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Joint moments' contributions to vertically accelerate the center of mass during stair ambulation in the elderly: An induced acceleration approach

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ABSTRACT

Falls are a serious problem faced by the elderly. Older adults report mostly to fall while performing locomotor activities, especially the ones requiring stair negotiation. During these tasks, older adults, when compared with young adults, seem to redistribute their lower limb joint moments. This may indicate that older adults use a different strategy to accelerate the body upward during these tasks. The purposes of this study were to quantify the contributions of each lower limb joint moment to vertically accelerate the center of mass during stair ascent and descent, in a sample of community-dwelling older adults, and to verify if those contributions were correlated with age and functional fitness level. A joint moment induced acceleration analysis was performed in 29 older adults while ascending and descending stairs at their preferred speed. Agreeing with previous studies, during both tasks, the ankle plantarflexor and the knee extensor joint moments were the main contributors to support the body. Although having a smaller contribution to vertically accelerate the body, during stair descent, the hip joint moment contribution was related with the balance score. Further, older adults, when compared with the results reported previously for young adults, seem to use more their knee extensor moment than the ankle plantarflexor moment to support the body when the COM downward velocity is increasing. By contributing for a better understanding of stair negotiation in community dwelling older adults, this study may help to support the design of interventions aiming at fall prevention and/or mobility enhancement within this population.

1. Introduction

Approximately 30% of older adults living in the community fall each year and the impact of such events on elderly's quality of life and on health care costs is well documented (World Health Organization, 2007). Gait and balance problems are among the strongest and potentially modifiable risk factors for falling (Ambrose et al., 2013; Deandrea et al., 2010). Further, falls are reported to occur mostly while walking and dealing with steps and stairs (Lord et al., 2007; Timsina et al., 2017).

The biomechanical and motor control requirements necessary to successfully negotiate with stairs are high, not only increasing fall risk but, more importantly, the risk of fall related injuries (Jacobs, 2016). In particular, stair walking requires a higher demand at the knee and ankle joints, when compared with level walking (Jacobs, 2016). This could be especially critical for older adults who, compared with younger adults, redistribute their joint moments during stair ambulation (Karamanidis and Arampatzis, 2011, 2009; Novak and Brouwer, 2011; Reeves et al., 2009, 2008).

While ascending stairs, older adults apply lower knee extensor and ankle plantarflexion joint moments, and higher hip extensor joint moments, when compared with younger adults (Karamanidis and Arampatzis, 2009; Reeves et al., 2009). This proximal shift in movement strategy has been mostly attributed to changes in neuro-muscular system occurring with aging (Jacobs, 2016; Karamanidis and Arampatzis, 2009). While descending stairs, older adults seem also to apply lower ankle plantarflexor joint moments, higher hip extensor joint moments and the same or higher knee extensor joint moments, when compared with young subjects (Karamanidis and Arampatzis, 2011; Novak and Brouwer, 2011; Reeves et al., 2008). By applying a lower leading limb plantarflexor joint moment during early stance and a higher trailing limb knee extensor joint moment during mid stance, older adults seem to use more their trailing limb to prepare the double support phase than younger adults (Karamanidis and Arampatzis, 2011).

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This joint moment redistribution that occurs with ageing may be the cause why older adults appear to have more difficult in controlling fast vertical displacements of the center of mass (COM) during stair ambulation (Jacobs, 2016).

While the mentioned studies provided a great insight about the age effect on the generation of lower limb joint moments during these tasks, they do not allow a direct measure between the joint moments and the COM acceleration. Induced acceleration analysis (IAA) is based on the dynamic coupling principles that each joint moment applied to a body will accelerate all joints of the body (Zajac and Gordon, 1989) and allows the direct quantification of the contribution of each lower limb joint moment to the COM acceleration. To the best of our knowledge, IAA was only used to analyze lower limb function during stair ambulation in healthy adults (Harper et al., 2018; Lin et al., 2015).

Therefore, this study aims to quantify, using IAA, the lower limb joint moments' contributions to vertically accelerate the COM during stair ascent and descent in a sample of community dwelling older adults. Further, because age may not be the only factor contributing to this joint moment redistribution (Hortobágyi et al., 2016) and because, in the field, professionals use simpler functional fitness measures to determine fall risk level and to monitor the effects of exercise interventions on gait and balance performance, we also aimed to verify if those contributions are correlated with age and commonly used functional fitness tests. It was hypothesized that joint moment contributions would be related with both age and functional fitness level in the tested sample.

2. Methods

2.1. Study design

A cross-sectional study was conducted.

2.2. Participants

Sample size was determined based on Cohen's work (Cohen, 1988), considering a two tailed test, 5% level of significance, 80% power and an effect size of 0.5. A minimal number of 28 participants was obtained. Nevertheless, to account for withdraws, non-attenders and to increase precision 33 participants from the Biomechanics of Locomotion in the Elderly Project (PTDC/DES/72946/2006) (Moniz-Pereira et al., 2012) were invited to participate.

Participants were considered eligible if they were above 60 years, living in the community independently, and able to ascend and descend a flight of stairs without using the handrail. The exclusion criteria included any reported neurologic or orthopedic condition, as well as any uncorrected visual problem, that would affect their locomotion pattern.

From the 33 invited participants, data from 4 different participants were excluded from each task due to problems in data acquisition or modeling. Thus, in order to maximize sample size and power (Knudson, 2017), two similar groups of 29 participants were included for analysis. All the participants were informed about the aims and study protocols, agreed to participate and signed the informed consent. The Faculty Ethics Committee approved the study protocol.

2.3. Procedures

On their first session, participants answered a health and falls questionnaire and performed different functional fitness tests, following the procedures described elsewhere (Moniz-Pereira et al., 2012). In the health questionnaire participants were asked about their demographic data, general health, medication intake (and associated diseases) and fall history. This questionnaire was used to verify the eligibility of the participants according to the previously mentioned criteria. The functional fitness tests performed included the 8 foot Up-and-Go (UG) test, a measure of motor agility from Senior Fitness Test battery (Rikli and Jones, 1999), and items 4 (step up and over), 5 (tandem walk), 6 (stand on one leg) and 7 (stand on foam eyes closed) from Fullerton Advanced Balance Scale (Rose et al., 2006). In the UG test, a higher functional fitness level is present if the subject takes less time to complete the test. The sum of the balance tests scores represents a total score and a better result is obtained with a higher score (in a maximum of 16 points). The results of the mentioned functional fitness tests have been previously associated with fall risk (Hernandez and Rose, 2008; Rose et al., 2002).

During the second visit, anthropometric measures (body mass, stature and trochanteric height) and motion capture tests were performed. The participants were barefoot and wore tight black shorts and t-shirts. Thirty passive markers and four marker clusters were placed based on the calibrated anatomical system technique (Cappozzo et al., 1995) by the same researcher. Specifically, six markers were placed on the trunk, one on top of each acromion, one on the C7 spinous process and three on the sternum area (placed so that soft tissue artifact and collinearity was avoided). At the pelvis, two markers were placed on each posterior superior iliac spines and two along each iliac crest. A virtual marker was created in each anterior superior iliac spine using a digitizing pointer. Markers were also placed on the lateral and medial femur epicondyles, the lateral and medial ankle malleoli and on the top of the first and fifth metatarsal heads. Each foot had also one marker on the heel, other laterally on the middle of the foot and a third one between the two metatarsal heads. Finally, the mentioned marker clusters were attached to both thighs and shanks.

Kinematic and kinetic data were collected at 200 Hz using 8 infrared cameras (Oqus 300, Qualisys AB, Sweden) synchronized in time and space with two force plates (9281B and 9283U014, Kistler, Switzerland).

For the stairs trials, a wooden staircase with three steps was built. Each step was 15 cm high and 27 cm deep, except for the last step which depth was 80 cm. The first force platform was imbedded on the floor in front of the staircase while the second was covered by the first step. This step was securely fixed to the second force platform and was built ensuring the rigidity of the structure. Each force platform was independent of the surrounding wooden pieces. A similar wooden structure has been used previously (Alcock et al., 2014) and the staircase mounting error associated with this structure type was shown to be negligible (Chesters et al., 2014).

For the ascend task, participants stood still in front of the staircase and stepped on the floor in front of the staircase prior to climbing up the stairs and stopped on top of the staircase. For the descend task, participants stood still on top of the staircase and continued for one more step after stepping on the floor. They walked at their comfortable pace and to use a step over step pattern during both ascending and descending tasks. Practice trials were performed before collecting 10 trials (five with each limb) from each task.

2.4. Data processing

Three trials of each task, in which the right limb would step on the first step of the staircase, were selected to be analyzed, in order to maximize sample size.

Kinematic and kinetic data were filtered using a fourth order Butterworth low pass filter at 10 Hz.

The biomechanical model built for each participant had 7 segments (feet, shanks, thighs and a head-arms-trunk segment). The

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