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The influence of gait cadence on the ground reaction forces and plantar pressures during load carriage of young adults

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ABSTRACT

Biomechanical gait parameters—ground reaction forces (GRFs) and plantar pressures—during load carriage of young adults were compared at a low gait cadence and a high gait cadence. Differences between load carriage and normal walking during both gait cadences were also assessed. A force plate and an in-shoe plantar pressure system were used to assess 60 adults while they were walking either normally (unloaded condition) or wearing a backpack (loaded condition) at low (70 steps per minute) and high gait cadences (120 steps per minute). GRF and plantar pressure peaks were scaled to body weight (or body weight plus backpack weight). With medium to high effect sizes we found greater anterior-posterior and vertical GRFs and greater plantar pressure peaks in the rearfoot, forefoot and hallux when the participants walked carrying a backpack at high gait cadences compared to walking at low gait cadences. Differences between loaded and unloaded conditions in both gait cadences were also observed.

1. Introduction

Standing or walking with backpacks shifts posterior and superiorly the combined centre of mass of the system backpack and backpacker, inducing postural imbalance for static and dynamic conditions (Singh and Koh, 2009). When wearing a backpack there is an increase in the load carried by the musculoskeletal system, which may lead to adaptation in postures and forces acting on the human body. Many studies indicated that load carriage changed the kinematics (Attwells et al., 2006; Birrell and Haslam, 2010; Birrell et al., 2007; Cobb and Claremont, 1995; Majumdar et al., 2010), ground reaction forces (GRFs) (Birrell and Haslam, 2010; Birrell et al., 2007; Castro et al., 2013, 2014a; Cobb and Claremont, 1995; Simpson et al., 2012), and plantar pressures (Castro et al., 2013, 2014b) of walking. These biomechanical changes caused by load carriage might contribute to the high levels of back pain (Grimmer and Williams, 2000; Skaggs et al., 2006), muscle discomfort (Johnson et al., 1995), joint problems (Birrell and Haslam, 2009), metatarsal stress fractures (Hodge et al., 1999), metatarsalgia (Knapik et al., 1992; Pau et al., 2011), and foot blisters (Knapik et al., 1996) observed in people wearing backpacks.

Changing gait speed or cadence—the relationship between cadence and speed during walking tends to be linear (Perry, 1992)—influences many biomechanical gait parameters during "normal" walking (without a backpack). At higher gait speeds, the vertical and anterior-posterior GRFs (Chiu and Wang, 2007; Chung and Wang, 2010; Goble et al., 2003), and the plantar pressure peaks in the heel and medial forefoot were higher, whereas in the midfoot and lateral forefoot they were lower (Rosenbaum et al., 1994) compared to slower gait speeds. Previous studies observed changes in gait stability (Hsiang and Chang, 2002), and in spatial-temporal gait parameters (Charteris, 1998) as a consequence of changing gait speed during load carriage. However, it is unclear the influence of gait speed on kinetic gait parameters, such as shear and vertical forces and plantar pressures, during load carriage.

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The GRFs and plantar pressure approaches are insightful techniques for assessing gait biomechanics. The vertical GRF provide information about mechanical stress (Piscoya et al., 2005). This measure might be related to joint contact forces, which appear to play an important role in the development of pathological conditions such as low back pain and osteoarthritis (Piscoya et al., 2005). The anterior-posterior GRF is the main component that indicates shear stress (Chang et al., 2011). This force provides insights into the friction between the foot and shoe or shoe and ground, and their increase might be linked to the development of foot-related injuries such as foot blisters (Knapik et al., 1992), and tendency to slip (Chang et al., 2011). Both of the mentioned GRF components inform about the overall forces acting on the human body. However, the GRFs do not provide any information about where the forces are being applied on the foot (Castro et al., 2014c). In-shoe plantar pressure systems allow quantification of the amount of vertical GRF being applied on each region of the plantar surface, providing information about foot structure and function (Cavanagh and Ulbrecht, 1994). Positive correlation between plantar pressure peaks and pain ratings have been previously found (Hodge et al., 1999). Finally, to achieve a more detailed and comprehensive picture of the forces acting on the musculoskeletal system, combining the GRFs and plantar pressure analyses appears to be relevant.

Students, hikers and soldiers often change their gait cadence while they are walking, or, depending on their aims, adopt a low or high gait cadence during activity. The knowledge of the loads imposed to the musculoskeletal system caused by alterations in gait cadence may help in developing accessories (e.g. shoes and insoles) more suitable for specific gait conditions (walking with or without a backpack, at a low or high gait cadence), as well as to identify plantar foot areas more susceptible to damage, with the purpose of making the activity safer and more comfortable and preventing injuries. Therefore, the aim of this study was to compare biomechanical gait parameters—GRFs and plantar pressures—during load carriage of young adults at a low gait cadence and a high gait cadence. We also assessed differences on these biomechanical gait parameters between load carriage and normal walking during both gait cadences. We hypothesised that during load carriage at the high gait cadence higher GRFs and plantar pressures will be found compared to the low gait cadence. We also hypothesised that differences in GRFs and plantar pressures will be observed between load carriage and normal walking (values scaled to body weight plus backpack weight for the load carriage condition, and scaled to body weight for the normal walking condition) in both gait cadences.

2. Methods

2.1. Participants

All participants were physically active and their body mass indexes (BMIs) were between 18 and 25 kg/m^2. They were excluded if they presented any traumatic-orthopaedic dysfunction or difficulties on independent walking. Sixty participants (30 males and 30 females) with age of 22.8 ± 3.8 years old, weight of 65.5 ± 9.8 kg, height of 168.8 ± 8.8 cm, and BMI of 22.8 ± 1.7 kg/m^2 were enrolled in this investigation. This experimental repeated-measures study was approved by the local ethical committee and all participants freely signed an informed consent term, based on Helsinki's declaration, which explained the purpose and the procedures of the study.

2.2. Apparatus

To record the GRFs, we used a Bertec force plate model 4060-15 (Bertec Corporation, Columbus, USA), operating at 1000 Hz. To assess the plantar pressure distribution, we used an F-Scan insole pressure system (TekScan, South Boston, USA), operating at 300 Hz with about 960 pressure cells (depending on the foot size) and a 0.18 mm thick insole sensor. We used a metronome (Wittner Maelzel Metronome, Germany) to control gait cadence, and walking speed was measured by videogrammetry using three digital video camera recorders. An external trigger was developed to synchronise the force plate, in-shoe plantar pressure system, and video by starting them simultaneously.

2.3. Tasks and procedures

The participants underwent three phases at the lab: preparation, familiarisation and test. In the first phase, the study procedures were explained to the participants, and their weight and height were recorded using the force plate and a stadiometer (Seca, Birmingham, United Kingdom), respectively. For each participant, the external weight required to raise their total weight (body weight plus backpack weight) to a "loaded BMI" of 30 kg/m^2 was calculated (Castro et al., 2013). Then a backpack was filled with sand and fixed at the central area of each participant's back (Fig. 1). The participants were allowed adjusting the position of the backpack to make it the most similar with the position they usually used. We selected this backpack model as it was the most used among the participants in preliminary studies performed by our research group. There is no well-established recommendation of backpack's weight limit for young adult population based on biomechanical parameters. Obesity (BMI > 30) is associated with elevated risk of both degenerative and inflammatory musculoskeletal conditions (King et al., 2013). Thus, even recognizing differences in weight distribution between obese people and subjects using a backpack, we used the total amount of mechanical load found in obese individuals as criterion in order to assess the human locomotor system during a challenging condition. So, the weight placed inside the backpack was 20.3 ± 4.4 kg, allowing an "artificial" BMI of 30 for each subject.

A cuff unit measuring 98 × 64 × 29 mm was attached with Velcro straps up the lateral malleolus region of both legs of the participants and a 9.25 mm cable linked the cuff to the VersaTek hub (F-Scan system), which was beside the walkway connected to a computer; the cable did not cause any restriction for walking

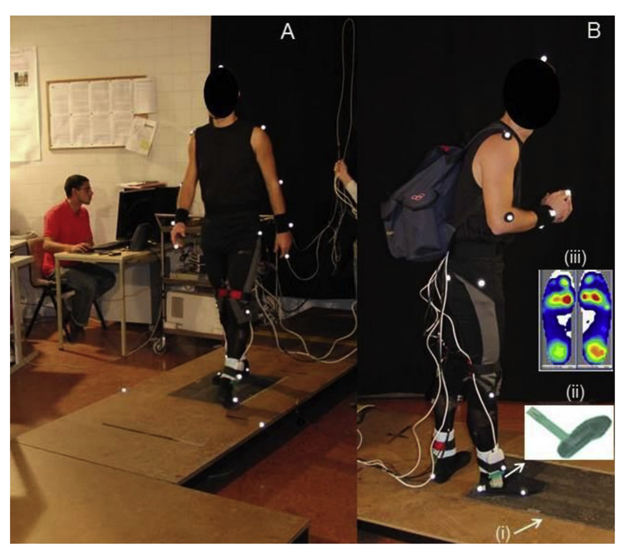

Fig. 1. Experimental setup (A); and participant setup (B). Force plate (i), sensor insole (ii) and plantar pressure data from one trial (iii).