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Changes in lower extremity peak angles, moments and muscle activations during stair climbing at different speeds

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ABSTRACT

Stair climbing is a common daily activity, yet there is no basic knowledge on how lower extremity joint angles, moments or muscle activations are affected by stair climbing speed. This information will determine whether speed matching is necessary for stair climbing studies. Moreover, changes in lower extremity biomechanics during stair climbing at different speeds will aid in the clinical interpretation of a patient's maximal stair climbing speed.

Thirty healthy participants provided consent. Kinematics, kinetics, and muscle activations were collected on a three step staircase. Subjects climbed the staircase at normal, slow and fast self-selected speeds. Linear mixed models for repeated measures were used to study the associations between speed and the lower extremity peak joint angles and moments, and muscle activations.

The peak hip flexion and extension moments increased with increasing speed, while peak knee flexion moment did not vary consistently with speed. The peak muscle activations varied consistently with respect to the sagittal plane kinetics.

These results suggest that in healthy subjects, the hip is the greatest contributor when modulating stair climbing speed, while additional knee contributions do not appear necessary to increase speed. Further stair studies should consider speed matching in order to accurately assess biomechanical differences.

1. Introduction

Stair climbing is a daily activity that is important for maintaining mobility in the home and community, a high quality of life, and independence. Due to the increased physical demand of stair climbing compared to level ground walking (Andriacchi et al., 1980; Costigan et al., 2002; Jevsevar et al., 1993; Kirkwood et al., 1999; McFadyen and Winter, 1988), clinicians and researchers use stair climbing performance to track and describe function in patients with knee pathology such as osteoarthritis (OA) or total knee arthroplasty (TKA). The stair climbing test (SCT) is a clinical measure frequently used to quantify stair climbing function and performance (Adegoke et al., 2012; Mizner et al., 2005; Schmitt et al., 2008; Stevens-Lapsley et al., 2011; Yoshida et al., 2008; Zeni et al., 2010). The SCT tracks the functional status of populations of individuals with knee pathology by measuring the time it takes for the individual to ascend and descend a flight of stairs as fast as possible, with lower values indicative of better performance (Almeida et al., 2010; Kennedy et al., 2005). Understanding the typical differences in biomechanics with respect to stair climbing speed in a healthy population may help aid clinicians' interpretation of the SCT and development of rehabilitation protocols to enhance stair climbing performance and improve quality of life.

Stair climbing biomechanics have been described in healthy populations in order to understand the support necessary to manage the applied loads (Andriacchi et al., 1980; Costigan et al., 2002; Kirkwood et al., 1999; Kowalk et al., 1996; Livingston et al., 1991; McFadyen and Winter, 1988; Nadeau et al., 2003; Protopapadaki et al., 2007; Riener, 2002; Yu et al., 1997), but only at self-selected speeds. During stair ascent, the greatest support contribution comes from the knee extensors, while the knee extensors and ankle plantar flexors provide relatively similar support

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during the weight acceptance phase of stair descent (McFadyen and Winter, 1988). Compared to gait, larger sagittal plane range of motion is required at the knee for both stair ascent and descent, at the hip for stair ascent, and ankle for stair descent. External peak flexion moments are reported to be 3 times larger for the knee during stair ascent than gait (Andriacchi et al., 1980), and 1.5 times larger for the hip during stair descent (Jevsevar et al., 1993). However, stair climbing data collection methods in the literature have not accounted for speed of ascent/descent.

Speed has been investigated during level ground walking, where angles and moments at the hip, knee and ankle have a strong positive association with speed (Andriacchi et al., 1985; Bejek et al., 2006; Kirtley et al., 1985; Lelas et al., 2003; Yang and Winter, 1985). When investigating abnormal gait biomechanics in pathological populations, it has been strongly recommended to separate the effects due to pathology from the influence of slower gait speed (Chaudhari and Andriacchi, 2008). Along these same lines, since stair climbing is commonly used to assess the function of a patient it is important to identify whether variables should be speed-matched in order to accurately identify clinical and statistically significant differences.

The purpose of the present study was to identify how peak lower extremity angles, moments and muscle activations change with stair climbing speed in a healthy population. We hypothesized that the lower extremity joint angles, moments and muscle activation magnitudes would increase with increasing stair climbing speed during both stair ascent and descent, as they do during level ground walking (Andriacchi et al., 1985; Kirtley et al., 1985; Lelas et al., 2003; Yang and Winter, 1985).

2. Materials and methods

2.1. Investigated subjects

A convenience sample of thirty healthy subjects (15 males, 15 females, age = 27.5 ± 10.7 years, height = 1.8 ± 0.08 m, weight = 73.9 ± 12.6 kg) with no history of lower extremity or abdominal surgery participated in this study after providing IRB-approved informed consent.

2.2. Data collection methods

Each subject performed stair ascent and descent trials on a custom made three-step staircase (tread depth: 25.5 cm, step height: 20 cm) (Fig. 1) at three different self-selected speeds. At least three trials starting with both right and left legs for each direction and speed were collected. The subjects initially stepped forward with their preferred limb and were only instructed to step with a specific limb if necessary to collect all trials. The subjects started with their normal self-selected (SS) speed, then were instructed to navigate the stairs slower than SS, and finally, faster than SS speed but without running (i.e. without a flight phase). The first two steps of the staircase were attached to force plates (Bertec 4060) embedded in the floor, and kinetic data was recorded at 1500 Hz. A modified point-cluster marker set was used on the upper and lower extremities (Jamison et al., 2012). Three-dimensional marker data were captured with 10 Vicon MX-F40 cameras (Vicon; Oxford, UK) at 150 Hz. Unilateral lower extremity muscle activation from a randomly assigned limb was quantified using a wireless surface electromyography (EMG) system (Telemyo DTS, Noraxon USA, Inc; Scottsdale, AZ) collected at 1500 Hz. Electrode locations, placed according to the SENIAM model (Seniam), were shaved, lightly abraded and cleaned with alcohol pads. Pre-gelled, rectangular Ag/AgCL surface dual electrodes with a 42 mm inter-electrode distance (Vermed, Inc; Bellows Falls, VT) were placed on the muscle belly and oriented parallel to the fibers of the gluteus maximus (GMAX), gluteus medius (GMED), rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), semimembranosus (SM), biceps femoris (long head (BF-L) and short head (BF-S)), medial gastrocnemius (MG), lateral gastrocnemius (LG) and soleus (SOL). Each subject also performed a sit to stand task which was used to normalize the EMG signals recorded during the stair climbing task. For the sit to stand task, subjects were instructed to keep their arms crossed across their chest and to sit down and stand up four times.

Fig. 1. Stair Setup. The first and second steps, in the identified areas, are instrumented. The peak angles and moments during stance were measured on step 2 during ascent and step 1 during descent.

2.3. Data analysis

Ground reaction force data were translated to the point of application according to the equations in the Bertec Force Plate Manual (Bertec, 2009). Marker and force data were filtered with fourth order low-pass Butterworth filters at a cutoff frequency of 6 Hz, to minimize skin artifact and artifacts due to resonance of the staircase structure and to avoid introducing filtering artifacts from mismatched cutoff frequencies (Bisseling and Hof, 2006; Kristianslund et al., 2012). Force data were visually examined to confirm that no flight phase occurred. Inverse dynamics for the lower extremity were calculated using custom Matlab and Vicon BodyBuilder scripts. All moments are expressed as externally applied to the joint of interest.

EMG data were hardware band pass filtered with 10 and 500 Hz cutoff frequencies to remove motion artifact (Konrad, 2005). Centering was not needed after inspection of the signal activity while resting revealed that the RMS signal amplitude in a 500 ms window was less than 0.01 V, and therefore did not introduce any bias. The muscle activation signals obtained during stair climbing were smoothed using a Root Mean Square (RMS) filter with a 100 ms window, and the maximum activation during stance phase was identified for each muscle. The stair climbing muscle activation data were normalized to the maximum 500 ms running average muscle activation after RMS smoothing for each muscle during the sit to stand task. Quality control of EMG was accomplished by visual inspection of each of the muscles raw EMG signals. EMG with questionable magnitude indicating possible artificial signal due to electrode motion, or missing data due to signal loss was removed from analysis (Jamison et al., 2013).