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Temporal dependency of sway during single leg stance changes with age

Karen Roemer [a,*], Louisa Raisbeck [b,1]

[a] Department of Nutrition, Exercise, and Health Sciences, Central Washington University, USA
[b] Department of Kinesiology, University of North Carolina at Greensboro, USA

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ABSTRACT

Background: Balance deteriorates with age and fall related injuries are often linked to long-term disability and loss of independence in older adults. This study focuses on the task of establishing single leg stance, which requires the ability to shift the center of mass onto the supporting leg.
Methods: Fifteen younger adults and eight older adults participated in the study. Subjects performed a step with self-selected step length onto the force plate to establish a single leg stance (SLS) on their dominant leg. The first four seconds of SLS were analyzed to investigate age related temporal dependencies of sway area, sway velocity, anterior–posterior sway, and medio-lateral sway.
Findings: Younger adults show a rapid decrease of sway area, anterior–posterior sway, medio-lateral sway, and sway velocity within the first fours seconds while older adults show elevated initial values in anterior–posterior sway and sway velocity and less decrease over time.
Interpretation: Older adults have not only diminished initial sway, but also less ability to control sway during the initial phase of single leg stance. The early phase of single leg stance is rather dynamic in older adults compared to younger adults who maintain their balance after three seconds with small adjustments.

1. Introduction

The trend of increasing age and increasing dependency in the United States is becoming more prevalent. Falling and risk of falls are considered health problems among older adults with falls becoming more apt after the age of 65 (Clemson et al., 2012). Fall related injuries could be costly with 20–30% of falls classified as severe (Sterling et al., 2001). Balance is a very complex motor skill that requires sensory organization of the somatosensory, vestibular, and visual system, as well as biomechanical and motor coordination (Horak, 1997) and it is not possible to link a single sensory system to imbalance in older adults (Baloh et al., 1995, 1998). However, the rate of falls and increasing dependency suggest that there is a need to investigate balance related mechanisms that change with age.

Double Leg Stance and Single Leg Stance (SLS) are common tasks used to assess balance. However, Double Leg Stance has been shown to cause ceiling effects while assessing balance in older adults with Parkinson's Disease (Morris et al., 2000) while SLS is more challenging and therefore more sensitive in healthy individuals (Zumbrunn et al., 2011). Using of SLS as a task to assess balance disorders and risk of falling across age groups is widely accepted (Berg, 1989; Jonsson et al., 2004). Initiating SLS involves a shift of the center of mass and therefore the center of pressure (COP) to the standing leg. The ability to shift the center of mass to the supporting leg and maintain balance is known to deteriorate with age (Prado et al., 2011). Various factors such as a change in leg stiffness (Melzer et al., 2010), cutaneous sensitivity (Callisaya et al., 2009), or balance strategy (Clifford and Holder-Powell, 2010) have been attributed to age related changes in sway performance. Therefore, older adults have increased sway area, sway velocity, and increased sway amplitudes during balance tasks such as the SLS (Berger et al., 2005; Jonsson et al., 2004; Yack and Berger, 1993). However, mixed results are reported for the age related temporal dependency of sway parameters during SLS. Recommendations differ with respect to the stance time that should be analyzed. Using longer time frames (>30 s.) and excluding the initial timeframe of stabilization or even use external support to allow older adults to establish balance has been recommended to increase the reliability of COP measures (Carpenter et al., 2001; Hile et al., 2012; Parreira et al., 2013). However, other studies suggest that the initial timeframe and increased COP movements is meaningful in understanding postural control (Carpenter et al., 2010; Hile et al., 2012; Jonsson et al., 2004). Shifting the COP onto the supporting leg during the initial phase requires postural corrections that will diminish over time after SLS is assumed. This process can be described in two different phases: a dynamic phase in which the magnitude of COP oscillation varies but rapidly decreases and a static phase in which the magnitude of COP oscillation remains relatively stable (Jonsson et al., 2004).

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* Corresponding author at: Department of Nutrition, Exercise and Health Sciences, Central Washington University, 400 E University Way, Ellensburg, WA 98926, USA.
E-mail addresses: roemerk@cwu.edu (K. Roemer), ldraisbe@uncg.edu (L. Raisbeck).
[1] Department of Kinesiology, School of Health and Human Sciences, University of North Carolina at Greensboro, 1408 Walker Ave, 250 HHP Bldg, Greensboro, NC 27402, USA.

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Age related differences in the initial phase during the first five seconds have been reported by Jonsson et al. (2004). They found, that the initial five-second time frame is crucial for SLS balance performance and suggest that age related changes in balance during longer time frames result from disturbances caused during the initial time frame and assumed that force variability would generally decrease during the dynamic phase. In contrast, Parreira et al. (2013) investigated the effect of sample duration on age related differences in sway area and reported that age related differences only occur after the initial phase. The initial phase was defined as the initial five-second time frame of SLS. Therefore, Parreira et al. (2013) recommend longer sample duration to distinguish between age groups. The conflicting results could be attributed to the respective definition of the analyzed time frames. Jonsson et al. (2004) analyzed their data for sequential time intervals (0.0–0.49 s., 0.5–0.99 s., 1.0–4.99 s., 5.0–9.99 s., and 10.0–30 s.) whereas the time frames analyzed by Parreira et al. (2013) always included the initial phase (0.1–4.99 s., 0.1–9.99 s., 0.1–14.99 s., and 0.1–30 s.). Dingenen et al. (2013) reported a time to stabilization of four seconds for the transition between double-leg stance to SLS. Hence, the length of the time interval seems to be crucial to detect age related changes in balance components during the initial phase of SLS. Therefore, only the initial transition phase of four seconds divided into four one-second time intervals will be of interest in this study. Sway area, medio-lateral and anterior–posterior sway amplitude, and sway velocity have been identified as reliable balance parameters (Baldini et al., 2013) and will be used to quantify balance in this study. All four parameters have previously been related to quantify risk of falls in older adults (Piirtola and Era, 2006). It is anticipated that sway area, sway velocity, and sway amplitudes will decrease rapidly during the initial phase of SLS.

To improve our understanding about the temporal dependency of sway during SLS, the aim of the study was to investigate how age impacts the continuous decrease in sway during the initial phase of SLS. It was hypothesized that the decrease in sway area, sway velocity, and medio-lateral and anterior–posterior sway amplitude during the initial phase of SLS will be higher in healthy younger adults than healthy older adults. Additionally, we investigated the impact of age on sway area, sway velocity, and medio-lateral and anterior–posterior sway amplitude within each time interval and hypothesized that younger adults will perform better within each time frame.

2. Methods

2.1. Subjects

Healthy subjects with no history of injuries to the lower extremities or falls were recruited to avoid balance bias related to previous lower limb injuries. Exclusion criteria included any self-reported injuries, falls, medication, musculoskeletal or neurological diseases, and cardiovascular or pulmonary diseases. The purpose of the study was explained to the subjects, and all subjects provided informed consents. This study was approved by the institutional review board.

2.2. Protocol

The experimental session started with a familiarization procedure providing the subjects with standardized instructions that defined the starting position and how to perform a single step onto the force plate. The subjects were allowed to perform test trials until they felt comfortable with the situation. Subjects were then equipped with motion caption markers on their back and leg dominance was determined using a previously validated balance recovery test; the experimenter pushed the subject forward so that the subject had to perform a step to regain balance (de Ruiter et al., 2010). The balance recovery test was chosen to establish balance specific functional leg dominance (Hoffman et al., 1998). This was repeated 3 times and leg dominance was determined as the leg used to step forward at least two out of three times. During this procedure an experimenter assistant was close to the subject to prevent a fall if balance was fully lost. Once leg dominance was determined, subjects were instructed to stand behind a force plate with their feet parallel and hip width apart with hands akimbo so that their toes did not touch the force plate. Upon a verbal cue the subjects performed a step with self-selected step length onto the force plate to establish a single leg stance (SLS) on their dominant leg. The forward step was chosen because anterior–posterior weight shift favors the ankle strategy that is beneficial for balance control (Creath et al., 2005; Hatzitaki et al., 2009). The tests were performed barefoot with eyes open. A valid trial required the movement to be performed without hesitation or prolonged double support phase followed by a stance phase, which had to be maintained for 15 s. A total of five trials were recorded per subject. The COP was measured using an AMTI (60 × 90 cm) force platform using a frequency of 2000 Hz.

2.3. Data analysis

Data analysis started when the load on the stance leg exceeded 50% of the body weight.

The coordinates of the center of pressure (COP) over time were used to calculate the sway path and its first derivative to quantify sway velocity. Furthermore, sway area was calculated using principle component analysis (Oliveira et al., 1996). The first principal component represented the semi-major axis of the sway ellipse, while the second component represented semi-minor axis. The axes lengths were defined as 1.96 times the standard deviation along the respective axis, which includes 95% of data points along each axis.

It was assumed that the subjects established a stable SLS by the fourth second (Dingenen et al., 2013). Therefore, the first three seconds of SLS were analyzed and compared to the fourth second to investigate age related temporal dependencies of sway area (SA), sway velocity (SV), semi-major axis (PC1), and semi-minor axis (PC2).

2.4. Statistics

Data was tested for normality followed by a Levene's test. The data was analyzed with a generalized linear mixed model using the time interval and age as fixed effects with simple contrasts. Satterthwaite approximation and robust covariance were used to address the heterogeneity in the data and the difference in sample size (Catellier and Muller, 2000). The significance level was defined as $p < 0.05$.

3. Results

Fifteen healthy young (Y) adults (mean age 22.5 ± 3.4 y; mean height 168.9 ± 9.3 cm and mean body weight 63.2 ± 10.5 kg) and eight healthy older (O) adults (mean age 67.6 ± 4.1 y; mean height 162.6 ± 10.4 cm and mean weight 63.2 ± 13.9 kg) participated in the study.

3.1. Sway area

The comparison between age groups within each time interval showed no differences in sway area for the younger and older adults for the baseline and in the initial phase. In the time intervals two ($p < 0.001$) and three ($p = 0.03$) the older adults had a larger sway area compared with the younger adults (Fig. 1). The within age group analysis revealed that young adults reduced their sway area over time and showed a smaller sway area in time interval 4 compared to all preceding time frames (1. Sec: $p < 0.001$, 2. Sec.: $p < 0.001$, 3. Sec.: $p = 0.022$). However, the older adults did not decrease their sway area over time (Fig. 1).