000; Devroey et al., 2007). This increased trunk flexion together with possible increased muscle activity (Bobet and Norman, 1984; Obusek et al., 1997; Stuempfle et al., 2004) may place the load carrier at increased risk of low back pain due to the increased lumbosacral forces on the spine (Goh et al., 1998), as well as increased discomfort, particularly in the neck, shoulders and lower back. In fact, Johnson et al. (2000) found that their male subjects ranked a low load position with the poorest overall acceptability, due mainly to the increased forward trunk flexion resulting in neck and back soreness.

Interestingly, although load placed in a high position is associated with a more upright posture, it has been suggested that loads in high positions tend to destabilise an individual while standing and walking to a greater extent than a low load position (Hellebrandt et al., 1944; Harman et al., 1999). As evidence of the increased need for stability during gait, Harman et al. (1999) found increased double support when their female subjects carried a backpack (73% BW) that had a higher COM than one with a lower COM. Consequently, it has been suggested that a low or mid load position might be preferable to maintain walking stability on uneven terrain (Knapik et al., 2004). However, other studies investigating male soldiers carrying loads of 36 kg (Johnson et al., 2000) and 15% BW (Devroey et al., 2007) have not found any differences in spatio-temporal parameters when subjects carried a load in a low and high position. Therefore, due to the conflicting results in the related literature, possibly as a consequence of the different loads, positions, subject samples and parameters being investigated, it is unclear how load position affects the biomechanical variables characterising gait in recreational hikers, particularly female recreational hikers who are estimated to comprise 50% of recreational hikers in Australia (Australian Sports Commission, 2007). Therefore, the purpose of this investigation was to determine whether vertical load position (high, medium or low) affected the biomechanics of gait and subjective responses of female recreational hikers when carrying the recommended load of 30% BW. The findings of this study will be used to develop recommendations on how to position load during load carriage for this population.

2. Methods

2.1. Participants

Fifteen healthy, active females (mean age = 21.6 ± 2.8 years; height = 1.65 ± 0.05 m; mass = 62.3 ± 6.9 kg) volunteered to participate in the study. Participants were recruited from recreational hikers within the general student population at the University of Wollongong, Australia. To be eligible to participate in the study, the participants had to be free from any substantial musculoskeletal or neurological disorders that could affect their gait, have completed one overnight hike in the past 12 months and have experience carrying a backpack with loads of 20–30% BW. Information relating to each participant's health status and physical activity were obtained through a screening questionnaire that comprised questions from the American Sports Medicine pre-exercise screening guidelines (American College of Sports Medicine, 1997) and the Physical Activity Rating (PA-R) Scale (Jackson et al., 1990). The experimental protocol was approved by the University of Wollongong Human Research Ethics Committee (HE05/016) and all participants gave written informed consent prior to data collection.

2.2. Experimental protocol

During testing, participants were required to walk 2 km at a self-selected speed carrying 30% BW in a backpack under three randomly allocated load position conditions: high, medium and low. Following familiarisation with the load carriage course, backpack, equipment and testing protocols, each participant was then prepared for electromyography (EMG) and kinematic data collection.

The load carriage course consisted of 5 sets of 10 × 40 m figure-of-8 circuits (400 m). After completing each 400 m circuit, participants walked over a simulated hiking trail (50 m), typical of what may be encountered during hiking. The simulated hiking trail included four obstacles resembling those commonly found on rough terrain, such as low step-over logs, stepping stones and a single log bridge (see Fig. 1). Participants then completed 10 × 20 m circuits (200 m), where they walked along a 9 m level walkway and across a force platform positioned in the centre of the walkway while kinematic, ground reaction force (GRF) and EMG data were collected. Consequently, each participant walked 2 km and 10 trials of data were collected at the end of the load carriage course. Participants completed all conditions, as well as a baseline trial (0% BW), which was used to normalise the EMG data, in a single testing session, with sufficient rest between each condition to minimise fatigue. Participants wore their own shoes and shorts.

2.3. Backpack load position

Participants carried a modified Alpamayo ND Crossbow backpack (60 L; 3.2 kg; Lowe Alpine, UK), fitted according to the manufacturer's instructions with the shoulder and hip belt tightened to participant comfort. Within the backpack a metal tray was attached to the metal stays of the backpack and was loaded with 30% of the participant's BW (mean backpack mass = 18.6 ± 2.1 kg) using lead weights. The weights were bound together and secured to the metal tray with tape. This allowed for alteration of the COM of the load in the backpack to be placed in a low load position (aligned with lumbar vertebrae 1–5), high load position (thoracic vertebrae 1–6) and medium load position (thoracic vertebrae 7–12) with 22 cm between each load position and the COM of the backpack a consistent distance from the spine. The buckle to strap distances measured for the shoulder straps, chest strap and hip belt remained the same to ensure consistency in backpack fit between conditions.

2.4. Ground reaction forces

Ground reaction force signals were collected for 4 s at 1000 Hz in synchronisation with the kinematic and EMG data using a Kistler Multichannel force platform (Type 9253A, Kistler Instruments AG Winterthur, Switzerland) embedded flush with the laboratory floor, in conjunction with a OPTO***TRAK*** 3020 motion analysis system (Northern Digital Inc., Ontario, Canada). The raw data from the eight output channels of the force platform were collected using NDI ToolBench software (Version 1.1; Northern Digital, Canada) and