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Effects of lower-limb muscular fatigue on stair gait

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ABSTRACT

The objective of the present study was to determine the effects of lower-limb muscular fatigue on stair gait. Twelve healthy young male adults between 20 and 30 years old participated in the experiment. There were two experimental sessions corresponding to a no fatigue condition and a lower-limb muscular fatigue condition, respectively. Lower-limb muscular fatigue was induced using repetitive lower-limb pushing exertions. Both ascent and descent were studied. Stair gait was assessed by lower-limb joints and trunk kinematics, and postural stability measures. It was found that lower-limb muscular fatigue compromised stair gait during descent, but did not make any difference during ascent. These findings highlighted the importance of minimizing exposures to lower-limb muscular fatigue during descent in stair accident prevention.

1. Introduction

Stair negotiation, which is one of the most demanding locomotor tasks, is very common in daily life. Stairs are considered as one of the most hazardous locations in the workplace and at home (Cayless, 2001), as a large proportion of accidents and injuries happen when people ascend or descend stairs. The most common accidents during stair negotiation are fall accidents. Around one out of ten fall accidents take place on staircases (Startzell et al., 2000; Svänstörm, 1974). Gait abnormality is a key risk factor for falls (Rubenstein, 2006). Therefore in order to prevent stair falls, there is a need to better understand stair gait. Some researchers reported the kinematic and kinetic differences between stair negotiation and level walking (Costigan et al., 2002; Nadeau et al., 2003). It was generally found that stair gait was associated with larger lower-limb joint range of motion and larger joint moments compared to level walking. Some researchers studied age-related differences in stair gait and attempted to use their findings to explain the higher risk of falls in older adults during stair negotiation (Bosse et al., 2012; Mian et al., 2007; Novak and Brouwer, 2011). For instance, Bosse et al. (2012) found that older adults showed a lower ankle and knee joint angular impulse before the initiation of the single support phase. Based on this finding, they further suggested that decreased leg-extensor muscular output with aging is the cause of higher risk of falls in older adults during descent.

Many studies presented that safe stair negotiation was dependent on adequate lower-limb muscle strength (Karamanidis and Arampatzis, 2011; Reeves et al., 2008). Muscular fatigue leads to decreased muscle strength (Vøllestad, 1997), which could be a risk factor compromising stair gait. The effects of lower-limb muscular fatigue on gait have been investigated in previous work (Longpré et al., 2013). In general, lower-limb muscular fatigue was found to have adverse effects on gait. However, in previous studies, gait was mainly assessed during level walking. The effects of lower-limb muscular fatigue on stair gait are seldom studied. A recent study has evaluated the effects of muscular fatigue of the triceps surae and quadriceps muscles in stepping down in ongoing gait (Barbieri et al., 2014). However, in this study, only localized muscular fatigue at the ankle and knee was examined. Multi-joint movements are more common than single-joint movements in both daily activities and occupational settings, and mobility of one joint is typically dependent on the position of an adjacent joint (aka. two-joint muscle effect) (Chaffin et al., 1996). Thus, applying localized muscular fatigue protocols to a single lower-limb joint is limited in replicating the muscular fatigue in real life.

The objective of the present study was to determine the effects of lower-limb muscular fatigue on stair gait during both ascent and descent. Gait analysis is typically conducted from kinematic and kinetic perspectives (Prince et al., 1997). In the present study, lower limb joints and trunk kinematics were used to characterize stair gait. Kinetic analysis was not undertaken here due to the lack of necessary measuring device in the experiment. Besides, stair gait was also assessed by postural stability measures as understanding how humans maintain postural stability is essential for

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predicting the likelihood of falls (Hsiao and Simeonov, 2001; Rubenstein, 2006). In order to replicate the fatigue in real life, the examined lower-limb muscular fatigue was multi-joint muscular fatigue. It was hypothesized that lower-limb muscular fatigue would compromise lower limb joints and trunk kinematics, and lead to decreased postural stability, during both ascent and descent.

2. Methods

2.1. Participants

Twelve healthy young male adults between 20 and 30 years old participated in the experiment. The mean ± SD of the age, height and body weight of the participants are 24.0 ± 1.4 years, 174.7 ± 6.2 cm, and 68.3 ± 7.9 kg, respectively. All the participants self-reported to have no musculoskeletal injuries in the past 12 months. They all also self-reported to prefer using their right foot to kick a soccer ball, and such information was used to determine their foot dominance. Informed consent which was approved by the local ethical committee was obtained from each participant.

2.2. Apparatus

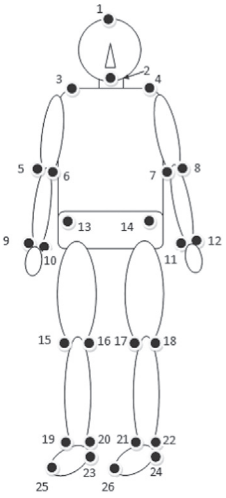
An eight-camera motion capture system (Motion Analysis Eagle System, CA, USA) was used to collect the body kinematic data. The sampling rate was set at 100 Hz, and the raw data from the motion capture system were filtered using a second order Butterworth filter with the cut-off frequency at 6 Hz. Stair negotiation was conducted on a five-step staircase without handrail (tread 30 cm, width 80 cm, riser 15 cm). This staircase was customized based on the Singapore BCA Building Code 2007. A commercial isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) was used to measure strengths and to induce lower-limb muscular fatigue.

2.3. Experimental protocol

A within-subject design was adopted. There were two experimental sessions corresponding to a no fatigue condition and a lower-limb muscular fatigue condition, respectively. The participants were randomly assigned to two even groups. One group started with the no fatigue session followed by the lower-limb muscular fatigue session. The other group started with the lower-limb muscular fatigue session followed by the no fatigue session. The interval between these two sessions was at least three days in order to minimize carry-over effects.

At the beginning of each session, the participants were asked to wear tight-fitting suit. A total of 26 reflective markers were placed bilaterally over selected anatomical landmarks of the body (Fig. 1). This marker placement scheme can help model the body as a 12-segment rigid body model including the head, trunk, upper arms, lower arms, thighs, shanks, and feet. After that, the stair negotiation protocol which is similar as that in Qu and Hu (2014) was introduced to the participants. Subsequently, each participant was given around two minutes to practice stair negotiation. During practice, the appropriate start points for ascent and descent for each participant were determined so that the participants could clear the first stair edge with their non-dominant foot at a self-selected comfortable speed.

In the no fatigue session, stair negotiation data collection was conducted right after practice. In the lower-limb muscular fatigue session, the participants were instructed to perform fatiguing exercises after practice. The details of fatiguing exercises have been presented elsewhere (Lew and Qu, 2014). Briefly, lower-limb muscular fatigue was induced using repetitive lower-limb pushing exertions on a lift simulation attachment for the commercial isokinetic dynamometer when the participants were told to lie on the floor and not to move their torso and upper limbs during the exertions. The pushing exertions involved the movements of the ankle, knee, and hip with minimal movements of the torso and upper limbs, and were performed at the rate of 10 times/min against the resistance of 60% of the corresponding maximum voluntary contraction which was determined at the beginning of the fatiguing exercises. Fatigue was considered induced when the participants were unable to perform the exertion for three consecutive attempts, and then stair negotiation data collection was started immediately.



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 ASIS (Anterior Superior Iliac Spines)
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

Fig. 1. Marker placement on the human body.

In the stair ascent trials, the participants walked from a start point about two meters away from the staircase on the ground level, and then ascended to the top of the staircase in a step-over manner. Similarly in the stair descent trials, the participants started walking on the top platform of the staircase about two meters away from the first step, and then descended to the ground by placing one foot on each step. In both the ascent and descent trials, the participants were instructed to walk at their self-selected comfortable speed, and to clear the first stair edge with their non-dominant foot. An experimenter stood by the staircase to protect the participants from any unexpected incidents occurring during the experimental trials. Each participant underwent 30 trials in each session. Five ascent and five descent trials were grouped and carried out consecutively. Each ascent trial and descent trial in each group were performed in sequence. Upon completion of the 10 trials in each group, a 3 min break was provided to minimize confounding fatigue effect that did not result from the fatigue protocol used in the study. In the lower-limb muscular fatigue session, the fatiguing exercise was reinitiated after completing the first and second groups of stair negotiation trials to ensure the consistency of fatigue level between trials.

2.4. Dependent variables

Dependent variables accounted for lower-limb joints and trunk kinematics and postural stability, respectively. They were measured during a complete stair gait cycle. The selected stair gait cycle during ascent was defined as that starting from the dominant foot contact on the second step (i.e. 0% of gait cycle) and ending at the dominant foot contact on the fourth 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 step down

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