Journal of Biomechanics 48 (2015) 4191–4197

Contents lists available at ScienceDirect

Journal of Biomechanics

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

Biomechanical demands of the 2-step transitional gait cycles linking level gait and stair descent gait in older women

Lisa Alcock [a,b,*], Thomas D. O'Brien [c,d], Natalie Vanicek [b,e]

[a] Institute of Neuroscience, Newcastle University, Newcastle upon Tyne NE4 5PL, United Kingdom
[b] Department of Sport, Health and Exercise Science, University of Hull, Hull HU6 7RX, United Kingdom
[c] Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool L3 3AF, United Kingdom
[d] School of Sport, Health and Exercise Science, Bangor University, Gwynedd, Bangor LL57 2DG , United Kingdom
[e] Discipline of Exercise and Sport Science, Faculty of Health Sciences, The University of Sydney, Sydney, NSW 2141, Australia

ARTICLE INFO

Article history:
Accepted 24 September 2015

Keywords:
Older women
Gait
Stair descent
Transition biomechanics

ABSTRACT

Stair descent is an inherently complex form of locomotion posing a high falls risk for older adults, specifically when negotiating the transitional gait cycles linking level gait and descent. The aim of this study was to enhance our understanding of the biomechanical demands by comparing the demands of these transitions. Lower limb kinematics and kinetics of the 2-step transitions linking level and descent gait at the top (level-to-descent) and the bottom (descent-to-level) of the staircase were quantified in 36 older women with no falls history. Despite undergoing the same vertical displacement (2-steps), the following significant ($p < .05$) differences were observed during the top transition compared to the bottom transition: reduced step velocity; reduced hip extension and increased ankle dorsiflexion (late stance/pre-swing); reduced ground reaction forces, larger knee extensor moments and powers (absorption; late stance); reduced ankle plantarflexor moments (early and late stance) and increased ankle powers (mid-stance). Top transition biomechanics were similar to those reported previously for continuous descent. Kinetic differences at the knee and ankle signify the contrasting and prominent functions of controlled lowering during the top transition and forward continuance during the bottom transition. The varying musculoskeletal demands encountered during each functional sub-task should be addressed in falls prevention programmes with elderly populations where the greatest clinical impact may be achieved. Knee extensor eccentric power through flexion exercises would facilitate a smooth transition at the top and improving ankle plantarflexion strength during single and double limb stance activities would ease the transition into level gait following continuous descent.

1. Introduction

Descending stairs is a common task that permits functional ambulation between different levels. The knee extensors and ankle plantarflexors play an important role in stair descent biomechanics (McFadyen and Winter, 1988; Samuel et al., 2011) by dissipating mechanical energy and enabling forward progression, respectively (Cluff and Robertson, 2011). Considerable eccentric control of the knee and ankle musculature is required to resist the downward influence of gravity as the body undergoes repetitive free fall from one step to the next. Stair locomotion presents a considerable falls risk with early work indicating that 14% of all falls occur on stairs (Cohen et al., 1985) and 75% of all stair-related falls occur during descent compared to ascent in older adults (Masud and Morris, 2001). An important element in designing effective falls prevention programmes requires a comprehensive biomechanical understanding of task demand.

Studies have frequently analysed gait cycles that are initiated and terminated on independent steps while participants negotiate the stairs using a step-over-step, reciprocal gait pattern representative of continuous descent (McFadyen and Winter, 1988; Christina and Cavanagh, 2002; Hamel et al., 2005; Sheehan and Gottschall, 2011). During continuous descent, older adults operate within a higher proportion of their maximal dynamometer-derived capacity for both knee moments (old vs. young; 42% vs. 30%) and ankle dorsiflexion angle (107% vs. 91%) (Reeves et al., 2008). Further work has confirmed that mechanical demands at the knee are greater than at the hip with older adults using on average 100%, and in some cases 150% of available capacity (Samuel et al., 2011). Functional demands at the hip were on average ∼20% of available isometric hip strength for both the

* Corresponding author. Tel.: +44 191 208 1283; fax: +44 191 208 1251.
E-mail addresses: lisa.alcock@ncl.ac.uk (L. Alcock), t.d.obrien@ljmu.ac.uk (T.D. O'Brien), n.vanicek@hull.ac.uk (N. Vanicek).

http://dx.doi.org/10.1016/j.jbiomech.2015.09.020
0021-9290/

flexor and extensor muscles (Samuel et al., 2011). Demands exceeding 100% of capacity may reflect the age-related differences in voluntary drive to activate muscles during selected testing protocols and variation in the protocols utilised (i.e., contraction type, chosen angular position/velocity) which makes direct comparisons challenging. Whilst it is well known that continuous descent poses heightened mechanical demands for older adults, the kinematic and kinetic demands of the transitions linking level and continuous descent gait are less well understood.

One study investigating the influence of step location (comparison between continuous descent in the top and mid-stair region) upon ground reaction forces (GRF) during descent found altered GRF in both young and old (Christina and Cavanagh, 2002). Interestingly, an interaction effect was observed (step location*age) such that loading rates were larger as participants progressed down the staircase and this was more apparent for older adults. In support of this, Lee and Chou (2007) showed that both young and older adults completed the bottom transition more quickly compared to continuous descent. Moreover, the same study indicated that unlike the young, older adults were unable to reduce their centre of mass (COM) sway angles from continuous descent to the bottom transition which the authors suggested may represent a reduced ability to stabilise during this transition (Lee and Chou, 2007). Given the likely increased severity of injury that would result from a fall from the top compared to the bottom of the staircase, and the progressive change in demands thought to occur throughout descent, analysis of lower limb mechanics during both transitions is vital to provide a thorough understanding of task demand and falls risk.

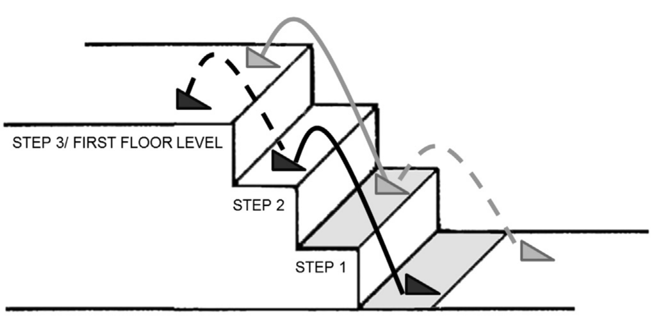

Fig. 1. Schematic demonstrating the lead (black line) and trail (grey line) limb gait cycles during stair descent. The dashed lines represent the 1-step transitional gait cycles of the lead and trail limbs, while the solid lines represent the 2-step transitional gait cycles that were selected for further analysis. The grey shaded steps denote the positioning of force plates for kinetic data acquisition of the lead (ground) and trail (step 1) limbs. Both gait cycles studied were initiated and terminated by toe-off and data are presented firstly by swing, followed by stance.

To the best of the authors' knowledge, only one early study directly compared the top and bottom transitions in young adults. This work revealed that whilst lower limb joints operate within a similar range of motion (ROM) during both transitions, differing kinematic profiles were observed (Andriacchi et al., 1980). Moreover, increased external hip and knee flexor moments and earlier onset of knee extensor muscle activity were noted for the top transition, albeit these differences were not evaluated statistically (Andriacchi et al., 1980) and require confirmation. Redirecting the COM from one level to another requires a prescribed change in lower limb mechanics modulated by changes in both step height and depth in response to staircases of varying design. These movement alterations require a superior level of postural and motor control facilitating appropriate multi-segment co-ordination. The biomechanical requirements to complete both transitional phases are likely to differ from one another as has been demonstrated for stair ascent (Alcock et al. 2014a) and when comparing 1-step transitions with continuous stair gait (Sheehan and Gottschall, 2011). Identifying the biomechanical demands of these transitions would guide evidence-based recommendations for targeted exercises, especially in high-falls risk groups, and encourage safer stair locomotion. This could have greatest impact for older women due to their increased falls occurrence and amplified falls risk associated with stair locomotion (Blake et al., 1988; Campbell et al., 1989; Gine-Garriga et al., 2009).

Therefore, the aim of this study was to compare the lower limb mechanics involved in the 2-step transition from the top and bottom of the staircase in older women with no falls history. It was hypothesised that functional differences would exist between the transitions particularly during stance, with the top transition necessitating greater controlled lowering and presenting demands similar to that of continuous descent (i.e., greater eccentric control of the knee extensors in terminal stance) and the bottom transition stance phase closely representing level gait (i.e., greater concentric knee power generation mid-stance, and larger ankle plantarflexor moments).

Table 1
Mean [SD] temporal–spatial, peak joint kinematics and ROM (degrees) of the limb completing the top transition (top floor level to step 1) and the limb completing the bottom transition (step 2 to level ground).

Variable	Top transition	Bottom transition	95% Confidence interval (lower:upper)	*t*	Sig.	Corrected sig.	Cohen's *d*
Temporal–spatial							
Gait speed (m/s)	.64 [.1]	.84 [.2]	.17:.21	16.7	.001	.0018	9.4
Cycle time (s)	1.36 [.3]	1.22 [.2]	−5.91: −2.91	−6.0	.001	.0018	4.6
Stance (%)	57.7 [3.6]	53.3 [3.6]	−.18: −.11	−8.4	.001	.0018	10.2
Joint kinematics (degrees)							
Hip flexion (early swing)	53.3 [7.8]	46.8 [10.0]	−8.73: −.52	−2.3	.029	.1128	
Hip extension (late stance)	9.2 [11.4]	−2.3 [9.3]	−14.15: −8.78	−8.7	.001	.0064	9.3
Hip ROM	44.4 [8.2]	50.1 [6.9]	1.02:8.48	2.6	.014	.0713	
Knee flexion (early swing)	103.1 [7.2]	100.5 [9.4]	−5.00: −.25	−2.2	.031	.1128	
Knee ROM	91.0 [5.4]	92.3 [7.3]	−1.49:3.95	.9	.362	1.000	
Ankle dorsiflexion (early swing)	18.8 [8.3]	20.7 [7.6]	−.88:4.79	1.4	.170	.541	
Ankle plantarflexion (late swing/early stance)	−18.3 [5.8]	−21.0 [6.6]	−3.99: −1.38	−4.2	.001	.0064	3.7
Ankle dorsiflexion (late stance)	39.4 [7.8]	22.6 [4.9]	−19.38: −14.30	−13.5	.001	.0064	22.0
Ankle ROM	57.7 [6.1]	45.1 [5.7]	−14.92:10.21	−10.8	.001	.0064	17.7

ROM denotes range of motion. At the hip and ankle joints, a negative value [−] indicates hyper [extension] and plantarflexion, respectively.