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Effects of backpack load on stair gait in young male adults

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ABSTRACT

Backpack load has been found to be a potential risk factor for accidental falls during level walking. Stairs are considered one of the most hazardous locations in occupational settings, and falls often occur on stairs. However, how backpack load affects stair gait in young adults was still unknown. The objective of the present study was to reveal the effects of backpack load on stair gait in young male adults. Thirty male adults participated, and completed three ascent and three descent trials in the no load, low load, and high load conditions, respectively. Four categories of dependent measures were used to characterise stair gait, including lower limb and trunk kinematics, foot clearance measures, spatial-temporal gait parameters, and postural stability measures. We found that participants adjusted their postural control to compensate for the disturbance caused by backpack load and maintain their postural stability as in the no load condition. However, loaded participants may encounter increased risk of stair contact during ascent and increased risk of over-stepping during descent when passing over a step. These findings support that backpack load could be a risk factor for stair falls and imply that loaded people should pay more attention to the step when passing over it.

Relevance to industry: Findings from this study could aid in developing instructions for safe stair negotiation in occupational settings.

1. Introduction

Backpack carriage is one of the most common load transfer approaches in military and occupational activities. Backpack load has been found to have adverse effects on an individual's physical performance in a variety of tasks, such as vertical jumping and mobility tasks (Holewun and Lotens, 1992). It could also induce additional muscular tensions, and thus be associated with many medical problems, such as low-back injuries and knee pain (Chow et al., 2014; Lobb, 2004). Due to this, backpack load has recently attracted much attention from researchers in the field of human factors and ergonomics.

Load transfer is always accompanied by locomotion. Gait (walking) is about the most common locomotion activity. Hence, recent relevant research has focused on the assessment of the effects of backpack load on gait characteristics (Majumdar et al., 2010; Mullins et al., 2015; Rice et al., 2017). Majumdar et al. (2010), for example, reported that additional 11.2 kg military load led to an increase of 2.9 cm in step length and 3.1 steps/min in cadence. We have completed some experiments to investigate the relationship between backpack load and level-walking gait. In particular, we found that the application of backpack load could result in increased step width variability (Qu and Yeo, 2011) and decreased local dynamic stability (Qu, 2013). As fall accidents often result from loss of postural stability, these findings provided empirical evidence that backpack load was a potential risk factor for accidental falls.

Compared to level walking, stair walking is a more physically demanding locomotion task. In fact, stairs are suggested to be one of the most hazardous locations in the workplace and at home (Cayless, 2001). Researchers often used lower-limb kinematics and kinetics to assess postural control during stair walking. Larger lower-limb joint range of motion and joint moments were generally reported in stair walking versus level walking (Costigan et al., 2002; Nadeau et al., 2003). However, few existing studies reported the effects of backpack load on stair gait. Hong and Li (2005) examined the effects of backpack load on school children's stair gait phases. They found that backpack load of 15% of body weight induced significant increased double stance duration during both ascent and descent. Later, Hong et al. (2011) reported that backpack load did not affect spinal posture during stair negotiation. Song et al. (2014) compared gait patterns of stair descent between lean and obese male children with backpack load. They oberved that backpack load resulted in larger trunk and head forward inclination angle, and longer gait cycle and stance duration in obese children versus their lean counterparts. A common limitation with the above-mentioned studies is that their target population was school children. Backpack load is often seen in recreational, occupational, and

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military activities as well. Therefore, there also exists a need to know how backpack load affects stair gait in young adults.

The objective of the present study was to reveal the effects of backpack load on stair gait in young male adults. Four categories of dependent measures were used to characterise stair gait, including lower limb and trunk kinematics, foot clearance measures, spatial-temporal gait parameters, and postural stability measures. According to the findings from the existing relevent studies (e.g., Hong and Li, 2005; Qu, 2013), we hypothesized that backpack load would increase flexion in the lower-limb joints at foot contact, decrease foot clearance, increase double support duration and gait cycle duration, and decrease postural stability during both stair ascent and descent.

2. Methods

2.1. Participants

Thirty healthy young male adults volunteered to participate in this study, with mean (S.D.) age = 24.2 (1.5) years, height = 175.1 (6.0) cm, and body weight = 69.0 (6.4) kg. They all self-reported to have no musculoskeletal injuries in the past 12 months. We planned to measure lower-limb kinematics from the dominant side, as foot dominance was considered as a potential confounding factor. In order to determine participants' foot dominance, participants were asked to self-report which foot they prefer using to kick a soccer ball. This research was approved by the local ethics committee. Informed consent was obtained from each participant.

2.2. Apparatus

A five-step staircase without handrail (tread 30 cm, width 80 cm, riser 15 cm) was used for stair negotiation in the experiment. Body kinematic data during stair negotiation were collected by an eight-camera motion capture system (Motion Analysis Eagle System, CA, USA) at the sampling rate of 100Hz. The raw kinematic data were filtered using a second order Butterworth filter with the cut-off frequency at 6Hz.

2.3. Experimental protocol

The experiment was completed in one session. At the beginning, participants were asked to wear tight-fitting suit and standard footwear for the convenience of reflective marker attachment. To collect the whole-body kinematics, 26 reflective markers were placed bilaterally on the selected anatomical landmarks of the body (Fig. 1). The human body can be modeled as a 12-segment model by this marker placement scheme. The 12 segments include the head, trunk, upper arms, lower arms, thighs, shanks, and feet. Subsequently, participants were instructed to practice stair negotiation with the examined backpack load in the laboratory where the experiment was carried out. The practice lasted around two minutes. During practice, the appropriate start points for ascent and descent for each participant were determined so that the first stair edge could be cleared by the non-dominant foot of the participant at a self-selected comfortable speed.

There were three backpack load conditions corresponding to the no load, 10% body weight (i.e., low load), and 20% body weight (i.e., high load). The additional loads were symmetrically located at the bottom of the backpack in the loaded conditions, and the backpack straps were adjusted by each participant at the self-selected comfortable length. In each backpack load condition, participants completed three stair ascent trials and three stair descent trials. One ascent trial and one descent trial were carried out continuously without a break between them. Upon completion of one ascent trial and one descent trial, participants were unloaded and took a 3-minute break to minimize confounding fatigue effects. The three backpack load conditions were presented in a random order across participants in order to minimize order effects. The stair negotiation protocol was similar with that in Qu (2015). In particular, participants walked from the predetermined start point around two meters away from the staircase on the ground level, and then ascended to the top of the staircase by placing one foot on each step. Once reaching the top platform, participants continued to walk to the pre-determined start point for descent (around two meters away from the first step), turned around, walked to the first step down, and then descended to the ground in a step-over manner and stopped at the start point on the ground. Fig. 2 illustrates a participants climbing the staircase with a backpack in the experiment.

2.4. Dependent measures

Stair gait was characterized by lower-limb and trunk kinematic measures, foot clearance measures, spatial-temporal gait parameters, and postural stability measures. These measures were calculated using the kinematic data from a complete stair gait cycle. We were more interested in steady-state stair gait. The gait patterns in the mid-stair portion of stair negotiation should be in a more steady state compared to those in the floor-to-stair and stair-to-floor transition. Thus, the selected stair gait cycle during ascent started from the dominant foot contact on the second stair step (i.e. 0% of gait cycle) and ended at the dominant foot contact on the fourth stair step (i.e. 100% of gait cycle). During descent, the stair gait cycle was defined by the moments of dominant foot contact on the second stair step down (i.e. 0% of gait cycle) and dominant foot contact on the fourth stair step down (i.e. 100% of gait cycle).

2.4.1. Lower-limb and trunk kinematics

Lower-limb kinematics were measured on the dominant side (i.e., the right side for each participant). Lower-limb joint angles were defined in the sagittal plane using a two-dimensional rigid linkage model (Fig. 3). In this linkage model, the joint centers were defined as the midpoints of the corresponding bilateral joint markers (Table 1). The reference angle (0°) for each joint was defined at the standard anatomical position. Positive angles indicate ankle dorsiflexion, knee flexion, and hip flexion, respectively.

Lower-limb joint measures were determined at four important gait events, including dominant foot contact, non-dominant foot release, non-dominant foot contact, and dominant foot release (Fig. 4). These four gait events correspond to the boundaries of the key stair gait phases defined by McFadyen and Winter (1988). Foot contact and foot release were determined using an approach similar to Foster et al. (2014). In particular, for stair ascent, foot contact was defined as the instant of local minima in the corresponding toe marker vertical velocity, and foot release was the time when vertical displacement between the corresponding toe marker and the mid-point of the right and left ASIS markers reached local maxima. For stair descent, foot contact was determined by local minima of the center of mass (COM) vertical velocity, and foot release was the time of local maxima in the knee flexion of the corresponding limb. The COM displacement was computed as the weighted sum of each body segment's center-of-mass from the 12-segment model. Body segments' center-of-mass locations were determined by the corresponding joint kinematic data collected from the motion capture system and the parameters provided by de Leva (1996). The velocities of the toe and COM were determined as the derivatives of the corresponding displacement data using the finite difference method.

Besides lower-limb joint measures, trunk tilt angles were also calculated (Novak et al., 2016). Trunk tilt angles were determined by the midpoints of the hip joint centers and the midpoints of the shoulder markers with respect to the standard anatomical position in the sagittal and frontal plane, respectively. Trunk tilt angles were measured at the moments of non-dominant foot release and non-dominant foot contact. These two gait events correspond to initiation of the single-stance and double stance phases, respectively. Note that trunk orientation was not assessed at dominant foot release and dominant foot contact. This is