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Gender difference in older adult's utilization of gravitational and ground reaction force in regulation of angular momentum during stair descent

Kunal Singhal *, Jemin Kim, Jeffrey Casebolt, Sangwoo Lee, Ki-Hoon Han, Young-Hoo Kwon

Motion Analysis Laboratory, Department of Kinesiology, Texas Woman's University, 304 Administration Drive, P.O. Box 425589, Denton, TX 76204, United States

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ABSTRACT

Angular momentum of the body is a highly controlled quantity signifying stability, therefore, it is essential to understand its regulation during stair descent. The purpose of this study was to investigate how older adults use gravity and ground reaction force to regulate the angular momentum of the body during stair descent. A total of 28 participants (12 male and 16 female; 68.5 years and 69.0 years of mean age respectively) performed stair descent from a level walk in a step-over-step manner at a self-selected speed over a custom made three-step staircase with embedded force plates. Kinematic and force data were used to calculate angular momentum, gravitational moment, and ground reaction force moment about the stance foot center of pressure. Women show a significantly greater change in normalized angular momentum (0.92 Nms/Kgm; $p = .004$) as compared to men (0.45 Nms/Kgm). Women produce higher normalized GRF ($p = .031$) during the double support phase. The angular momentum changes show largest backward regulation for Step 0 and forward regulation for Step 2. This greater difference in overall change in the angular momentum in women may explain their increased risk of fall over the stairs.

* Corresponding author at: 930 Madison Ave, Memphis, TN 38163, United States. Tel.: +1 901 448 2632.
E-mail address: ksinghal2@hotmail.com (K. Singhal).

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1. Introduction

Walking is a complicated task involving careful control of movement; executed through various cognitive, musculoskeletal, physiological, and psychological processes. With aging, these functions decline predisposing older adults to increased risk of fall and diminished activities of daily living (ADL). Activities like stair negotiation become highly demanding with age (Brouwer & Olney, 2004; Reid, Graham, & Costigan, 2010; Williamson & Fried, 1996) and are associated with a large number of falls among older adults in the U.S. (Centers for Disease Control., 2010; Lord, Ward, Williams, & Anstey, 1993). Stair descent accounts for 75% of falls making it more unsafe than stair ascent (Startzell, Owens, Mulfinger, & Cavanagh, 2000).

Numerous biomechanical studies have been conducted to understand the reasons for increased risk of fall by analyzing the stair walking mechanism in older adults through comparisons of kinematics (Andriacchi, Andersson, Fermier, Stern, & Galante, 1980), ground reaction force (Hamel, Okita, Bus, & Cavanagh, 2005; Novak & Brouwer, 2011; GRF), joint moments and muscle activity (James & Parker, 1989; Spanjaard, Reeves, van Dieen, Baltzopoulos, & Maganaris, 2007, 2008), and center of mass–center of pressure (COM–COP) interactions (Startzell et al., 2000; Zachazewski, Riley, & Krebs, 1993). Though these studies indicated altered walking patterns in older adults, none provided an explanation of how people maintained a stable, fall-free descent.

Mechanically, fall occurs due to a failure to control the angular momentum of the body. Whole body angular momentum is considered a tightly controlled variable (Bennett, Russell, Sheth, & Abel, 2010; Neptune & McGowan, 2011) during a variety of human tasks and studies have suggested that it may be important in maintaining balance and stability during ADL such as sit-to-stand (Riley, Krebs, & Popat, 1997) and trip events (Pijnappels, Bobbert, & van Dieen, 2004). It has also been suggested that during walking, the central nervous system and the control synergies help regulate the angular momentum and thus, the altered regulation of the angular momentum may be a sign of an increased risk of fall (Popovic, Hofmann, & Herr, 2004; Rietdyk, McGlothlin, & Knezovich, 2005).

Most studies utilize segmental contribution in calculating angular momentum. This approach provides important information about the role of segments in whole body stability; nevertheless, the angular momentum is affected by the movement of the body COM with respect to the COP and the external forces acting on the body (Herr & Popovic, 2008; Popovic et al., 2004; Silverman, Wilken, Sinitski, & Neptune, 2011). However, the effects of external forces (ground reaction force and gravitational force) and COM–COP interactions on changes in the angular momentum have been largely overlooked. During the single support phase, the angular momentum is controlled by the gravitational moment alone as COM of the body moves from behind the COP of the stance leg to in front of the COP. However, during the subsequent double support phase, GRF moment acting on the contralateral foot provides an additional mechanism to control the fall of COM. Analyzing the angular momentum from the stance foot perspective reduces these external forces to gravitational force and GRF acting about the contralateral foot. In addition, Pijnappels et al. (2004) suggested that the stance leg provides maximum control of the angular momentum during fall-related events (Pijnappels et al., 2004). Therefore, utilizing the stance foot perspective is a novel way of understanding regulation of whole body angular momentum about the stance foot.

Walking on stairs presents a unique situation where the motion of the body is constrained by step dimension, forcing individuals to walk in a certain pattern. Transition from level walking to stair descent and vice versa would require a careful regulation of angular momentum in order to maintain stability because stair descent and level walking are inherently different. Theoretically, the top most transition step should result in anticlockwise momentum in order to provide control to the descent motion while the step from stairs to level ground should result in clockwise momentum as individuals land on the ground. However, this has not yet been examined and it is important to analyze the mechanism of regulation of the angular momentum of the body during the stair descent transitions. Since most studies do not include a level walk prior to the stair descent provides a more realistic and unique approach to investigate stair descent mechanics as compared to other studies.