Gait & Posture 64 (2018) 213–219

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Carrying asymmetric loads during stair negotiation: Loaded limb stance vs. unloaded limb stance

Junsig Wang[a,*], Jason C. Gillette[b]

[a] Department of Orthopaedic Surgery, University of Arizona, Tucson, AZ, USA
[b] Department of Kinesiology, Iowa State University, Ames, IA, USA

A R T I C L E I N F O

Keywords:
Gait
L5S1
Joint moments
Asymmetric load
Stair negotiation

A B S T R A C T

Background: Individuals often carry items in one hand instead of both hands during activities of daily living. Research Question The purpose of this study was to investigate low back and lower extremity frontal plane moments for loaded limb stance and unloaded limb stance when carrying symmetric and asymmetric loads during stair negotiation.

Methods: Participants were instructed to ascend and descend a three-step staircase at preferred pace using a right leg lead and a left leg lead for each load condition: no load, 20% body weight (BW) bilateral load, and 20% BW unilateral load. L5/S1 contralateral bending, hip abduction, external knee varus, and ankle inversion moments were calculated using inverse dynamics.

Results: Peak L5/S1 contralateral bending moments were significantly higher when carrying a 20% BW unilateral load as compared to a 20% BW bilateral load for both stair ascent and stair descent. In addition, peak L5/S1 contralateral bending moments were significantly higher during step one than for step two. Peak external knee varus and hip abduction moments were significantly higher in unloaded limb stance as compared to loaded limb stance when carrying a 20% BW unilateral load.

Significance: General load carriage recommendations include carrying less than 20% BW loads and splitting loads bilaterally when feasible. Assessment recommendations include analyzing the first stair step and analyzing both the loaded and unloaded limbs.

1. Introduction

Individuals frequently carry heavy items (e.g., suitcases or grocery bags) in one hand during activities of daily living. Carrying heavy loads in one hand can result in adverse changes in posture and how loads are distributed throughout the body during locomotion. Previous studies have reported that asymmetric load carriage increased trunk lateral bending angles [1,2] and levels of perceived low back pain [3]. Other studies have found that carrying asymmetric loads with a bag resulted in higher hip abduction moments [4], a sidepack resulted in higher hip abduction and L5/S1 contralateral bending moments [5], and a hockey bag resulted in increased lower extremity muscle activation [6]. Therefore, asymmetric load carriage appears to increase frontal plane loading in both the low back and lower extremity.

Increased frontal plane loading has been associated with potential risk for development of knee osteoarthritis (OA) and low back injury. For example, persons with medial knee OA exhibited higher external knee varus moments than healthy controls [7,8]. This change can lead to increased medial knee compartment compression and further thinning of articular cartilage [9]. An epidemiological study found that a 1% increase in external knee varus moments increased risk of knee OA progression by 6.46 times [10]. Furthermore, external knee varus moments remain higher even after total knee arthroplasty [11]. As a second example, increases in L5S1 lateral bending moments are linked to increased compressive and lateral shear loading [12]. Increased intervertebral loading for a prolonged period can lead to rapid degeneration of the disc fibers [13]. Taken together, increased frontal plane loading in the low back and lower extremity when carrying asymmetric loads may be of concern for knee OA and low back injury.

When carrying a unilateral load, there is a larger moment arm from the load to the stance leg on the opposite side of the body (unloaded limb stance) as compared to the moment arm from the load to the stance leg on the same side of the body (loaded limb stance). Therefore, it is of interest to investigate if frontal plane joint moments are increased during unloaded limb stance. Matsuo et al. (2008) found higher hip abduction moments in unloaded limb stance when carrying a bag [4], and DeVita et al. found higher hip abduction and external knee varus moments during unloaded limb stance when carrying a sidepack

* Corresponding author.
E-mail addresses: Jwang0408@email.arizona.edu, cvcuil@gmail.com (J. Wang).

https://doi.org/10.1016/j.gaitpost.2018.06.113
Received 22 June 2017; Received in revised form 8 June 2018; Accepted 17 June 2018
0966-6362/

during walking [5]. These studies investigated asymmetrical load carriage during walking, while the effects of asymmetrical load carriage on unloaded and loaded limb stance during stair negotiation remain unknown.

Stair ascent and descent require higher knee range of motion and knee extension moments than walking [14,15]. Fewer studies have investigated load carriage during stair negotiation. For example, Hong and Li found that vertical ground reaction forces were higher for a 15% body weight (BW) load during stair descent and a 10% BW load during stair ascent when carrying asymmetric loads in a one-strap athletic bag [16]. Hall et al. reported higher external knee varus moments when carrying symmetric loads of approximately 20% BW during stair ascent as compared to walking and stair descent [17]. These findings support the ideas that stair negotiation is more demanding on the knees than walking, load carriage increases overall loading on the body, and asymmetric load carriage may further increase frontal plane knee joint moments.

The purpose of this study was to investigate low back and lower extremity frontal plane moments for loaded and unloaded limb stance when carrying symmetric and asymmetric loads during stair negotiation. We hypothesized that 1) peak external knee varus, hip abduction, and L5/S1 contralateral bending moments would be increased during unilateral load carriage as compared to bilateral load carriage, and 2) peak external knee varus and hip abduction moments would be significantly higher during unloaded limb stance as compared to loaded limb stance during unilateral load carriage.

2. Methods

Twenty-three healthy young adults with an age range of 20 to 30 (11 males/12 females; age 21.8 ± 2.4 years; height 173.3 ± 8.8 cm; mass 72.6 ± 12.6 kg) participated in this study. G*Power was used to calculate a sample size of 23 using previously published data [18] to determine a minimum estimated effect size of 0.96 with an alpha error probability of 0.0125 (adjusted by the number of variables) and a power of 0.90. Participants were free of any pathology that would affect them while walking on stairs or prevent them from being able to carry a 20% BW load. Individuals were excluded if they had back, neck, leg, foot, or arm pain. Prior to participation, each subject read and signed an informed consent document approved by the university's institutional review board.

Three load conditions were tested: no load, 20% BW bilateral load, and 20% BW unilateral load (Fig. 1). The load was evenly split between the right and left hands during the bilateral load condition (10% BW in each hand). Two hand-held bags were filled with sealed bags of lead shot to match the loaded conditions. Since all participants were right-hand dominant, they carried the bag in the right hand during the unilateral load condition. The load carried in the bags was normalized according to each participant's body weight. The level of normalized load was based on the upper range of previous studies that indicated significant kinematic and/or kinetic changes when carrying loads ranging from 10% to 20% BW [5,16,19,20].

Participants were instructed to ascend and descend a three-step staircase (step height 18.5 cm, tread depth 29.5 cm) at preferred pace using a right leg lead and a left leg lead for each load condition. The order of the conditions was randomized, and each condition was repeated three times for a total of 36 trials (3 load conditions × ascent/descent × right/left leg leads × 3 trials). Both a right and a left leg lead were tested to avoid results being biased by any differences in joint moments that might occur when comparing step one versus step two of stair negotiation.

Eight cameras (Vicon, Oxford, UK) were used to collect three-dimensional kinematic data. The dynamic marker set included bilateral great toe, lateral midfoot, lateral malleolus, anterior calf, lateral calf, lateral knee joint, anterior thigh, lateral thigh, greater trochanter, anterior superior iliac spine (ASIS), posterior superior iliac spine, and acromion process markers, along with a single sacrum and cervical maker. Six additional markers (bilateral heel, medial malleolus, and medial knee joint) were recreated using transformations determined from a static standing trial. Two force platforms (AMTI, Watertown, MA) placed on the first and second steps were used to collect kinetic data. Video data were sampled at 160 Hz, and force platform data were sampled at 1600 Hz. Video and force platform data were synchronized using Vicon Nexus (Vicon, Oxford, UK).

Video and force platform data were processed with a fourth-order, symmetric low-pass Butterworth filter at a cut-off frequency of 6 Hz. The force data were downsampled from 1600 to 160 Hz. Segment masses, center of mass (COM) locations, and moments of inertia were scaled to participant anthropometrics [21]. Frontal plane moments were of interest for comparing symmetric and asymmetric loads. L5/S1 contralateral bending, hip abduction, external knee varus, and ankle eversion moments were calculated using inverse dynamics. The

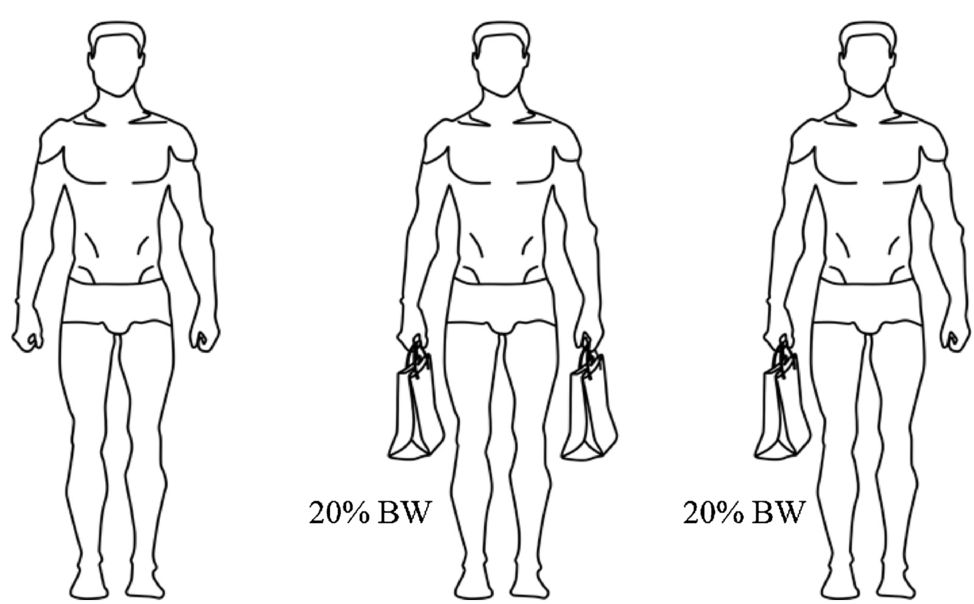

Fig. 1. Illustration of the three load conditions: no load (left), 20% BW bilateral load split between both sides of the body (center), and 20% body weight (BW) load on one side of the body (right).