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The effect of load distribution within military load carriage systems on the kinetics of human gait

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ABSTRACT

Military personnel carry their equipment in load carriage systems (LCS) which consists of webbing and a Bergen (aka backpack). In scientific terms it is most efficient to carry load as close to the body's centre of mass (CoM) as possible, this has been shown extensively with physiological studies. However, less is known regarding the kinetic effects of load distribution. Twelve experienced load carriers carried four different loads (8, 16, 24 and 32 kg) in three LCS (backpack, standard and AirMesh). The three LCS represented a gradual shift to a more even load distribution around the CoM. Results from the study suggest that shifting the CoM posteriorly by carrying load solely in a backpack significantly reduced the force produced at toe-off, whilst also decreasing stance time at the heavier loads. Conversely, distributing load evenly on the trunk significantly decreased the maximum braking force by 10%. No other interactions between LCS and kinetic parameters were observed. Despite this important findings were established, in particular the effect of heavy load carriage on maximum braking force. Although the total load carried is the major cause of changes to gait patterns, the scientific testing of, and development of, future LCS can modify these risks.

1. Introduction

The effect that military load carriage has on ground reaction force (GRF) parameters has been examined previously in the literature (Birrell et al., 2007; Harman et al., 2000; Kinoshita, 1985; Lloyd and Cooke, 2000a; Polcyn et al., 2002; Tilbury-Davis and Hooper, 1999). However, less attention has been paid to the distribution of load on the body, particularly with respects to the biomechanical changes of gait. It has long been suggested that the most efficient way to load the body is by keeping it as close as possible to the body's CoM, while also utilising the larger muscle groups (Legg and Mahanty, 1985). However, due to various ergonomic reasons the backpack is the only really viable option for members of the military to carry their own equipment. Research has shown that placing load closer to the body's CoM results in a reduction in energy cost (Abe et al., 2008; Coombes and Kingswell, 2005; Datta and Ramanathan, 1971; Lloyd and Cooke, 2000b), with a more upright walking posture being adopted (Kinoshita, 1985; Harman et al., 1994). In terms of the kinetic effects a reduced maximum braking force and stance time, while increasing force minimum are reported outcomes as a result of distributing load around the trunk (see references below). The actual implications that these changes to basal gait patterns have to injury or energy cost is relatively unknown. However, we can postulate that a decrease in maximum braking forces may have a positive effect on blister development, due a reduction in the sheering forces applied to the foot–boot interface when walking. In addition, sports research has shown that a reduction in horizontal braking forces can facilitate the forward advancement of the body during running (c.f. Ciacci et al., 2009), this principle may also relate to long distance marches with heavy loads in military situations. High magnitudes or volumes of impact forces (or force produced at heel strike), like those experienced during load carriage or running, are a major risk factor for overuse injuries. In particular, stress fractures of the tibia and metatarsals and knee joint problems (Cavanagh and Lafortune, 1980; Polcyn et al., 2002). A reduction in either of these two parameters would have clearer implications on injury as a result of load distribution.

To the author's knowledge only five studies have investigated some aspects of load distribution on GRF parameters, including just three papers in peer-reviewed journal (Kinoshita, 1985; Lloyd and Cooke, 2000a; Hsiang and Chang, 2002), one military report (Harman et al., 2001) and one conference paper (Koulmann, 2006). These available studies have generally been restricted to between

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4 and 6 load and carrying system combinations, with limited mechanisms put forward for the observed changes. The aim of this study is to build on and develop this current knowledge by investigating the effect that different distributions of carried load had on kinetic (specifically GRFs) parameters of human gait. This current study will use an increased number of load and backpack combinations (four different loads and three different backpack systems), and also military specific load carrying systems, while offering links to previous research to develop the implications of these changes to basal gait patterns.

2. Methodology

2.1. Participants and equipment

Twelve male participants volunteered for the study (mass 81.3 kg ± 9.9 S.D., height 184.4 cm ± 6.2, age 29.2years ± 9.0). All participants volunteering for the study had previous experience carrying military style backpacks, all were right foot dominant and rear-foot strikers. A verbal and written explanation of the study was given, after which a health screen questionnaire was completed. Finally signed, informed consent was obtained from all participants before commencing the trial.

Kinetic data were collected when participants walked over a Kistler force plate (Type 9286A; Kistler Group, Winterthur, Switzerland) in conjunction with a Coda Mpx30 motion analysis system (Charnwood Dynamics Ltd, Rothley, Leics, UK), with data sampled at 400 Hz. The force plate was embedded flush in an 8.4 m walkway, situated halfway along the walkway and slightly off centre. This gave adequate distance before and after the force plate to achieve a natural gait pattern. The target walking speed throughout was 1.5 m s^{-1} (±5%), and measured using three pairs of infra-red photoelectric cells (Brower SpeedTrap II; Brower Timing Systems, Draper, Utah, USA). One set recorded speed on approach to the force plate and the other speed after the force plate. Both speeds had to be within the desired range, thus limiting the potential for acceleration or deceleration that would affect the GRF produced. To assess the differences caused by altering the load distribution three military load carriage systems (LCS) were adopted (Fig. 1), and 4 different loads were carried 8, 16, 24 and 32 kg, these are absolute loads and not dependent on participants body mass. In addition to the load, a weighted replica SA80 assault rifle was carried in all testing conditions. The rifle condition also formed the control, or baseline, for the study. It was deemed essential for a rifle to be carried during this study as military personnel will almost always carry a rifle with loads when on training and operations. Also, rifle carriage has been shown to change basal gait parameters, reflected by changes to ground reaction force parameters (Birrell and Haslam, 2008).

The three LCS used for this study were:

1. Backpack LCS – Load solely carried in the '90 Pattern short back Bergen.
2. Standard LCS – This utilised the standard issue UK '90 Pattern Short back Bergen and PLCE waist webbing.
3. AirMesh LCS – This consisted of AirMesh Prototype III Bergen and PLCE vest webbing.

2.2. Protocol

Each participant completed 13 experimental conditions (Table 1), with the order in which the participants completed the conditions fully randomised. Ten successful trials were required for each condition. A trial was deemed successful if the speed was attained,

Fig. 1. Backpack, Standard and AirMesh LCS (left to right respectively, top and bottom). Top three images show LCS setup when 8 or 16 kg were carried, bottom three images when 24 or 32 kg were carried.