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Carrying asymmetric loads during stair negotiation

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ABSTRACT

Individuals often carry items in one hand instead of both hands during activities of daily living. The combined effects of carrying asymmetric loads and stair negotiation may create even higher demands on the low back and lower extremity. The purpose of this study was to investigate the effect of symmetric and asymmetric loading conditions on L5/S1 and lower extremity moments during stair negotiation. Twenty-two college students performed stair ascent and stair descent on a three-step staircase (step height 18.5 cm, tread depth 29.5 cm) at preferred pace under five load conditions: no load, 10% body weight (BW) unilateral load, 20% BW unilateral load, 10% BW bilateral load, and 20% BW bilateral load. Video cameras and force platforms were used to collect kinematic and kinetic data. Inverse dynamics was used to calculate frontal plane moments for the L5/S1 and lower extremity. A 20% BW unilateral load resulted in significantly higher peak L5/S1 lateral bending, hip abduction, and external knee varus moments than nearly all other loading conditions during stair ascent and stair descent. Therefore, we suggest potential benefits when carrying symmetrical loads as compared to an asymmetric load in order to decrease the frontal joint moments, particularly at 20% BW load.

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1. Introduction

Individuals often carry items in one hand instead of both hands during activities of daily living such as walking and stair negotiation. Holding an object with one hand is frequently utilized when the carried object has a handle or to allow the opposite hand to be free for other activities. Previous studies have shown that level walking while carrying asymmetric loads with one strap backpacks or mailbags resulted in higher trunk lateral bending [1,2], higher trunk forward lean [2], and higher levels of perceived low back pain [3] than unloaded walking. In addition, studies have shown that walking while carrying asymmetric loads in a bag or sidepack resulted in higher hip abduction moments [4,5] and higher L5/S1 bending moments [5] than unloaded walking. These studies provide evidence that asymmetric load carriage during walking increases frontal plane loading in both the low back and lower extremity. Therefore, it is important that further research is conducted to investigate the effect of asymmetric load carriage on the low back and lower extremity in an effort to reduce the potential for injury.

Stair negotiation is an activity of daily living that commonly involves load carriage. Previous studies have reported that unloaded stair ascent and descent required higher ankle dorsiflexion angles [6], knee flexion angles [6,7], and knee extension moments [6,7] as compared to level walking. Hall et al. found that carrying symmetric loads of 13.6 kg (approximately 20% body weight) in a container in front of the body or in a backpack resulted in higher external knee varus moments than when carrying no load [8]. Furthermore, stair ascent resulted in higher external knee varus moments than walking or stair descent across loading conditions. These findings indicate that stair negotiation involves higher knee extension moments than walking [6,7] and that load carriage during stair ascent may also result in higher external knee varus moments [6–8].

The effects of asymmetrical load carriage during stair negotiation remain largely unknown, as previous asymmetrical load carriage studies have primarily focused on level walking or lifting tasks. Hong and Li found that carrying asymmetric loads in a one-strap athletic bag resulted in higher normalized vertical ground reaction forces at 10% of body weight for stair ascent and at 15% of body weight for stair descent as compared to no load [9]. These results indicate that load amount likely plays an important role in asymmetric load carriage during stair negotiation. However, few studies have been done to investigate adaptive joint mechanisms in the lower extremity and low back when carrying asymmetric loads during stair negotiation. Thus, there is a need for additional joint moment data that may provide insight for

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potential risk and development of lower extremity injuries and low back disorders.

This purpose of this study was to assess low back and lower extremity moments when carrying symmetric loads and asymmetric loads at several load amounts during stair ascent and stair descent. We hypothesized that 1) peak L5/S1 lateral bending moments would be significantly higher during unilateral load carriage when compared to bilateral load carriage and 2) peak hip abduction and external knee varus moments would be significantly higher during unilateral load carriage when compared to bilateral load carriage. Increases of these parameters may be associated with potential concerns of intervertebral disc strain and/or degeneration [10] and development of knee and hip osteoarthritis [11,12].

2. Methods

Twenty-two healthy young adults with an age range of 20–36 (11 males and 11 females; age 24.2 ± 4.3 years; height 170.8 ± 7.7 cm; mass 67.8 ± 13.8 kg) participated in this study. Participants were free of any pathology that would prevent them from being able to carry a 20% body weight load. Individuals were excluded if they had back, neck, leg, foot, or arm pain. Prior to participating in the study, each subject read and signed an informed consent form approved by the university's institutional review board.

Five load conditions were tested: no load, 10% body weight (BW) bilateral load, 20% BW bilateral load, 10% BW unilateral load, and 20% BW unilateral load (Fig. 1). Loads were evenly split between the right and left hands during the bilateral load conditions. Hand-held bags were filled with sealed bags of lead shot to match the four loaded conditions. The unilateral load was carried in the participant's dominant hand. Since all participants were right-handed, they carried the hand-held bag in the right hand during the unilateral load condition. The weight carried in the bags was normalized according to each subject's body weight. These normalized loads were based on previous studies that indicated significant kinematic and/or kinetic changes when carrying loads ranging from 10% to 20% BW [2,5,8,13]. Participants were instructed to ascend and descend a three-step staircase (step height 18.5 cm, tread depth 29.5 cm) at a preferred pace for each condition. The order of the conditions was randomized, and each condition was repeated three times. Participants were instructed to initiate stair negotiation by using the left leg on the first step and then the right leg on the second step.

A motion analysis system with 8 high-resolution cameras (Vicon Nexus, Los Angeles, CA) was used to collect three-dimensional kinematic data during each testing condition. The dynamic marker set included bilateral great toe, lateral mid-foot, lateral malleolus, anterior calf, lateral calf, lateral knee joint line, anterior thigh, lateral thigh, greater trochanter, anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), and acromion process markers. Single sacrum and cervical markers were also included. Six additional markers (bilateral heel, medial malleolus, and medial knee joint line markers) were recreated using transformations determined from a static standing trial. Portable force platforms (AMTI, Watertown, MA) on steps one and two were used to collect ground reaction force data.

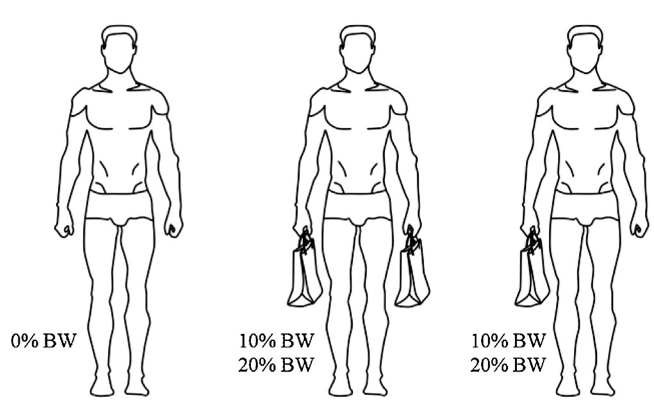

Fig. 1. Illustration of the five load conditions. No load (left), 10% body weight (BW) bilateral load (center), 20% BW bilateral load (center), 10% BW unilateral load (right), and 20% BW unilateral load (right).

Kinematic data were captured at 160 Hz, and noise was reduced with a fourth-order, low-pass Butterworth filter at a cutoff frequency of 6 Hz. A static trial was used to estimate joint center locations which were assumed to be stationary in the segmental coordinate systems. Kinetic data was sampled at 1600 Hz and filtered at a cutoff frequency of 6 Hz. The force data were downsampled so that kinetic and kinematic data both had corresponding data points. Segment masses, center of mass locations, and moments of inertia were obtained according to De Leva's anthropometric model [14]. L5/S1 lateral bending moments and lower extremity (ankle, knee, and hip) frontal plane joint moments were calculated using inverse dynamics and rigid body assumptions. The location of the L5/S1 joint center was defined by creating a virtual point 34% of the distance from the sacrum marker to the midpoint of the ASIS markers [15,16].

L5/S1 lateral bending moments were analyzed during single limb stance of the first and second stair steps. In order to calculate L5/S1 lateral bending moments during double limb stance, both left and right hip kinetics would be required. However, the hip kinetics for the lead and trial leg were not available at the top of the staircase (the third stair) because of the limited number of the force plates. Thus, single limb stance was utilized for L5/S1 lateral bending moments because the lead and trial legs were not always positioned on force platforms during double limb stance. Hip and knee frontal plane moments were analyzed during the entire stance phase of the first (left leg) and second (right leg) stair steps. Joint moments were transformed to the inferior segment coordinate axes and reported as an internal joint moments with the exception of knee varus moments, which were reported as external joint moments. Peak joint moments were determined during the stance phase for two steps and normalized by body mass. Absolute values of peak L5/S1 lateral bending moments were analyzed to avoid cancellation of left and right bending moments. All calculations were performed using a custom Matlab code.

Statistical analyses were performed using the SPSS statistical package (version 21; SPSS Inc., Chicago, IL, USA). The effect of the different loading conditions on peak joint moments was analyzed by using repeated measures Analyses of Variance (ANOVA). A one factor ANOVA design was used, and there were 5 levels of conditions (5 load conditions). When significant main effects were found, Bonferroni post-hoc tests were performed. The level of statistical significance for all tests was set at $p < 0.05$. To test the hypotheses, pairwise comparisons included differences between the five loading conditions.

3. Results

3.1. Peak L5/S1 lateral bending moments

There were significant differences in peak L5/S1 lateral bending moments as a function of load condition (Table 1). L5/S1 lateral bending moments were higher when comparing a 20% BW unilateral load to all other loading conditions during stair ascent and descent ($p < 0.001$). In addition, L5/S1 lateral bending moments were higher when comparing a 10% BW unilateral load

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