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ScienceDirect
Gait & Posture 28 (2008) 327–336
GAIT & POSTURE
www.elsevier.com/locate/gaitpost

Influence of light handrail use on the biomechanics of stair negotiation in old age

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Received 6 July 2007; received in revised form 14 January 2008; accepted 19 January 2008

Abstract

The high incidence of falls in older adults during stair negotiation suggests that this task is physically challenging and potentially dangerous. The present study aimed to examine the influence of light handrail use on the biomechanics of stair negotiation in old age. Thirteen older adults ascended and descended a purpose-built staircase at their self-selected speed: (i) unaided and (ii) with light use of the handrails. Ground reaction forces (GRFs) were measured from force platforms mounted into each step and motion capture was used to collect kinematic data. Knee and ankle joint moments were calculated using the kinetic and kinematic data. The horizontal separation between the centre of mass (COM) and the centre of pressure (COP) was assessed in the sagittal and frontal planes. During stair ascent, handrail use caused a different strategy to be employed compared to unaided ascent with a redistribution of joint moments. Specifically, the ankle joint moment (of the trailing leg) was reduced with handrail use, which has previously been shown to approach its limits during unaided stair ascent, but the knee joint moment (of the leading leg) increased. Previous research has shown that a larger joint moment reserve is available at the knee during unaided stair ascent. During stair descent, the ankle joint moment increased with handrail use, this was associated, however, with a more effective control of balance as shown by a reduced COM–COP separation in the direction of progression compared to unaided descent. These results indicate that although the biomechanical mechanisms are different for stair ascent and descent, the safety of stair negotiation is improved for older adults with light use of the handrails.

Keywords: Stairs; Older adults; Centre of mass; Joint moments; Handrails

1. Introduction

Stair negotiation is a physically challenging task requiring large ranges of joint motion and high joint moments in the lower limbs [e.g., 1]. In particular, we have previously identified the ankle joint to be of critical importance during this task [2,3]. The ankle joint moment required during stair negotiation actually approaches joint moment limits in both older and young adults. However, older adults have lower levels of strength and meet the requirements of stair negotiation by redistributing joint moments in order to operate within 'safer' limits [2,3]. The difficulty for older adults to meet the demands of stair negotiation also applies to the range of motion about the ankle joint. During stair descent, older adults operate around their dorsiflexion limits, whilst young adults remain further within their capabilities [2].

In line with the high musculoskeletal requirements of the task, epidemiological evidence shows that a high proportion of falls occur in older adults during stair negotiation [4–6]. Furthermore, many of these falls have been reported to occur on stairs where handrails were not present [5]. The actual

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doi:10.1016/j.gaitpost.2008.01.014

mechanisms leading to staircase falls remain unknown. Nevertheless, regardless of the mechanisms responsible for staircase falls, a fall will ultimately be preceded by a loss of balance. Maintenance of balance during gait relies upon appropriate regulation of the body centre of mass (COM) in relation to the centre of pressure (COP). The horizontal plane separation between the COM and COP naturally fluctuates during gait, with separation increasing in the transition to single leg support and reducing upon return to double leg support [2,7,8]. However, if the COM and COP separate to such an extent that the lower-limb joint moments cannot support an upright posture, a fall will occur. Most previous studies evaluating biomechanical aspects of stair negotiation in older adults have investigated performance of this task unaided [e.g., 9,10]. Clearly, it seems intuitive to hypothesize that handrail use will improve safety for older people on stairs; however, an appropriate biomechanical study is required to test this hypothesis and identify any relevant underlying mechanisms. There is only one previous study on the use of handrails during stair negotiation and its influence was examined in a young adult cohort in terms of peak joint moments only [11]. The present study aimed to examine the influence of light handrail use on the kinetics and kinematics of stair negotiation in old age. We hypothesized that light use of the handrails in older adults would aid dynamic balance control during stair negotiation, as indicated by a smaller separation between the COM and COP in the sagittal plane. Secondly, because of the potential benefit for dynamic balance control and based upon joint moment operating ranges established in older adults during unaided stair negotiation [2,3], we hypothesized that light use of the handrails would cause a redistribution of joints moments between the knee and ankle. More specifically, our hypothesis was that the ankle joint moment would decrease but the knee joint moment would increase with handrail use, because the ankle operates much closer to its joint moment limit than the knee during unaided stair negotiation [2,3]).

2. Methods

2.1. Participants

Thirteen older adults (8 females), age: 74.9 ± 2.9 years, body mass: 69 ± 11.9 kg, height: 1.63 ± 0.08 m (means ± S.D.) gave written informed consent to participate in this study. For two participants during stair descent data storage was unsuccessful, so the sample size for stair descent was 11. All procedures complied with the declaration of Helsinki and were approved by the institutional ethics committee. Participants were living independently in the community and received approval from their medical practitioner prior to participation. Exclusion criteria included neuromuscular disorders, a serious musculoskeletal injury, lower-limb pain to a level affecting gait and uncorrected visual problems. Information relating to participant's habitual stair use is shown in Table 1.

Table 1
Participant responses ($n = 13$) to a questionnaire on habitual stair use

Question	Response
1. Do you have stairs in your home?	Yes = 11 No = 2
2. Do you experience any difficulty walking *down* stairs?	Always = 1 Most of the time = 1 Sometimes = 5 Rarely = 2 Never = 4
3. Do you experience any difficulty walking *up* stairs?	Always = 1 Most of the time = 1 Sometimes = 3 Rarely = 3 Never = 5
4. Do you usually hold onto the handrail when walking *down* stairs?	Always = 3 Most of the time = 3 Sometimes = 5 Rarely = 1 Never = 1
5. Do you usually hold onto the handrail when walking *up* stairs?	Always = 2 Most of the time = 0 Sometimes = 5 Rarely = 5 Never = 1
6. Have you ever fallen whilst going *down* stairs?	Yes = 2 No = 11
7. Have you ever fallen whilst going *up* stairs?	Yes = 2 No = 11

Participants were limited to 'yes'/'no' answers for question numbers 1, 6 and 7; for question numbers 2–5 they chose one of 5 possible responses (see table for options).

2.2. Staircase design and experimental procedures

Participants negotiated a purpose-built 4-step instrumented staircase. The dimensions of the staircase were as follows: riser height: 170 mm, going: 280 mm and stair width: 900 mm (Fig. 1). Force platforms sampling at a frequency of 1080 Hz were embedded into the first three steps (Kistler type Z17068, Kistler instruments, Winterthur, Switzerland) and a fourth was embedded into the floor at the base of the staircase (Kistler type 9253A, Kistler instruments, Winterthur, Switzerland). Each step (including the handrails) was a rigid steel structure (the vertical steel frames of the steps had a width of 80 mm and a depth of 40 mm) independently bolted into the ground. This ensured a mechanically stiff construction that enabled forces to be measured independently from each platform (Fig. 1). Participants were asked to negotiate the stairs at their self-selected speed in a step-over manner. Three trials of both unaided stair ascent and descent were conducted with the third trial being selected for further analysis. For stair ascent, the analysed phase (stride cycle) ranged from