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The Association between Unilateral Heel-Rise Performance with Static and Dynamic Balance in Community Dwelling Older Adults

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Abstract

INTRODUCTION—As a measure of both strength and muscle endurance of the plantar flexors, the unilateral heel rise (UHR) test has been suggested as a method to evaluate balance capabilities in older adults. Thus, the purpose of this study was to examine the association between UHR performance with biomechanical measures of balance in seniors.

MATERIALS AND METHODS—Twenty-two older adults completed two testing sessions. The first visit included UHR performance; the second visit included dynamic and static motion analysis.

RESULTS—UHR performance was significantly associated with dynamic balance capability as measured by medial-lateral inclination angle during gait. As indicated by an analysis of center of pressure, there were significant associations between UHR performance and measures of static balance.

DISCUSSION AND CONCLUSION—Balance is influenced by plantar flexor performance as measured by the UHR test. We therefore suggest incorporating the UHR test in analyses of balance in seniors.

Keywords

Plantar Flexor; Triceps Surae; Muscle Test; Physical Therapy; Falls

INTRODUCTION

The increasing incidence of balance-related injuries among older adults is a public health concern.[1–3] According to the Center for Disease Control and Prevention, 1 in 3 adults 65

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years and older fall each year. Twenty to 30% of these falls result in severe injuries, leading to $30 billion in annual direct medical spending.[4]

Maintaining balance encompasses the ability to stand motionless and to react to postural challenges by properly controlling the center of mass relative to the base of support. Balance is realized and sustained by an integration of sensory input from the visual, vestibular, and somatosensory systems, and subsequent motor output.[3, 5, 6] The ability to control balance degrades with age, in part due to gradual declines in muscular performance.[7–9] Therefore, a comprehensive balance examination should include an assessment of static and dynamic activities, as well as lower-extremity muscle endurance and strength.[2, 3, 6, 10–12]

Previous examinations have reported linear associations between plantar-flexor performance with gait and balance capabilities in older adults.[13–18] Regarding *endurance*, Abdolvahabi et al (2011) demonstrated reduced balance ability following an ankle plantar-flexor and knee extensor fatiguing task in an analysis of 30 active older women.[17] Corroborating these findings, Davidson et al (2009) demonstrated a significant association between plantar-flexor fatigue and time to recover from a perturbation in healthy older and younger adults.[18] Ankle plantar-flexor *strength* also appears to be an important contributor to balance capabilities. For instance, recent investigations by Spink et al (2011) and Bok et al (2013) have revealed significant associations between plantar-flexor strength and measures of static and dynamic balance (postural sway, peak balance range, lateral-, and coordinated-stability).[13, 16]

Expectedly, the association between plantar-flexor performance and balance is influenced by age. Wu (1998), for example, reported a significant age-related negative association between ankle plantar-flexor strength and head movements in response to a backwards perturbation on a platform.[14] Similarly, Laughton et al (2003) showed that older adults fallers exhibit significantly greater amounts of anterior-posterior (AP) sway and muscle activity during quiet standing compared with young subjects.[15] These findings indicate age-related declines in muscle, leading to diminished capability to control the center of mass.[14, 15] The functional implications of these findings were demonstrated by Carty et al (2012). These researchers reported that seniors with lower limb muscle weakness of the ankle plantar-flexors were more likely to use multiple steps, compared with a single step, when recovering from a forward loss of balance.[5] These findings support the notion that ankle plantar-flexor performance influences laboratory measurements of balance, and highlights the importance of assessing plantar-flexor muscle performance when evaluating balance capabilities in older adults.

The manual muscle test is the most commonly used measure of strength performance in the clinic.[19–21] During manual muscle testing, patients are graded according to their ability to move voluntarily and resist an externally applied force by the practitioner.[19] Because of the small lever arms of the plantar-flexors across the foot (i.e. distance between muscle insertions and the ankle joint center), applying appropriate resistance can be challenging in healthy individuals.[22] Unsurprisingly, this creates a ceiling effect with manual muscle testing in individuals with normal strength.[23–26] Due to these limitations, the unilateral heel-rise test (UHR) has been implemented as a surrogate to manual muscle testing.[20, 27]

As the UHR test quantifies the number of repetitions a person can complete, it is an assessment of *both* muscular endurance and strength.[19, 20, 27]

Although the aforementioned studies have demonstrated that balance is independently associated with endurance and strength of the plantar-flexors [13–18], no single test that incorporates both endurance and strength has been examined in relation to balance performance in community-dwelling older seniors. Therefore, the purpose of this study was to investigate the hypothesized positive association between balance performance and UHR repetition in healthy, independent, older adults.

MATERIALS AND METHODS

Participants

All participants were part of the Yoga Empowers Seniors Study (YESS): a single-arm, 32-week intervention study examining the biomechanics and physical adaptations associated with yoga participation by seniors. We report findings from the baseline evaluation, which included a battery of functional performance and balance-assessment outcomes. Complete data (for functional and balance assessment measures) were available for twenty-two (6 males and 16 females) of the participants. The average age, height, and weight for these community-dwelling older adults was 71.0 ± 4.3 years, 1.67 ± 0.09 m, and 71.1 ± 15.9 kg, respectively. All participants resided in the greater Los Angeles area and were included if they were 65 years of age or older, were not high-level exercisers or frequent long walkers. For further details regarding the inclusion/exclusion criteria, please refer to Greendale et al (2012).[28] Informed consent was obtained from all participants on a format approved by the Institutional Review Board of the University of Southern California (USC).

Design & Outcome Measures

A cross-sectional secondary analysis of data from YESS was conducted. As a part of the baseline YESS protocol, participants attended the Musculoskeletal Biomechanics Research Laboratory (MBRL) at the USC Health Science Campus. The protocol consisted of two visits to MBRL, one-week apart. The first visit was approximately 1-hour in length and consisted of functional performance measures, including the UHR test. An examination of the UHR test was of particular interest attributed to its potential for implementation as part of a comprehensive balance evaluation. The second visit consisted of a biomechanical assessment of gait and balance, as well as yoga participation. The total duration of the second visit was approximately 3 hours.

Unilateral Heel Rise Test—The UHR testing procedure and criteria for a successful repetition was predicated upon previous investigations by Lunsford and Perry (1995) and Jan et al (2005).[19, 20] Initially, the height of a full heel-rise effort was assessed by asking the participant to perform a barefoot single-leg-stand on their dominant limb, defined as the leg with which they kick a ball. The participant was then instructed to stand tall on the ball of their foot with their heel as high off the ground as possible. Per the method of Yocum et al (2010), the level of the lowest edge of the heel was identified; then, the midway point from the heel to the floor was marked with masking tape on a wall.[27] For performance of the test, the participants were instructed to stand on their dominant limb, and raise their heel up and down as many times as possible at a pace of one heel-rise every two seconds, cued with a metronome.[19, 20] The subjects were allowed to place a single-finger on the wall and were guarded by a practitioner for safety. The number of heel-rise cycles (i.e. the number of times the dominant heel reached the tape) was recorded. The test was terminated when the participant was unable to continue, they could no longer reach the tape, or were unable to maintain pace with the metronome. The (single) practitioner who administered the UHR test – a post-doctoral fellow in Biokinesiology – demonstrated strong reliability in this methodology.

Biomechanical Assessment of Balance—One week later, in order to examine center of mass profiles, participants were instrumented for a whole-body biomechanical analysis. Reflective markers were placed on a head band and over the following anatomical landmarks of the lower- and upper-extremities bilaterally: first and fifth metatarsal heads, malleoli, femoral epicondyles, greater trochanters, acromions, greater tubercles, humeral epicondyles, radial and ulnar styloid processes, and third metacarpal heads. Markers were also attached to the spinous process of the 7th cervical vertebrae, jugular notch, L5/S1, bilateral iliac crests, and bilateral posterior superior iliac spines. Based on these markers, a total of 15 body segments were modeled: the head, trunk, pelvis, the upper arms, forearms, hands, thighs, shanks, and feet. Non-collinear tracking marker plates were placed on each of these segments using previously documented procedures.[29, 30] The research personnel involved with instrumentation – 2 PhDs, 2 Masters, and 2 PhD students – were reliable in their marker placement.

Three-dimensional coordinates of the body segments were recorded by an eleven-camera system at 60 Hz (Qualisys, Gothenburg, Sweden). Ground reaction forces (GRFs) were measured from separate force platforms at 1560 Hz (AMTI, Watertown, MA). With the use of Visual3D Version 4, (C-Motion Inc., Germantown, MD) standardized anthropometric data were used to calculate individual segment COM locations, and total body COM.[31] All balance measures were determined from a custom written program in MATLAB (The MathWorks; Natick, MA, USA).

Data Analysis

Dynamic Balance—Once instrumented, the participants were instructed by a practitioner to complete 2, 8-meter walking trials, at their self-selected speed. The participants were guarded during gait activity by a Physician or Physical Therapist involved with the study. The center of pressure was determined from ground reaction forces. Peak and mean center of mass – center of pressure inclination angles in the medial-lateral direction were quantified during the stance-phase of gait.[32] Inclination angles were assessed using the methods of Lee and Chou (2006) and Silsupadol et al (2009).[32, 33] A line between the participant's center of mass and the center of pressure of the supporting foot during gait was determined. The line was referenced to the vertical line passing through the center of pressure in order to provide a medial-lateral inclination angle in the frontal plane. Greater medial-lateral inclination angles are associated with poorer gait stability in older adults.[32]

Static Balance—For static balance, the participants were instructed to stand with their feet together as still as possible, on a force plate, with their arms at their sides. Each individual completed two conditions in double stance: eyes open and eyes closed. For the eyes open condition, they were additionally instructed to look straight ahead throughout the trial. Each static balance task was initiated by the examiner by verbalizing the word “go” to the participant. Each individual attempted to complete three, 20-second trials of the eyes open and closed conditions. During static balance testing, the participants were guarded by a Physician or Physical Therapist involved with the study.

Static balance was assessed using four variables of center of pressure motion [34–36]: Mean center of pressure deviation, root mean square values of center of pressure excursion in the medial-lateral and anterior-posterior directions, as well as the root mean square value of total center of pressure excursion. Mean deviation was measured as the distance relative to the average of all data points (the centroid) of the center of pressure excursion. The mean of three trials for each condition was calculated. Lower center of pressure excursions are associated with higher static balance ability in older adults.[35, 37]

Statistical Analysis

The number of complete heel rises achieved during the UHR test, and the mean of each of the aforementioned dynamic and static balance variables were used for statistical analysis. UHR performance was correlated with the respective balance variables using Pearson product-moment correlation coefficients ($p<.05$). All statistical calculations were conducted using SPSS Version 18.0 (IBM Corporation; New York, USA).

RESULTS

Mean UHR performance across participants was 21.3 +/− 6.1 repetitions. With regards to dynamic balance, there was a significant association between UHR and peak medial-lateral inclination angle (3.6+/−2.5°; $r= -0.422$) at the $p<.05$ significance level (Fig. 1), but not between UHR and mean medial-lateral inclination angle. During the static balance eyes open condition, there were significant correlations at the $p < .05$ level between UHR performance and mean deviation ($r=-.360$), medial-lateral root mean square ($r=-0.407$), total root mean square ($r=-0.376$), but not anterior-posterior root mean square ($r=-0.246$) (Fig. 2). During the static balance eyes closed condition, there were significant correlations at the $p <.05$ level between UHR performance and mean deviation ($R= -0.448$), medial-lateral root mean square ($r= -0.404$), anterior-posterior root mean square ($r= -0.456$) and total root mean square ($r= -0.460$) (Table 1 & Fig. 3).

DISCUSSION

The results for the correlation analysis between UHR and measures of medial-lateral inclination angle indicate that peak medial-lateral inclination angle was significantly associated. Measuring inclination angles provides a clear way of defining center of mass movement, independent of height, and gait speed.[32] Therefore, the significant correlation between peak medial lateral inclination angle and UHR (Fig. 1) has important implications. Lee and Chou (2006) found that older adults with balance disorders demonstrate significantly greater inclination angles than healthy older adults during both unobstructed gait and obstacle negotiation. Thus, these authors suggest peak medial-lateral inclination may be a sensitive measure of gait stability in older adults.[32] In accordance with these findings and in light of the negative correlation between peak medial-lateral inclination angle and UHR performance in our results, it is plausible that plantar-flexor muscular endurance capabilities may influence gait stability (and dynamic balance control) in older adults. Further research is required in order to directly examine this association, as well as to determine the link between these laboratory measures of balance and actual fall risk.

The UHR test demonstrated significant associations with 3 variables of center of pressure excursion in the eyes open condition (mean deviation, medial-lateral root mean square and total root mean square) and all 4 variables in the eyes closed condition (mean deviation, medial-lateral root mean square, anterior-posterior root mean square and total root mean square) (Table 1). In each of these negative correlations, better performance of UHR was associated with reduced center of pressure motion. Hasan et al. (1996) reported significant correlations between center of pressure-based and center-of-gravity-based measures of excursion in double support eyes open, eyes closed, and single-support eyes open stance conditions.[35] These authors suggested their findings strengthened the argument that center of pressure-based measurements are valid and can be used to quantify balance impairments in the standing position. Similarly, we have demonstrated significant correlations between UHR and mean deviation in both eyes open and eyes closed conditions, indicating that balance performance is related to plantar-flexor strength and endurance.

The UHR test is reliable to use in adults ages 21–80 (ICC= 0.89).[20] Lunsford and Perry (1995) reported that 25 repetitions is considered *normal* UHR performance for adults between the ages of 20–59 years.[19] To carry out the test, these researchers used an electrogoniometer to measure peak ankle angle.[19] To be considered a successful heel rise repetition, the participants had to reach at least 50% of initial starting range of motion. This method is in contrast to that of Yocum et al (2010), who examined this paradigm in children, and placed a mark on an adjacent wall to identify 50% of the maximal heel height excursion.[27] Incorporating this methodology, we report an average of 21.3+/− 6.1 UHR repetitions. Our findings are consistent with that reported by Lunsford and Perry (1995), albeit in an older subject population. We believe this will help inform clinical practice as to what is considered normal UHR performance for healthy older adults. Yet, there is a strong necessity to establish valid normative data for UHR performance in all age groups and sub-populations.

We acknowledge limitations of the current study. The study sample consisted of active older adults who were predominantly Caucasian women from the West Los Angeles area. Furthermore, in light of the study design, the participants were not randomly selected, but rather volunteered to participate in a yoga and biomechanics study. Therefore, this sample likely represents a healthier, physically-active subset of the older adult population. Accordingly, it is important to emphasize that our data can only be generalized to healthy community-dwelling older men and women.

CONCLUSIONS

The results of this study indicate that UHR performance is better correlated with variables of static than dynamic balance in community dwelling older adults. Balance is influenced by vision, vestibular, somatosensory, and physical functioning. Thus, the fact that UHR performance explained no more than 16% of the variance in any balance measure was not entirely surprising. Rather, the findings indicate the multimodality of balance and the need for *comprehensive evaluations* when assessing balance. We therefore suggest incorporating the UHR test in comprehensive evaluations of balance and plantar-flexor performance in older adults. Further research is required to determine the association between UHR capabilities with functional and community-based balance performance in healthy and health-compromised older adults.

Acknowledgments

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HIGHLIGHTS

- Mean UHR performance was 21.3 +/− 6.1 repetitions
- There was a significant association between UHR and a measure of dynamic balance
- There were significant associations between UHR and measures of static balance

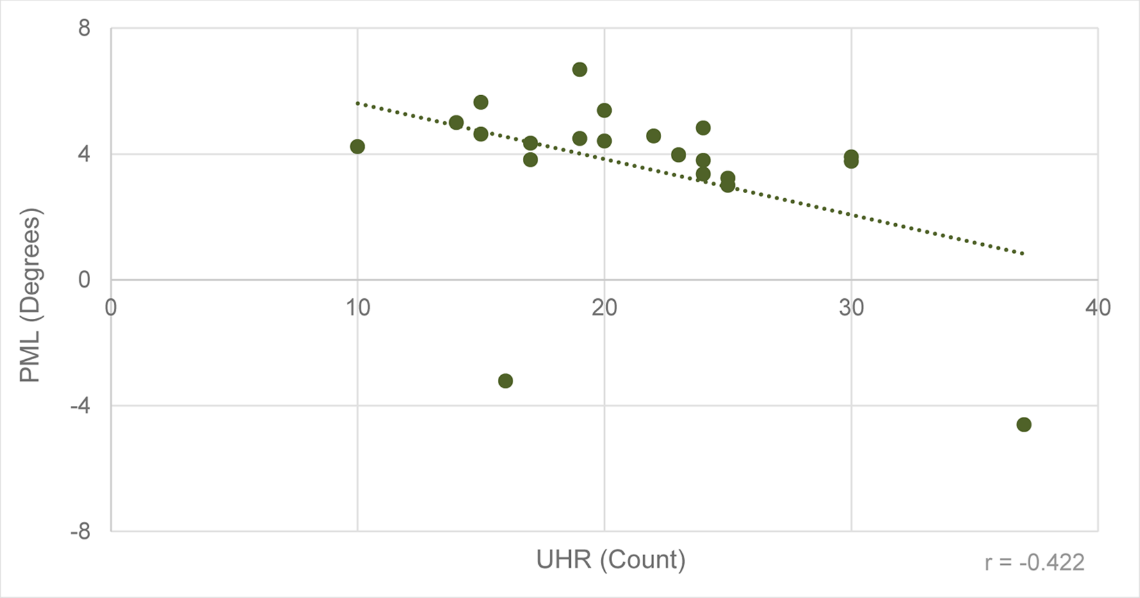

Figure 1.

Best fit line of the association between peak medial-lateral (PML) inclination angle and heel rise count. Lower peak inclination angles are suggestive of better dynamic balance.

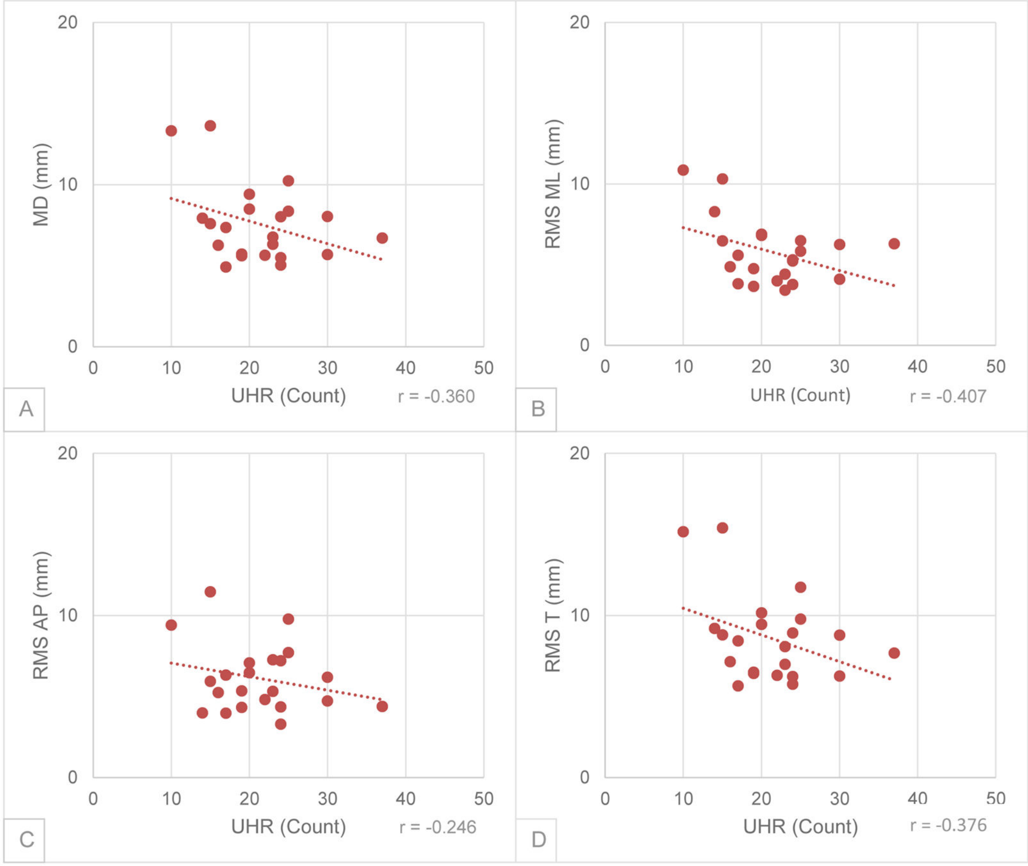

Figure 2.

Best fit line of the eyes-open static balance measures against heel-rise count: A) mean deviation (MD); B) root mean square medial-laterally (RMS ML); C) root mean square anterior-posteriorly direction (RMS AP); D) total root mean square (RMS T). There were significant negative associations between UHR and MD, RMS ML and RMS T at the p <.05 level. Less excursion is suggestive of better static balance.

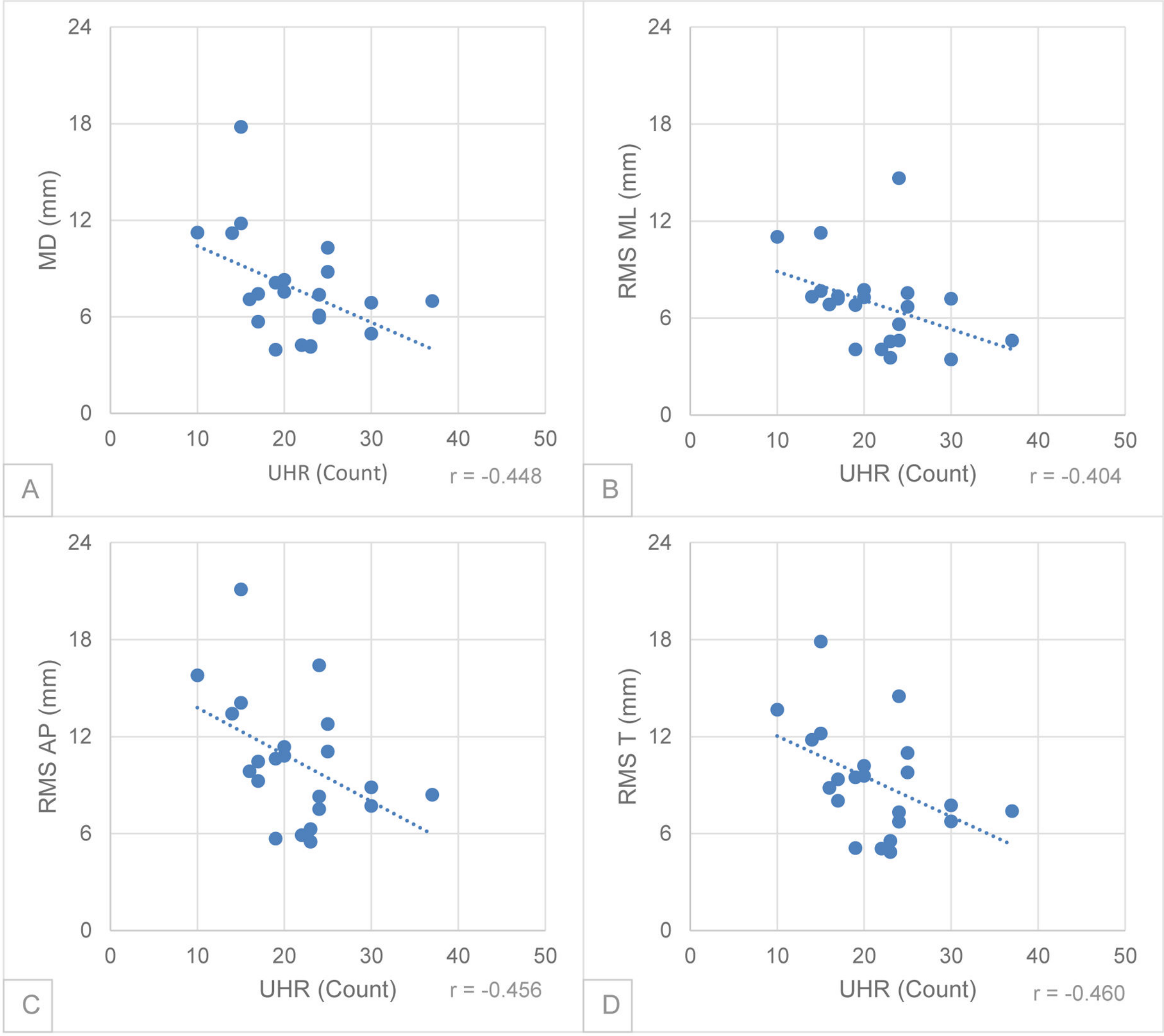

Figure 3.

Best fit line of the eyes-closed static balance measures against heel-rise count: A) mean deviation (MD); B) root mean square medial-laterally (RMS ML); C) root mean square anterior-posteriorly (RMS AP); D) total root mean square (RMS T). All (negative) associations were significant at the p <.05 level. Less excursion is suggestive of better static balance.

Table 1

Means and standard deviations across the static balance measures.

	MD (mm)	RMS ML (mm)	RMS AP (mm)	RMS T (mm)
Eyes Open	7.56 +/− 2.4*	5.78 +/− 2.0*	6.12 +/− 2.1	8.59 +/− 2.7
Eyes Closed	7.73 +/− 3.3*	6.86 +/− 2.7*	10.5 +/− 3.9*	9.21 +/− 3.3*

*Denotes significance at the p <.05 level