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Aging may negatively impact movement smoothness during stair negotiation

P.C. Dixon[a,b], L. Stirling[c,d], X. Xu[e], C.C. Chang[f], J.T. Dennerlein[a,g,*], J.M. Schiffman[b]

[a] Department of Environmental Health, Harvard T.H. Chan School of Public Health, Boston, USA
[b] Liberty Mutual Research Institute for Safety, Hopkinton, MA, USA
[c] Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, USA
[d] Institute for Medical Engineering and Science, Massachusetts Institute of Technology, Cambridge, USA
[e] Department of Industrial and Systems Engineering, North Carolina State University, Raleigh, NC, USA
[f] Department of Industrial Engineering & Engineering Management, National Tsing Hua University, Taiwan, ROC
[g] Bouvé College of Health Sciences, Northeastern University Boston, USA Sciences, Northeastern University, Boston, USA

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ABSTRACT

Stairs represent a barrier to safe locomotion for some older adults, potentially leading to the adoption of a cautious gait strategy that may lack fluidity. This strategy may be characterized as unsmooth; however, stair negotiation smoothness has yet to be quantified. The aims of this study were to assess age- and task-related differences in head and body center of mass (COM) acceleration patterns and smoothness during stair negotiation and to determine if smoothness was associated with the timed "Up and Go" (TUG) test of functional movement. Motion data from nineteen older and twenty young adults performing stair ascent, stair descent, and overground straight walking trials were analyzed and used to compute smoothness based on the log-normalized dimensionless jerk (LDJ) and the velocity spectral arc length (SPARC) metrics. The associations between TUG and smoothness measures were evaluated using Pearson's correlation coefficient (r). Stair tasks increased head and body COM acceleration pattern differences across groups, compared to walking ($p < 0.05$). LDJ smoothness for the head and body COM decreased in older adults during stair descent, compared to young adults ($p \leq 0.015$) and worsened with increasing TUG for all tasks ($-0.60 \leq r \leq -0.43$). SPARC smoothness of the head and body COM increased in older adults, regardless of task ($p < 0.001$), while correlations showed improved SPARC smoothness with increasing TUG for some tasks ($0.33 \leq r \leq 0.40$). The LDJ outperforms SPARC in identifying age-related stair negotiation adaptations and is associated with performance on a clinical test of gait.

1. Introduction

In the context of the world's aging population, falls have become a major issue in public health. In the United-States, 2.8 million older adults visit emergency rooms for fall-related injuries, making falls the leading cause of injury-related death (56% for adults 65 years and older, 2014) (Centers for Disease Control and Prevention, 2017). In the built environment, there are many barriers to safe locomotion that may lead to falls such as slippery surfaces, uneven walkways (Dixon et al., 2018), and stairs (Li et al., 2006).

Stair negotiation is a complex task that requires some precaution be taken by older adults to avoid potential injury (Buckley,

* Corresponding author at: Department of Physical Therapy, Movement & Rehabilitation Science, Bouvé College of Health Sciences, Northeastern University, 360 Huntington Ave., Boston, MA 02115, USA.
E-mail address: j.dennerlein@northeastern.edu (J.T. Dennerlein).

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Cooper, Maganaris, & Reeves, 2013; Jacobs, 2016). The joint kinematics and kinetics of stair use in older adults are well known; however, the way older adults control the motion of the body center of mass (COM) to maintain stability and avoid falls during stair negotiation is unclear. Buckley et al. (2013) reported that older adults employed a cautious gait strategy during stair descent characterized by reduced peak vertical body COM velocity and acceleration, compared to young adults. In contrast, Hsue and Su (2014) found increased peak three-dimensional body COM velocity in older, compared to young, adults during stair descent. Mian, Narici, Minetti, and Baltzopoulos (2007) did not find any significant age-related changes in peak COM velocity during stair ascent and decent; however, their cohort of older men had above average levels of physical activity and reported high confidence in performing daily living activities. Analysis of COM acceleration across the entire gait cycle may provide more definitive information than inspection of single peaks (Lenhoff et al., 1999). Also, from a motor control perspective, head stabilization, which is important for visual and vestibular sensory feedback, may be prioritized over body acceleration during gait. Therefore, analysis of head COM acceleration during stair negotiation may also be enlightening.

Based on the qualitative description of older adults' stair gait as "cautious" (Buckley, Cooper, Maganaris, & Reeves, 2013), a quantified understanding of the underlying motion quality is important in analyzing and interpreting these movement patterns. Movement quality has been quantified and found to improve with motor learning and decrease in populations with pathological movement patterns. Hogan and Flash (1987) theorized that healthy, coordinated movement patterns can be characterized as having minimal jerk (time derivative of acceleration) and are therefore smooth. Understanding the underlying motion quality can be challenging as the human movements themselves are complex and variable, and additionally, several jerk-based measures of movement smoothness exist to address these complexities, as Hogan and Sternad (2009) illustrated. Hogan and Sternad highlight that jerk-based analysis ought to consider sensitivity to periods of arrest during the movement and multiple speed peaks. Since then, various metrics to measure movement quality via smoothness have been proposed, c.f. (Balasubramanian, Melendez-Calderon, & Burdet, 2012), which also highlights the complexities of quantifying movement quality or smoothness. Of these, measures based on jerk or analysis of a movement's frequency spectrum appear promising. Hogan and Sternad (2009) showed that jerk measures can be sensitive to differences across populations, but only if they have been rendered dimensionless. Balasubramanian et al. (2012), using simulated movements as well as a reaching task across therapy sessions for a stroke patient, found that dimensionless jerk was valid, but could be improved by applying the natural logarithm. They also proposed a new measure, based on a movement's frequency spectrum arc length, that is valid, reliable, robust, and outperforms existing smoothness metrics (Balasubramanian, Melendez-Calderon, Roby-Brami, & Burdet, 2015). Balasubramanian et al. (2015) state that a general measure of movement smoothness should be able to be applied to a wide range of movement types; however, these two measures have not been implemented in gait or stair negotiation studies to date. Measuring the movement quality during stair negotiation may be helpful to understand how older adults take precautions to avoid fall-related injuries and is important in demonstrating the robustness of a proposed general measure of smoothness.

Stair negotiation contains a similar rhythmic motion and fluidity to gait, but is more challenging from a balance, motor control, and energetics perspective, making it ideal to assess age-related changes in movement ability. There have been attempts to develop clinical tests based on stair negotiation (Bean, Kiely, LaRose, Alian, & Frontera, 2007), but it remains unclear which measures would be most informative. The timed-up and go (TUG) test is a common clinical test of functional mobility (Podsiadlo & Richardson, 1991), but its relationship to difficulties faced by older adults during stair negotiation is unknown. Therefore, a relationship between smoothness of stair negotiation and the TUG test could support the development of smoothness related outcome measures to better understand mobility and improve fall prevention programs.

The aims of this study were to quantify both task- and age-related differences in head and body COM acceleration patterns and movement quality as well as to and determine the relationship between the TUG test completion time and smoothness of the head and body COM during walking, stair ascent, and stair descent in older and young adults. We hypothesized that, for the head and body COM (1) differences in acceleration between older and young adults would be amplified by stair negotiation, not just at peaks, but across the entire movement pattern, compared to walking; (2) older adults would show decreased smoothness compared to young adults especially during stair negotiation, and (3) the association between the TUG test time and smoothness would increase during stair ascent and descent, compared to overground walking, given the increased challenge of these tasks.

2. Methods

2.1. Participants

Nineteen older (74.2 ± 6.0 years, 163.0 ± 8.6 cm, 72.5 ± 17.4 kg) and twenty young (25.0 ± 4.5 years, 171.4 ± 8.6 cm, 70.5 ± 11.0 kg) adults (mean ± standard deviation) were recruited into this study. Exclusion criteria included any history of neurological impairments, musculoskeletal abnormalities, vestibular disorders, or uncorrected visual impairments. The institutional review board of the Harvard T.H. Chan School of Public Health approved this study and all participants provided written informed consent before participating.

2.2. Data collection and initial processing

Participants were fit with a full-body retro-reflective marker set and performed barefoot overground straight walking trials (8.0 m walkway) as well as stair descent and ascent tasks (minimum of six trials per condition) using a reciprocal stepping pattern on a four-step wooden staircase with force plates (Kistler Instrument Corp., Novi, USA) embedded on the ground and first three steps (Fig. 1).