Journal of Biomechanics 44 (2011) 1259–1263

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

# Effects of load carriage and fatigue on gait characteristics

Xingda Qu*, Joo Chuan Yeo

*School of Mechanical and Aerospace Engineering, Nanyang Technological University, Blk N3, North Spine, Nanyang Avenue, Singapore 639798, Singapore*

ARTICLE INFO

*Article history:*
Accepted 16 February 2011

*Keywords:*
Fatigue
Load carriage
Gait
Gait variability
Gait kinematics

ABSTRACT

The objective of this study was to determine the main and interactive effects of load carriage and fatigue on gait characteristics. Twelve young male participants were recruited in this study. Fatiguing protocol involved a running exercise, and fatigue was considered to be induced when the participants first gave an RPE rating at or above 17. Gait data were collected when the participants walked on a medical treadmill at their self-selected comfortable speed, both before and right after the fatiguing exercise. Different back-carrying loads (i.e. 0, 7.5, and 15 kg) were applied separately to the participants during the walking trials. Gait variability measures and kinematic measures were used to quantify gait characteristics. The results showed that gait width variability, hip range of motion, and trunk range of motion increased with fatigue and with the application of the heavy load. These findings suggest that both fatigue and load carriage compromise gait. Findings from this study can help better understand how fatigue and load carriage affect gait, and further aid in developing interventions that are able to minimize fall risks especially with the application of fatigue and/or external load.


## 1. Introduction

Falls are a major health problem nowadays. In the year of 2002, over 12,900 adults in the US died as a result of falls, over 1,016,700 patients were treated in emergency departments for fall-related injuries and 388,000 were subsequently hospitalized (Stevens et al., 2006). Falls are serious not only for the general population, but also for military personnel. In the military, falls are costly due to time lost from duty and medical care (Schiffman et al., 2006). On average, falls among US military personnel led to a hospital stay of 6.4 days (Senier et al., 2002).

Almost all fall incidents occur during dynamic activities, particularly locomotion (Prince et al., 1997). Gait (walking) is the most common locomotion activities, and gait parameters have been reported to be critical determinant of fall risk (Dingwell and Cusumano, 2000). For example, it was reported that fallers tend to have higher gait variability compared to non-fallers (Hausdorff et al., 2001). Hence, in order to develop and assess fall prevention strategies, there is a need to better understand gait characteristics.

Falls are often multi-factorial. In general, the risk factors associated with falls can be classified as environmental factors, task-related factors, and personal factors (Hsiao and Simeonov, 2001). Interventions aimed at modifying fall-related risk factors have been suggested to be a possible solution to preventing falls (e.g. Arampatzis et al., 2011; Kim, 2009). However, in order to be effective, the development of these interventions should be based on good knowledge of how the risk factors affect gait characteristics.

Load carriage and fatigue have been identified as two major task-related risk factors that have effects on gait (Hsiao and Simeonov, 2001), especially for military personnel. The carrying of load by troops is necessary and important for military training and combat. Soldiers must be able to carry heavy load while maintaining battlefield performance. However, overloading and poorly designed load carriage systems can lead to excessive fatigue which significantly impairs the soldiers' ability to combat and at the same time also results in many health problems for soldiers (e.g. falls) (Knapik et al., 2004).

The effects of military load carriage on gait have been reported previously (Attwells et al., 2006; Birrelll and Haslam, 2009; Martin and Nelson, 1986). For example, Attwells et al. (2006) examined the changes in soldiers' walking gait caused by four load levels (i.e. 8, 16, 40, and 50 kg). Joint angles and spatiotemporal parameters were measured during gait at a self-selected speed. Results showed that stride remained the same but the range of motion of some joint angles (e.g. knee and craniovertebral angles) significantly changed with back-carrying load. Most recently, Birrell and Haslam (2009) have studied the lower limb kinematics with the application of military back-carrying load. They found that the range of motion of flexion/extension of the knee and pelvic rotation significantly decreased when the load was applied. A common limitation of these studies is that they did not investigate the possible effects of fatigue on gait, while military operations with load carriage could often be associated

* Corresponding author. Tel.: +65 67904458; fax: +65 67924062.
*E-mail address:* xdqu@ntu.edu.sg (X. Qu).

0021-9290/$ - see front matter 
doi:10.1016/j.jbiomech.2011.02.016

with fatigue. Therefore, it is of interest to study gait characteristics when load carriage and fatigue are applied at the same time.

The objective of this study was to determine the main and interactive effects of load carriage and fatigue on gait characteristics. Back carriage is one of the most common load transfer approaches in the military. Therefore, back-carrying load was applied in this study. Fatigue was induced using a running exercise, since running is common in military marches. Gait variability has been reported to be an indicator to predict the risk of falls (Maki, 1997). Specifically, people at high risk of falls tend to show high gait variability (Hausdorff et al., 2001; Owings and Grabiner, 2004). In addition, kinematic gait measures are able to objectively account for the movements of body segments during gait and to differentiate fall-prone and healthy adults (Prince et al., 1997). Therefore, gait variability measures and kinematic gait measures were used to quantify gait characteristics. We hypothesized that (1) both load carriage and fatigue would have effects on gait characteristics, and (2) the effects on gait caused by load carriage would depend on the presence or absence of fatigue (i.e. interaction would exist between load carriage and fatigue).

## 2. Methods

### 2.1. Participants

Twelve young male participants were involved in this study (age $=26.6\pm2.9$ years; height $=1.77\pm0.07$ m; body mass $=65.4\pm8.0$ kg). Since healthy Singaporean males are required to serve as soldiers, these participants were randomly selected from Singaporean males between 20 and 30 years old. The participants self-reported to have no injuries, illness, or musculoskeletal disorders that could affect their gait patterns. All participants signed the informed consent form approved by a local ethic committee.

### 2.2. Experimental procedure

At the beginning of experimental sessions, the participants were required to change into shorts and sleeveless shirt. Subsequently, a total of 26 reflective spherical markers were placed bilaterally over selected anatomical landmarks of the body (Fig. 1 and Table 1). An eight-camera motion capture system (Motion Analysis Eagle System, Santa Rosa, CA, USA) was used to monitor whole-body kinematics in three dimensions, the sampling frequency of which was set at 100 Hz.

During data collection, the participants were instructed to walk on a medical treadmill (Biodex RTM 600, Shirley, NY, USA) at their self-selected comfortable speed. Each walking trial lasted 2 min. Different levels of back-carrying loads were applied to the participants during the walking trials (Fig. 2). These load levels were set at 0 kg (i.e. no load), 7.5 kg (i.e. low load), and 15 kg (i.e. high load). The 7.5 kg load composed of a 5 kg field-pack and a 2.5 kg light bullet vest, and the 15 kg load composed of a 12.5 kg field-pack and a 2.5 kg light bullet vest.

Three pre-fatigue walking trials were performed by each participant under the three back-carrying loading conditions. There was an at least 3-min break between two consecutive pre-fatigue walking trials in order to minimize carry-over effects and confounding fatigue effects. In order to minimize order effects, the order in which the different loading conditions were presented was randomized across the pre-fatigue trials.

After the three pre-fatigue trials, fatiguing exercise was conducted to induce fatigue. During the fatiguing exercise, the participants were instructed to run on the medical treadmill at the speed of 8 mph. This running speed was determined according to the observations of the experimenters from a pilot study. All the healthy male participants involved in the pilot study reached the fatigued condition between 2 and 10 min when running at 8 mph on the treadmill.

Borg's rating of perceived exertion (RPE) (Borg, 1982) was used to assess the fatigue level. Specifically, we selected Borg 6–20 scale, in which '6' corresponds to 'No Exertion at all' and '20' corresponds to 'Maximal Exertion'. Ratel et al. (2006) have suggested that RPE ratings were highly related to fatigue after short-term high-intensity exercises. At every 30-s interval during the fatiguing exercise, the participants were asked to rate their fatigue level using the RPE scale. Fatiguing exercise was stopped and fatigue was considered to be induced when the participants first gave an RPE rating at or above 17, which corresponds to 'Very Strenuous, and You are very Fatigued' in the Borg 6–20 scale.

Right after the fatigue onset, the participants performed three post-fatigue walking trials under the three loading conditions in a random order. To ensure the consistency of the fatigue level across post-fatigue trials, fatiguing exercise was re-initiated before the second and the third post-fatigue trials. The flow of the experimental procedure is illustrated in Fig. 3.

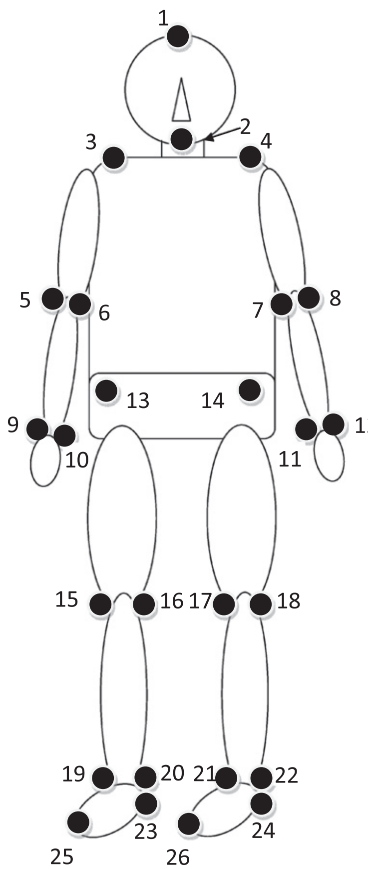


**Fig. 1.** Marker placement on the human body.

**Table 1**
Body landmarks for reflective marker placement. Marker number is defined in Fig. 1.

| Marker number | Body landmarks |
|---|---|
| 1 | Forehead |
| 2 | Chin |
| 3 and 4 | Right and left acromions |
| 5 and 6 | Right lateral and medial epicondyles of humerus |
| 7 and 8 | Left lateral and medial epicondyles of humerus |
| 9 and 10 | Right styloid processes of radius and ulna |
| 11 and 12 | Left styloid processes of radius and ulna |
| 13 and 14 | Right and left anterior superior iliac spines (ASIS) |
| 15 and 16 | Right lateral and medial epicondyles of femur |
| 17 and 18 | Left lateral and medial epicondyles of femur |
| 19 and 20 | Right lateral and medial malleoli |
| 21 and 22 | Left lateral and medial malleoli |
| 23 and 24 | Right and left heels |
| 25 and 26 | Right and left 5th metatarsal |

### 2.3. Dependent measures

Dependent measures in this study were defined by gait variability and kinematic gait measures. Gait variability measures included step length variability and step width variability. Step length was measured as the anterior–posterior distance between sequential left and right heel-strikes. Step width was defined as the medial–lateral distance between sequential left and right heel-strikes (Owings and Grabiner, 2004). After establishing a steady-state gait pattern, 30 strides selected from each walking trial were used to calculate the standard deviations of the step length and the step width. These standard deviations were used to account for the gait variability.

It was reported that the highest reliable kinematic gait measures took place in the hip and knee in the sagittal plane (McGinley et al., 2009). In addition, trunk