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Centre of mass motion during stair negotiation in young and older men

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Abstract

The aim of this study was to compare centre of mass (COM) motion and its separation from centre of pressure (COP) as 13 young men (aged 23–36 years) and 15 healthy, community dwelling older men (aged 73–84 years) ascended and descended a three step staircase at a controlled cadence of approximately 90 steps/min. Centre of mass was obtained from whole body motion analysis, and simultaneously, COP was obtained using force plates built into the steps. The following variables were investigated: medio-lateral COM range of motion; peak antero-posterior and medio-lateral COM–COP separation; and peak antero-posterior, medio-lateral, and vertical COM velocities. No significant differences in these variables between young men and older men were present during ascent or descent. It was concluded that frontal plane dynamic stability during stair negotiation is well maintained in healthy older men, and that healthy older men do not exhibit an altered strategy in traversing the COM in the plane of progression during stair negotiation.

Keywords: Staircase; Gait; Elderly; Ageing; Mobility

1. Introduction

About 10% of all injurious or fatal falls happen on staircases [1,2]. This is a particular problem in older adults, with the incidence of injurious and fatal falls on stairs increasing in old age [3]. Whilst this may be partly due to an increased likelihood of injury after a fall and an impaired ability to recover from a slip or trip [4], it is apparent that stair negotiation does become inherently challenging in old age. Older adults cite stair negotiation as one of the most challenging tasks attributable to ageing [5] with age-related declines in musculoskeletal, visual, somatosensory, cardiovascular, and cognitive factors thought to be involved [2].

In spite of this, few studies have compared the biomechanics of stair negotiation between young and older adults [6–10]. Earlier studies involved comparisons of ground reaction forces [6–8] and foot clearance [9], ignoring whole body or segmental kinematics and motion outside of the plane of progression. In a recent analysis of lower extremity motion during stair descent it was reported that older adults descended stairs with greater frontal and transverse plane pelvis and hip motion than younger adults [10]. It was suggested that this extra motion outside the plane of progression, perhaps due to inadequate or inappropriate neuromuscular control of body segments, might be indicative of lack of stability and could result in difficulties in maintaining balance.

To further investigate the impact of ageing on dynamic stability during stair negotiation a three-dimensional (3D) analysis of whole body motion is necessary. Motion of the centre of mass (COM) and its interaction with the centre of pressure (COP) is highly regulated during gait [11]. The maintenance of stability during gait is dependent on the ability to control COM motion and more specifically its horizontal distance from the COP beneath the feet within appropriate limits, beyond which a corrective adjustment to gait would be necessary to avoid falling. Due to declines in sensory and motor systems such regulation during the challenging task of stair negotiation may be impaired in old

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age leading to a higher propensity toward falling. Reductions in antero-posterior COM motion and COM–COP separation during level gait and stepping over obstacles have been observed in old age which was interpreted as a compensatory strategy to ease balance maintenance [12,13]. Although COM motion and COM–COP separation have been reported during stair negotiation in young adults [14] they have never been investigated in older adults.

Hence, the purpose of this study was to compare 3D whole body motion during stair negotiation between healthy young and older adults through an analysis of COM motion and COM–COP separation. Based on earlier observations of increased frontal plane hip and pelvis motion during stair descent in older adults [10] our primary hypothesis was that whole body frontal plane motion during stair negotiation, as reflected by medio-lateral COM motion and COM–COP separation would be increased in older adults. We also investigated vertical and antero-posterior motion because we expected this might reveal difficulties experienced or compensatory strategies utilised by older adults. Hypotheses about directionality of age-related differences in vertical and antero-posterior directions were not made. The comparison was performed at an experimentally controlled cadence in order to eliminate the confounding influence of speed, and hence isolate the effect of age, on any observed age-related differences.

2. Methods

Thirteen young men (YM; aged 23–36 years) and 15 older men (OM; aged 73–84 years) were recruited to the study. Recruitment was via advertisement through the local press and the faculty e-mail system. The older men were medically screened by their general practitioner and the younger men by medical questionnaire. Exclusion criteria included known sensory, neuromuscular, skeletal or cardiovascular disorders, or inability to negotiate the instrumented staircase used in the study without use of the handrail. All participants were in good general health and were living independently in the local community. All procedures had been approved by the institutional ethics committee and all participants gave informed consent before participation.

Prior to the main laboratory visit, the OM (but not YM) visited the laboratory to complete a number of questionnaires and functional tests (administered to document aspects of the physical and psychological status and not for screening purposes). Activity levels were assessed using the physical activity scale for the elderly (PASE) [15]. Higher scores on the PASE indicate higher activity levels. Reliability of the PASE has been demonstrated [15] and there is modest support for its validity when compared with accelerometer and doubly labelled water assessment of activity levels [16,17]. Fall-related efficacy was assessed using the falls efficacy scale (FES) [18]. Score on the FES can range from 0 (lowest confidence in perceived ability to perform daily activities without falling) to 100 (highest confidence). Reliability of the FES has been demonstrated [19] and low scores are associated with activity avoidance [18]. Functional capacity was assessed using the short physical performance battery (SPPB) [20] and the timed up and go test (TUG) [21]. Score on the SPPB can range from 0 (lowest performance) to 12 (highest performance). Low performance on SPPB is predictive of subsequent disability and nursing home admission [20,22]. A quicker time on the TUG denotes better performance. Reliability of the TUG has been demonstrated [23] and TUG time is associated with balance and gait speed [21].

During the main laboratory visit, habitual speed of stair ascent and descent was assessed in both OM and YM prior to the main experimental task. Habitual cadence during stair ascent and descent was measured over a standard flight of stairs (12 steps, rise = 16.5 cm, tread = 28 cm). We calculated cadence using the measured time (by stopwatch) over the central eight steps (i.e. removing any acceleration/deceleration effects on the top and bottom two steps). After a familiarisation trial, two trials of ascent and descent were timed and the average during ascent and during descent was used. Habitual cadence was measured on this staircase rather than the instrumented staircase (described in next paragraph) since the instrumented staircase only contains three steps. The particular staircase used to measure habitual cadence was chosen since the tread and riser dimensions were almost identical to those of the instrumented staircase.

Height, mass, and leg length were also recorded in all participants. Leg length was measured as the distance along the leg from the vertical height of the anterior superior iliac spine to the vertical height of the medial maleoli.

2.1. Experimental protocol

The main experiment was conducted on a three-step staircase (rise = 17 cm, tread = 28 cm, width = 50 cm) with force plates (Kistler type 9286AA, Kistler Instruments, Winterthur, Switzerland) mounted in each step and in the ground (Kistler type 9253A) directly in front of the staircase [10]. Each step in the staircase as well as the landing was constructed separately using a solid steel frame securely bolted to the ground (upright supports had a width and depth of 8 and 4 cm, respectively) ensuring a mechanically stiff structure and enabling forces to be recorded independently from each step. The surface was covered with 0.2 cm thick linoleum with grit bonded to the top surface to give slip resistance.

Trials were conducted at a controlled cadence to eliminate the effect of speed on centre of mass motion [24]. Participants synchronised their steps to a metronome set at 90 beats/min. This was chosen because a self-selected cadence of approximately 90–95 steps/min was previously reported in healthy older adults during stair ascent and descent [25]. From a standing start, participants were required to take one step (always commencing with the right leg) on the ground (ascent trials) or upper landing (descent trials) before taking the first step on the staircase. In addition, participants were required to place only one foot on each step (foot-over-foot), and to stop a distance of one metre beyond the staircase upon reaching the landing (ascent) or ground (descent). Trials were performed barefoot with participants clothed in tight fitting Lycra shorts and vest. All participants performed five ascent and five descent trials without using the handrails. The motion analysis system (see next section) measured cadence. Trials in which measured cadence was more than 5 steps/min away from target cadence and trials with misplaced footing were excluded from further analysis. Per participant, at least three ascent and three descent trials were analysed.