Journal of Biomechanics xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Alternate stair descent strategies for reducing joint moment demands in older individuals

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ARTICLE INFO

Article history:
Accepted 20 July 2018
Available online xxxx

Keywords:
Strategy
Hip extensor shift
Step-by-step
Side-step

ABSTRACT

Descending stairs requires elevated joint moment-generating capability in the lower limbs, making it a challenging daily activity, particularly for older individuals. The aim of the study was to investigate the influence of three different strategies for descending standard and increased height stairs: step-over-step (SoS), step-by-step (SbS) and side-step (SS) on lower limb kinetics in older people. Eleven participants (mean ± SD age: 74.8 ± 3.1 years, height: 1.63 ± 0.07 m, mass: 67.7 ± 9.5 kg) descended a four-step custom built instrumented staircase at a self-selected speed, adopting each of the three strategies, at two configurations: a step-rise height of 170 mm (standard; STD) and a step-rise height of 255 mm (increased; INC). 3D motion capture, synchronised with embedded force plates enabled the calculation of joint kinetics of lead and trail limbs. Data were analysed using a Linear Mixed Model with gait speed selected as a covariate during weight acceptance (WA) and controlled lowering (CL) phases. A large increase in hip extensor moment in both WA and CL in the lead limb was evident during both SoS and SbS at INC step height compared to STD ($P < .015$ for all), with no such increase in hip flexor moment evident in SS strategy ($P = .519$). Lead limb knee extensor moment decreased and plantarflexor moment increased in INC SoS compared to STD SoS during CL ($P < .001$ for both). In the trail limb, increased hip extensor and plantarflexor moments were seen in INC SS compared to STD SS ($P < .001$ for both). The alternate strategies result in the overall task demand being split between the lead limb (weight acceptance) and trail limb (controlled lowering). Differential demand distribution patterns exist between strategies that imply targeted interventions and/or advice could be provided to older individuals in order to promote safe descent of stairs, particularly for those with specific muscle weaknesses or at high risk of falls.

1. Introduction

Stair descent can be a hazardous activity for those lacking the necessary musculoskeletal capacity to accomplish this demanding task. Approximately 70% of community-reported falls occur in the home, with 10% of those falls occurring on stairs (Soriano et al., 2007), which can have drastic consequences; not only on the financial burden to health services (Carey and Laffoy, 2005), but also on the subsequent personal impact on quality of life and independence (Bialoszewski et al., 2008).

The demands placed on the lower limbs during stair descent are much greater than that of level gait (Hamel et al., 2005; Nadeau et al., 2003) with substantial eccentric forces generated by the ankle and knee extensor muscles of the leading limb during weight acceptance and by the knee extensor muscles of the trailing limb during controlled lowering, to control the downwards momentum of the centre of mass. Given the age-associated declines in strength and physical function (Clark et al., 2013; Guralnik et al., 1995; Hairi et al., 2010; Raj et al., 2010), it follows that older people have to work close to their maximum strength capacity at their ankles and knees when performing this task (Reeves et al., 2008a; Samuel et al., 2011). This places the older population at a much higher risk of falls, particularly when the demand of the task increases; for example when muscle strength declines further, or when the dimensions of the staircase change i.e. the height of

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https://doi.org/10.1016/j.jbiomech.2018.07.029
0021-9290/

the step increases; which has previously been shown to increase kinematic and kinetic demands in younger adults (Spanjaard et al., 2008). Given that older individual and public dwellings may not comply with post-2010 regulations governing stair design (Government, 2010) and that older individuals negotiate staircases differently to their younger counterparts (Reeves et al., 2008a), this population may require additional support, advice and/or rehabilitation in order to safely negotiate such staircases.

The effects of potential mechanisms or strategies which older people could adopt to ensure safer stair negotiation have been sparsely investigated. Reid et al. (2011) reported that centre of pressure velocity (COPv) was comparable in older and younger individuals with and without handrail use. However, older adults with a fear of falling had a reduced COPv without handrails which reduced further when handrails were used indicating the use of handrails provides additional dynamic stability. In a similar study, Reeves et al. (2008b) explored the impact of light handrail use on lower limb kinetics and kinematics and identified a redistribution of joint moment away from the knee extensors and towards the ankle plantarflexors in older individualss. Despite this increased demand on a smaller and weaker muscle group (Morse et al., 2005), the relative falls risk would be reduced by the additional points of contact (two hands in contact with the handrail) enabling a more effective dynamic balance control strategy to be adopted. Reid et al. (2007) explored the impact of an alternate stair negotiation strategy (i.e. not a traditional step-over-step manner) on knee function in young, healthy adults and revealed reductions in sagittal plane knee moments in both the trailing and leading limbs during weight acceptance and markedly reduced knee moment during controlled lowering in the leading limb. However, given that older individuals typically redistribute joint moments towards the knee in comparison to younger adults (Reeves et al., 2008a) the mechanisms by which older individuals would utilise alternate strategies is unclear.

The purpose of the study was to determine the effect of alternate stair negotiation strategies on lower-limb kinetics in older individuals and quantify how these kinetics change in response to stair negotiation at an increased step height, representing an increase in task demand. This was achieved by drawing comparisons between three stair negotiation strategies, performed at two step heights, in a group of healthy older people. The three strategies investigated were (a) the standard mode of descent with one foot contacting each step (Step-over-Step; SoS), (b) two feet contacting each step (Step-by-Step; SbS) and (c) sideways descend with two feet making contact with each step (Side-Step; SS). It was hypothesised that the alternate stair negotiation strategies would impart different musculoskeletal demands on the limbs and provide a means to alter joint loading in the face of increased step height.

2. Methods

2.1. Participants

All study procedures were approved by the University ethics committee (Manchester Metropolitan University) and all participants gave written informed consent to participate. A total of 11 older adults (six female and five male, mean ± SD age: 74.8 ± 3.1 years, height: 1.63 ± 0.07 m, mass: 67.7 ± 9.5 kg) were recruited from the local and surrounding areas via advertisements placed in newspapers and through links with local community groups. Due to the potentially challenging physical tasks involved in the study, only volunteers receiving approval from their medical practitioner were accepted into the study and were included if living independently in the community and recreationally active.

2.2. Staircase dimensions

Data were collected on a custom-made staircase instrumented with force platforms embedded into three consecutive steps (Kistler type Z17068, Winterthur, Switzerland) and a fourth at the base of the stairs embedded into the floor (Kistler type 9253A, Winterthur, Switzerland). Force data were sampled at 1080 Hz and recorded synchronously with a nine-camera optoelectonic motion analysis system sampling at 120 Hz (Vicon 612 system, Vicon Motion Systems Ltd, Oxford, UK). Each step, including an independently mounted top platform, were independent structures consisting of solid steel frames bolted into the ground. This ensured a mechanically stiff construction that enabled forces to be measured independently form each platform. A handrail was also independently mounted on both sides. Two staircase configurations were utilised in the study; a standard step height (STD; riser 120 mm, tread depth 280 mm, step width 900 mm) and, in keeping with current staircase regulations (Government, 2010), an increased step height (INC; riser 220 mm, tread depth 280 mm and step width 900 mm).

2.3. Testing procedures

All participants were asked to descend the staircase at their own self-selected speed during the three descent strategies: Step-over-Step (SoS), Step-by-Step (SbS) and Side-Step (SS) (Fig. 1). Handrails were present throughout testing as a safety precaution and participants were asked not to use them unless necessary, however no trials were recorded where handrails were used. For the SoS strategy the analysed portion of the descent was taken as initial contact of the left foot on the second step down until initial contact of the same foot on the floor. For the SbS and SS strategies, initial contact was taken from contact of the leading limb (i.e. the limb chosen to initiate the stepping down movement) on step two until initial contact of the same limb onto step three. These gait cycles represent steady-state gait for the leading limb. In the SS strategy, only those trials where the participant descended perpendicular to the staircase (i.e. pelvis and trunk were at an angle 90° relative to the direction of progression) were taken forward for further analysis. For clarity, the trailing limb for all strategies was analysed as a function of the lead limb gait cycle (i.e. graphs are plotted according to the gait cycle % of the leading limb). Due to mechanical and logistical constraints reconfiguring the staircase, full randomisation of strategy sequence was not possible and all three strategies (SoS then SbS followed by SS) were performed at the STD step height followed by all three strategies performed in the same order at the INC step height, on different days, minimising learning effects.

2.4. Data analysis

In order for joint kinetics to be calculated, 34 reflective markers were placed according to the Plug-in-Gait model (Bodybuilder, Plug in Gait model, Vicon Motion Systems, Oxford, UK) and filtered within Vicon using the Woltring filtering routine with a MSE of 20. For exact marker placement see (Reeves et al., 2008a). Anthropometric measurements from each participant were entered into the model and data were exported into Visual3D (C-motion, Rockville, MD, USA) whereby kinetic data were filtered using a low-pass Butterworth filter with an 8 Hz cut off frequency and data were processed for further analysis. Here, gait cycles were identified for each strategy, temporal-spatial parameters (determined through individual gait cycles) were generated, and lower-limb joint moments and powers (both normalised to body mass) were calculated using inverse dynamics prior to being exporting into Microsoft Excel ®, whereby specific peak values were identified

Please cite this article in press as: King, S.L., et al. Alternate stair descent strategies for reducing joint moment demands in older individuals. J. Biomech. (2018), https://doi.org/10.1016/j.jbiomech.2018.07.029