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Lower-extremity kinematics and postural stability during stair negotiation: Effects of two cognitive tasks

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ABSTRACT

Background: Concurrent cognitive tasks were found to affect gait characteristics during level walking, such as decreasing speed, cadence, step length, etc. Given that many accidents occur during stair negotiation and people often perform cognitive tasks concurrently with stair negotiation in daily life, there is a need to study how cognitive tasks affect gait characteristics and postural stability during stair negotiation. This study aimed to determine cognitive task effects on lower-extremity kinematics and postural stability during stair negotiation. We also examined the difference in cognitive demands between ascent and descent.
Methods: Two cognitive tasks, i.e. 'backward digit recall' and 'counting backward in threes', were examined. There were three testing conditions corresponding to a baseline and the two cognitive tasks, respectively. In the baseline, no cognitive task was performed. In the cognitive task conditions, the cognitive task was performed continuously throughout the stair negotiation trial. Each participant performed six ascent trials and six descent trials under each testing condition. We measured the cognitive task performance. Lower-extremity kinematics and postural stability were calculated using the data collected from a complete stair gait cycle that was obtained for the dominant leg.
Findings: In general, concurrent cognitive tasks had adverse effects on lower-extremity kinematics and postural stability during both ascent and decent. No differences in dependent measures were found between cognitive tasks. Additionally, ascent and descent appeared to be equally cognitively demanding.
Interpretation: The findings from this study can help better understand inadequate postural reactions due to cognitive load that may cause stair accidents.

1. Introduction

Stair negotiation is common in daily life and occupational settings. Compared to level walking and other daily activities, stair negotiation is more physically demanding and even more dangerous given that a large proportion of accidents occur during stair negotiation. It was reported that nearly 10% of home accidents and 14% of occupational injuries related to work surfaces occurred on stairs (Cohen et al., 1985; Roy, 2001). Most of stair accidents are associated with falls which is a major safety concern. Stairs are actually one of the most hazardous locations for fall accidents (Cayless, 2001).

In order to prevent stair falls, many studies have been conducted to facilitate a good understanding of stair gait. It was found that joint ranges of motion (RoMs) and joint moments at the lower extremity were significantly larger during stair negotiation compared to level walking (Costigan et al., 2002; Jevsevar et al., 1993; Nadeau et al., 2003). When comparing stair ascent and descent, greater hip and knee RoM and greater hip and knee moments were observed during ascent and greater ankle RoM was found during descent (Protopapadaki et al., 2007). There were age-related kinematic and kinetic differences at the lower extremity during stair negotiation. For instance, older adults showed larger hip abductor moment, smaller hip extension and adduction, and smaller knee adduction and ankle valgus than did younger adults (Bosse et al., 2012; Novak and Brouwer, 2011).

Motor tasks are cognitively demanding (Woollacott and Shumway-Cook, 2002). In a dual task condition, concurrent cognitive tasks could reduce available cognitive resources needed by a motor task. Therefore, there could be interference between the motor task and concurrent cognitive task (Marras et al., 2000; Simoni et al., 2013). It was reported that concurrent cognitive tasks could decrease muscular efforts at high exertion levels and thus impair motor performance (Mehta and Agnew, 2011, 2012). Gait is one of the most common motor tasks in daily life. In fact, many researchers have reported that gait characteristics are affected by concurrent cognitive tasks. For example, it was found that additional cognitive demands were associated with decreased speed, cadence, step length, stride length, and double support time (Simoni et al., 2013). Abbud et al. (2009) reported that the EMG amplitude of the lower-extremity muscles decreased while walking and performing cognitive tasks concurrently.

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Existing research mainly focuses on investigating cognitive task effects on level walking gait. Given that many accidents occur during stair negotiation and people may often perform cognitive tasks (e.g. talking and reasoning) concurrently with stair negotiation in daily life, there is a need to study how cognitive tasks affect gait characteristics and postural stability during stair negotiation. Je et al. (2011) reported increases in center-of-pressure (CoP) displacement and velocity measures due to a concurrent cognitive task during stair descent. CoP measures were good indicators of postural stability during static stance (Prieto et al., 1996). In order to sufficiently account for postural stability during dynamic activities such as stair negotiation, measurement of center-of-mass (CoM), which provides insight into dynamic postural control mechanisms (Hof et al., 2005), should be provided. Parker et al. (2005), for instance, used the CoM range of motion (RoM) as an indicator of postural stability during stair negotiation. In addition, lower-extremity kinematics was not reported by Je et al. (2011) which is important in stair gait analysis.

The main purpose of this study was to determine cognitive task effects on lower-extremity kinematics and postural stability during stair negotiation including ascent and descent. According to existing findings on cognitive task effects on level walking gait, we hypothesized that concurrent cognitive tasks would adversely affect lower-extremity kinematics and postural stability during stair negotiation. Two cognitive tasks, i.e. 'backward digit recall (BDR)' and 'counting backward in threes (CBT)', were examined. These two cognitive tasks involve different types of cognitive resources (Maylor and Wing, 1996). According to Wickens and Hollands (1999), between-task interference is dependent on the degree to which the primary and secondary tasks share the same type of cognitive resources. Thus, our second hypothesis was that cognitive tasks involving different types of cognitive resources would affect lower-extremity kinematics and postural stability differently. In addition, to our knowledge, few studies have examined cognitive demands of stair ascent and descent. Therefore, we also aimed to study the difference in cognitive demands between stair ascent and descent. Stair ascent and descent are different gait tasks. Thus, our third hypothesis was that cognitive demands would be different between stair ascent and descent.

2. Methods

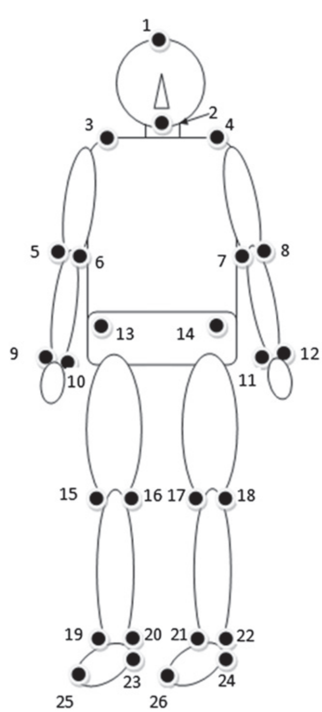
2.1. Participants

Twelve male volunteers from the university or local community participated in this study. The mean (SD) of their age, height and body mass were 25.6 (2.3) years, 174.7 (3.2) cm, and 67.8 (6.8) kg, respectively. These participants self-reported to be free of any medical conditions that may affect their ability to negotiate stairs. All participants signed an informed consent form approved by the local ethics committee. Among these 12 participants, 11 were right-handed and one was left-handed.

2.2. Experimental protocol

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. An eight-camera motion capture system (Motion Analysis Eagle System, CA, USA) was used to collect the body kinematic data. The sampling rate was 100 Hz, and the raw data from the motion capture system were filtered using a second order Butterworth low-pass filter. Winter (2009) found that 99.7% of the signal power of gait data was contained below 6 Hz, so the cutoff frequency for the low-pass filter was set at 6 Hz.

Stair ascent and descent were performed on a five-step staircase (tread 30 cm, width 80 cm, riser 15 cm). This staircase was customized based on Singapore BCA Building Code 2007 and had a platform at the upper end. In the stair ascent trails, the participants walked from a start point about 2 m away from the staircase on the level ground, 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 2 m 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



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 laterral 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.