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Ankle Dorsiflexion Effects on Gait and Balance

The relationship of weight-bearing and non-weight bearing ankle dorsiflexion to balance and gait performance in young and older adults

Abstract

Background: Limitations in ankle dorsiflexion have been associated with balance dysfunction and the development of altered gait patterns. Methods to assess ankle dorsiflexion include non-weight bearing and weight-bearing positions. While the non-weight bearing position is the traditional method for the assessment of ankle dorsiflexion range of motion, the mobility requirements for ankle DF during gait and balance are primarily weight-bearing related. The purpose of this study is to investigate the relationship of ankle dorsiflexion, measured in non-weight bearing and weight bearing positions, to balance and gait performance in healthy young and older adults.

Methods: Subjects were divided into a young age group (n=22; age range 20-40; mean age 27.5±4.4 years old) and an older age group (n=15; age range 60-80; mean age 70.3±5.3 years old). Ankle dorsiflexion was measured under 3 conditions: non-weight bearing active range of motion, non-weight bearing passive range of motion and weight bearing dorsiflexion. Balance was assessed using the limits of stability test on the Neurocom Smart Balance Master. End point excursion and maximal excursion were used to quantify balance performance in the forward direction of the LOS. Gait performance was assessed using spatiotemporal gait parameters using the GAITRite electronic walkway. Gait speed, cadence, step length, stance time, and single support time were used to quantify gait performance. Two-way ANOVA compared each method of ankle dorsiflexion for each age group. Independent t-tests examined differences between each age group for balance and gait parameters. Pearson correlation coefficients assessed associations between each method of ankle dorsiflexion to gait and balance measures.

Results: There was a significant difference between all measures of ankle dorsiflexion (non-weight bearing active<non-weight bearing passive <weight bearing) for each age group ($P<0.01$). For the young age group, the correlation between method of ankle dorsiflexion and balance was significant for non-weight bearing methods and the variable of maximal excursion ($r=0.43-0.51$; $p<0.04$). For the older age group, the correlation between method of ankle dorsiflexion and balance was significant for weight bearing methods and maximal excursion ($r=0.53$; $p=0.04$). The correlation between method of ankle dorsiflexion and gait performance was significant only for the young age group and the methods of non-weight bearing dorsiflexion and the parameters of cadence, stance time, and single support time ($r=0.51-0.57$; $p<0.01$). The correlations between gait and method of dorsiflexion for the older age group were non-significant.

Conclusion: The correlations between method of ankle dorsiflexion measurement and balance and gait performance differed between the young and older age groups. Ankle dorsiflexion measured with non-weight bearing methods resulted significant correlations for balance and gait in the young age group, while ankle dorsiflexion measured with weight bearing methods resulted in a significant correlations for balance in the older age group.

Keywords: Weight bearing dorsiflexion, ankle dorsiflexion range of motion, older adults, limits of stability, spatiotemporal gait paramters

Introduction

Ankle dorsiflexion (DF) range of motion (ROM) is commonly assessed when impairments of gait and balance are identified during the clinical examination process. Methods to assess ankle DF ROM can be broadly categorized by the contact position of the foot, non-weight bearing (NWB) or weight bearing (WB). The weight bearing dorsiflexion (WBDF) method is reported to have higher intrarater and interrater reliability and to result in significantly greater ankle DF as compared to NWB methods [1]. WBDF methods include the weight bearing lunge test as described by Bennell et al., [2] or variations involving the use of an inclinometer to measure ankle DF of the forward or backward positioned lower extremity in the lunge [3]. NWB methods to measure ankle DF ROM include active (AROM), passive (PROM) and active-assisted (AAROM). While the NWB position is the traditional method for the assessment of ankle DF ROM, mobility requirements for ankle DF during the stance phase of gait and during dynamic standing balance tasks are primarily WB related. Prior research has examined the relationship of ankle DF ROM to balance and to gait performance, however, this research has focused primarily on one method, weight bearing or non-weight bearing, and one age group, young or older adults.

Research involving young adults has examined the relationship of ankle DF mobility to dynamic balance using the Star Excursion Balance Test (SEBT)or to gait using spatiotemporal gait parameters [4-7]. Significant correlations (r=0.41 to 0.59) between ankle DF measured in WB and the anterior direction of the SEBT have been reported for healthy young adults 4 and for young adults with chronic ankle instability (CAI) [3,6,7]. When ankle DF was measured in NWB using AROM methods, the relationship between ankle DF ROM and dynamic balance was fair (r=0.40, p=0.015) [7]. Only one study has investigated the relationship of ankle DF ROM to gait performance of young adults [5]. This study involved young adults with lateral ligament sprain of the ankle and measured ankle DF using passive NWB methods. Significant correlation were reported between ankle DF ROM and stride velocity (r=0.472) and step length (r=0.422).

Research investigating the relationship of ankle DF to gait and balance in older adults has utilized either NWB or WB methods to measure ankle DF [8-11]. The findings of this research is less conclusive than the findings pertaining to young adults. Menz et al., [11] reported significant moderate correlations of WBDF ROM to forward leaning balance (r=0.51) and gait speed (r=0.550) in older adults, however, a follow-up study by Spink et al., 2011 found these correlations to be fair to poor (r<0.28). Mecagni et al., [9] found a significant correlation between NWBDF AROM and Functional Reach (FR) (r=0.52) and Performance-Oriented Mobility Assessment(POMA) gait score (r=0.44). Chiacchiero et al., [8] however, found non-significant relationship between NWB DF AROM and balance assessed with both TUG and FRT in both older adults classified as fallers or non-fallers despite significant differences in ankle DF ROM between the fall groups.

While NWB methods to examine the presence of ankle DF ROM are used more frequently than WB methods to measure ankle DF mobility in the clinical setting, WB methods more closely resemble the closed-chain function of the ankle during standing dynamic balance tasks and during the stance phase of gait. With the exception of one study of young adults, all prior research involving young or older adults and the relationship of ankle DR ROM to balance and gait has examined only one method of measuring ankle DF ROM [7]. It remains unknown how the method to measure ankle DF may affect the association of DF to balance and gait.

Research regarding the relationship of ankle DF to balance and gait performance is varied in the type of tests utilized to assess dynamic balance. In the research involving young adults, all studies have used the SEBT as a measure of dynamic balance. The SEBT measures the maximal distance reached with one lower extremity while standing on the opposite lower extremity. Maximal reach distance of the non-stance lower extremity is attained by varying combinations of hip and knee flexion and ankle DF of the stance lower extremity. Research involving older adults has examined dynamic balance primarily through the use of performance based tests such as FR, Timed Get Up and Go (TUG), and POMA. Only two studies have attempted to quantify postural control during dynamic standing tasks through the use of a sway meter [10,11]. Chiacchiero et al., [8] cite the use of performance based balance tests (FR and TUG) as a possible limitation to their study and recommend the use of more objective methods, such as the use of a force plate to quantify balance ability. One such objective measure of dynamic balance ability is the limits of stability (LOS) test in which ankle DF is a component of the forward leaning directions. During the LOS test, a force plate is used to measure center of gravity (COG) movement as an individual maximally leans in a direction toward a target displayed on a monitor screen without taking a step, lifting their heels or losing balance [12]. Postural stability is quantified during the leaning movements by selecting from the parameters of maximal excursion, end point excursion, directional control, and movement velocity.

A limited number of studies have examined the relationship of ankle DF ROM to gait performance. In the one study that involved young adults, gait performance was assessed using motion analysis to measure spatiotemporal gait parameters. Research involving older adults have utilized functional based tests as an indicator of gait ability such as TUG and POMA gait subset. Only two studies with older adults quantified gait performance by measuring the parameter of gait speed [10,11]. Deficits of ankle dorsiflexion during gait have been found to discriminate between healthy young and older adults, high performing and low performing older adults, and between fallers and non-fallers [13-15]. To date, however, only one study has examined the relationship ofankle DF ROM to multiple spatiotemporal gait parameters. This study measured ankle DF using NWB PROM methods and found significant correlations between ankle DF ROM and spatiotemporal gait parameters of stride velocity and step length in young adults. The relationship of ankle DF ROM to gait performance measured from multiple spatiotemporal parameters in older adults has not been investigated.

In summary, research regarding the relationship of ankle DF ROM to gait and balance performance has found fair to moderate correlations for both young and older adults, yet no research has included both NWB and WB methods to measure ankle DF ROM nor has research included both young and older adults. The use of more objective measures of balance and gait performance, such as balance assessed with the LOS test using a force plate during and spatiotemporal gait parameters collected with an instrument walkway, may provide further insight to the relationship of ankle DF ROM to balance and gait performance. Understanding the relationship of ankle DF mobility to gait and balance performance may lead to the identification of modifiable factors that, when addressed, could potentially affect the development of gait and balance dysfunction. Thus, the aim of this study was to investigate the relationship of ankle DF, measured with NWB and WB methods, to balance and gait performance in healthy young and older adults. Based on WBDF more closely resembling ankle dorsiflexion that occurs during the LOS test and during the stance phase of gait, we hypothesized that WBDF measurements would have stronger correlations to balance and gait parameters in both young and older adults as compared to NWB methods.

Materials and methodology

Subjects

Healthy, young (ages 20-40) and older (ages 60-80) adults were recruited as a sample of convenience sampling from the University and the surrounding community resulting in 22 young (27.5±4.4) and 15 older (70.3±5.3) participants. Participants were excluded if they were unable to follow simple instructions, had a recent (within the past 6 months) lower extremity musculoskeletal or neurological deficit, were unable to stand without loss of balance, or were unable to walk without an assistive device. Informed consent was obtained from each participant prior to participation in the study.

Testing protocol

Non-weight bearing ankle dorsiflexion ROM

The participant was positioned in a long-sitting position with their right foot off the treatment table. After a warm-up consisting of ankle pumps for 30 seconds, 3 trials of non-weight bearing active ROM (NWB-AROM) followed by 3 trials of non-weight bearing passive ROM (NWB-PROM) were measured using standard goniometric measurement methods with the knee extended [16]. The average of the 3 trials was used in the analysis. Intra-rater reliability of the examiner conducting NWB ROM measurements was established in a pilot study to be good for both NWB-AROM ($ICC_{3,1}$=0.976) and NWB-PROM ($ICC_{3,1}$=0.962) in healthy individuals.

Weight-bearing ankle dorsiflexion (WBDF)

Prior to performing the WBDF, the participant performed weight bearing mini-squats for 30 seconds at a comfortable speed to serve as a warm-up. The participant then stood facing a wall and performed a lunge by stepping their left lower extremity forward. The knee of the left lower extremity was slowly flexed toward the wall without either lifting the heel or bending the knee of the right leg. An inclinometer was placed on the anterior tibia of the right lower extremity to measure weight-bearing ankle DF (Figure 1). Three trails of WBDF were measured and the average of the 3 trials was used in the analysis. Intra-rater reliability of the examiner conducting the WBDF measurements was established in a pilot study to good ($ICC_{3,1}$=0.966) in healthy individuals.

Figure 1. Positioning for measuring weight bearing dorsiflexion range of motion.

Gait assessment

Quantitative gait assessment was performed using the GAITRite instrumented walkway (Figure 2). High validity and test-retest reliability has been reported for GAITRite measurements of spatiotemporal gait parameters [17,18]. A 2-meter acceleration and deceleration distance on either end of the GAITRite was provided to allow attainment of a stable gait pattern. The participant performed one practice trial before walking on the GAITRite walkway twice at their preferred speedwithout shoes. Data from footfalls were processed by the GAITRite

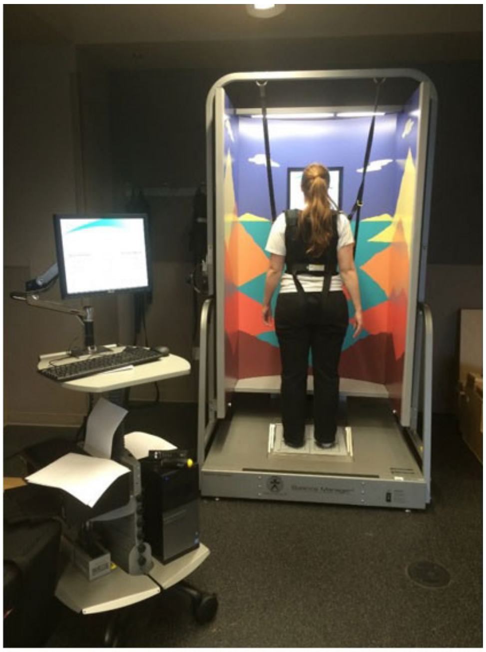

Figure 2. Limits of Stability test with the Neurocom SMART Balance Master.

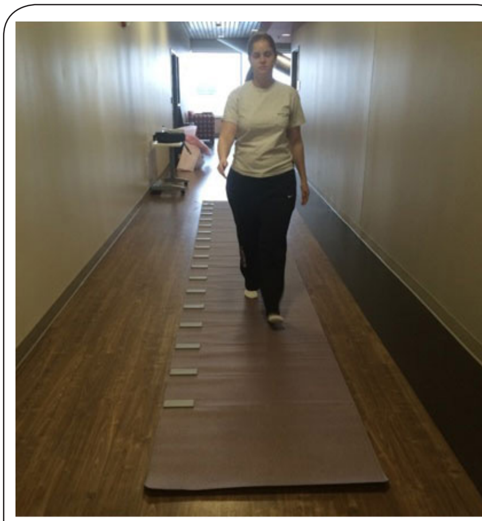

Figure 3. Gait performance assessed with the GAITRite electronic walkway.

software to compute spatiotemporal gait parameters from the average of the two passes across the GAITRite. Gait parameters assessed included velocity, cadence, stance time, single support time and step length. Since ankle DF was measured for the right LE, only step length left (SL-L), stance time right (ST-R) and single support time right (SST-R) were included in the analyses. Step length was defined as the distance in centimeters between the heel center of the right heel to the heel center of the previous foot on the opposite side. Stance time right was defined as the percentage of the gait cycle time weight bearing occurs on the right lower extremity. Single support time right was defined as the percentage of the gait cycle time between the last contact of the left footfall and the first contact of the next left footfall [19].

Limits of stability

Dynamic balance was assessed using the limits of stability (LOS) test on the Neurocom SMART BalanceMaster (**Figure 3**). Moderate to high test-retest reliability has been reported for LOS test performed using the Neurocom SMART Balance Master [20]. The LOS involves the participant standing on the platform of the BalanceMaster and leaning as far in the specified direction as possible without taking a step or lifting their heels. Three trails were performed in each of 4 cardinal directions and 4 diagonal directions. Since the relationship of ankle DF to LOS was of interest, only LOS parameters in the forward (F), right forward (RF) and left forward (LF) directions were included in the analyses. LOS parameters examined included end point excursion (EPE), defined as the percentage of distance achieved on the first movement toward a target placed at 100% of LOS based on height, and maximal excursion (MXE), defined as the maximum distance attained toward a target placed at 100% LOS [12].

Data analysis

A 2 (age group)x3 (measurement method of ankle DF) analysis of variance was conducted to examine measures of ankle DF between young and older participants. Independent t-tests were used to compare balance and gait parameters between each age group. Pearson correlation coefficients were calculated to examine the relationships of each method of ankle DF measurement to gait parameters and to measures of LOS. Relationships were interpreted as follows: little or no relationship (r=0.00-0.25), fair relationship (r=0.25-0.50), moderate to good relationship (r=0.50-0.75), good to excellent relationship (r>0.75) [21]. Coefficient of determination (r^2) was calculated for all significant correlations to estimate the variation in the balance and gait parameters that is explained by the ankle DF measurement method. Two-way mixed model 3 intraclass correlation coefficients (ICC) were used to analyze intra-rater reliability of the examiner conducting all ankle ROM measurements. All analyses were run with SPSS with statistical significance set at $p \leq 0.05$.

Results

Demographic characteristics for each age group is presented in **Table 1**. Intra-rater reliability for NWB and WBDF measurements was good for both young (AROM ICC=0.926; PROM ICC=0.959; WBDF ICC=0.935) and older adults (AROM ICC=0.919; PROM ICC=0.920; WBDF ICC=0.917). For both age groups, there were significant increases in ankle DF from NWB-AROM to NWB-PROM to WBDF ($p<0.001$). Young and older age groups had significant differences in ankle DF only for NWBAROM ($p=0.013$). There were significant differences ($p<0.02$) between age groups in gait velocity, step length, single support time, end point excursion in the forward (EPR-F) and right forward (EPE-RF) directions, maximal excursion in the forward (MXE-F) and right forward directions (MXE-RF), with younger adults having higher metrics for each of these parameters (**Table 1**).

Table 1. Mean (SD) of participant demographic characteristics, ankle range of motion values and performance metrics for balance and gait parameters.

	Young =22	Older=15	P-value
Demographic Characteristic			
Age (years)[a]	27.1±4.3	70.3±5.3	0.01
Height (inches)[a]	67.5±4.2	63.3±4.2	0.01
Weight (pounds)[a]	162.9±39.8	181.1±38.8	0.18
Gender (%female)[b]	50.00%	86.70%	0.02
Ankle DF ROM			
NWB-AROM (degrees)[a]	11.7±5.4	7.4±3.8	0.01
NWB-PROM (degrees)[a]	15.4±5.7	12.7±4.5	0.14
WBDF (degrees)[a]	28.1±7.2	28.8±8.9	0.80
Limits of Stability			
EPE-Forward (% LOS)[a]	65.2±21.9	46±17.9	0.01
MXE-Forward (% LOS)[a]	86.4±12.5	72.9±16.1	0.01
EPE-Right Forward (% LOS)[a]	80.6±11.3	67.7±21.8	0.02
MXE-Right Forward (% LOS)[a]	93.6±10.7	83.1±14.0	0.01
EPE-Left Forward (% LOS)[a]	82.5±21.7	75.8±23.6	0.38
MXE-Left Forward (% LOS)[a]	96.5±8.1	88.3±18.9	0.08
Gait			
Velocity (cm/s)[a]	136.1±16.9	116.0±22.7	0.00
Cadence (steps/min)[a]	117.7±9.7	120.5±11.7	0.45
Step Length Left (cm)[a]	69.6±5.9	57.4±7.6	0.00
Stance Time Right (% gait cycle)[a]	0.632±.02	0.641±.08	0.67
Single Support Time Right (% gait cycle)[a]	0.398±.02	0.366±.03	0.00

SD: Standard deviation; DF: dorsiflexion; ROM: range of motion; EPE: end point excursion; MXE: maximum excursion; cm: centimeter; s: second; min: minute
[a]Independent t-test; [b]Chi-Square

Table 2 presents the results of the correlation analysis of ankle DF ROM to balance parameters for young and older adults. In young adults, fair to moderate correlations were established between NWB-AROM to balance for the LOS parameter of MXE RF (r=0.48, r^2=0.28, p=0.02), and between NWB-PROM to balance for the LOS parameters of MXE-RF (r=0.43, r^2=0.18, p=0.04) and MXE LF (r=0.51, r^2=0.26, p=0.04). For older adults, NWB measurement methods of ankle DF did not result in significant correlations to balance for any of the LOS parameters. The correlation between WBDF and balance was moderate and significant for older adults for the parameter of MXE RF (r=0.53, r^2=0.28, p=0.04) and moderate but borderline significant for the variable of EPE-RF (r=0.48, r^2=0.23, p=0.07).

Table 3 presents the results of the correlation analysis of ankle DF ROM to gait parameters for young and older adults.

Table 2. Association between ankle dorsiflexion range of motion and balance parameters during the limits of stability test (Pearson *r*).

	Correlation between NWB DF AROM and Balance					
Age Group	**EPE F**	**MXE F**	**EPE RF**	**MXE RF**	**EPE LF**	**MXE LF**
Young	-0.003	0.15	0.34	0.48*	0.28	0.42
Older	-0.49	-0.23	-0.06	0.17	-0.16	0.02
	Correlation between NWB DF PROM and Balance					
Age Group	**EPE F**	**MXE F**	**EPE RF**	**MXE RF**	**EPE LF**	**MXE LF**
YOUNG	-0.04	0.17	0.24	0.43*	0.18	0.51*
OLDER	-0.07	-0.07	-0.01	0.36	-0.19	0.24
	Correlation between WBDF and Balance					
Age Group	**EPE F**	**MXE F**	**EPE RF**	**MXE RF**	**EPE LF**	**MXE LF**
YOUNG	-0.18	-0.31	0.07	-0.09	-0.04	-0.26
OLDER	-0.03	0.002	0.48	0.53*	0.22	0.33

NWB: non-weight bearing; DF: dorsiflexion; AROM: active range of motion; PROM: passive range of motion; WBDF: weight bearing dorsiflexion; EPE: end point excursion; MXE: maximum excursion; F: forward; RF: right forward; LF: left forward; *P<0.05.

Table 3. Association between ankle dorsiflexion range of motion and gait parameters (Pearson *r*).

Correlation between NWB DF AROM and gait parameters					
Age Group	**velocity**	**cadence**	**SL L**	**ST R**	**SST R**
YOUNG	0.33	0.56*	-0.08	-0.57*	-0.53*
OLDER	-0.02	0.03	-0.03	-0.2	-0.1
Correlation between NWB DF PROM and gait parameters					
Age Group	**velocity**	**cadence**	**SL L**	**ST R**	**SST R**
YOUNG	0.33	0.53*	-0.05	-0.53*	-0.51*
OLDER	-0.16	-0.07	-0.2	0.06	-0.12
Correlation between WBDF and gait parameters					
Age Group	**Velocity**	**cadence**	**SL L**	**ST R**	**SST R**
YOUNG	0.23	0.23	0.18	-0.27	-0.25
OLDER	0.45	0.23	0.48	-0.26	-0.07

NWB: non-weight bearing; DF: dorsiflexion; AROM: SL L: step length left; ST R: stance time right; SST R: single support time right; *P<0.05.

In young adults, the correlation of both NWB-AROM and NWB-PROM to gait was significant and moderate for the parameters of cadence (NWB-AROM r=0.56, r^2=0.31, p=0.01; NWB-PROM r=0.53, r^2=0.26, p=0.01), stance time on the right lower extremity (NWB-AROM r=-0.57, r^2=0.32, p=0.01; NWB-PROM r=-0.53, r^2=0.28, p=0.01) and single support time on the right lower extremity (NWB-AROM r=-0.53, r^2=0.28, 0.01; NWB-PROM r=-0.51, r^2=0.26, p=0.01). For older adults, neither of the NWB methods (AROM or PROM) resulted in significant correlations to gait parameters. WBDF did not correlate significantly with any of the measured gait parameters for either age group. For the parameters of velocity (r=0.45, p=0.090) and step length left r=0.48; p=0.068) correlations with WBDF ROM were fair and borderline significant for older adults.

Discussion

The purpose of this study was to examine the relationship of both NWB and WB measurements of ankle DF to balance and gait performance in both older and young adults. Balance was assessed using the LOS test and gait performance was assessed using spatiotemporal parameters of gait measured at preferred walking speed using the GAITRite system. The main findings of this study were that the relationship of ankle DF ROM to balance and gait performance differed between age groups despite both age groups having the same pattern of increasing ankle DF ROM from NWB-PROM to NWB-AROM to WBDF. NWB measurements of ankle DF resulted in significant correlations to select parameters of gait (cadence, stance time right, and single support time right) and balance (maximal excursion) for young adults. For older adults, WBDF measurements correlated significantly to one parameter of balance performance (maximal excursion in the right-forward direction) while there were no significant correlations identified between NWB measurements of ankle DF ROM and gait performance for this age group.

Balance performance was assessed using the LOS test, focusing on postural control during the forward leaning directions. We chose the forward directions of the LOS test since movements in these directions visually required more ankle dorsiflexion mobility than the backward or side leaning directions. The correlations of NWB-DF measurements to LOS parameters were moderate, explaining 18-26% of the variance in MXE-RF for young adults, whereas the correlation of WBDF to LOS was slightly higher for older adults explaining 28% of the variance in MXE-RF. These variances are similar to that reported in previous research. Terada et al., [7] reported NWB DF AROM to explain 22% of variance in SEBT reach distance in the anterior direction performed by young adults. Menz et al., [11] found WB DF ROM to explain 26% of the variance in postural sway during forward leaning task performed by older adults.

Gait performance was assessed by using an instrumented walkway to capture footfalls as each participant walked at their preferred speed. The footfall data was used to calculate spatiotemporal parameters of gait performance. We found NWB DF ROM to explain 28-32% (for AROM) and 26-28% (PROM) of the variance in gait performance of young adults for the parameters of cadence, stance time and single support time. This is slightly higher than the variances reported by Crosbie et al., [5] for young adults and the relationship of NWB DF PROM to stride velocity (variance=22%) and step length (variance=18%). Crosbie et al., [5] examined young adults with recent lateral ankle sprain as compared to healthy young adults in the present study which may contribute to the variance differences between the studies.

The control of balance during dynamic standing tasks and during gait is multifactorial, requiring the integration of vision, vestibular function, sensation, strength, reaction time, and joint mobility. While the range of variance reported for the correlation of ankle DF ROM to gait and balance parameters may seem low (18%-32%), consideration should be given to the fact that ankle DF ROM is only one variable of many possible variables that may contribute to variance in gait and balance performance. In addition, ankle dorsiflexion is a potentially modifiable impairment, that, when targeted through therapeutic exercise interventions, may contribute to improvement in balance and gait performance.

Our findings for young adults are opposite to those reported in prior research which found significant fair to moderate correlations of WBDF (r=0.41 to 0.59) to dynamic balance. The reason for these opposing findings may be due to the type of balance task examined in prior research as compared to the present study. The present study utilized the LOS test in which forward leaning is performed while the heels of both feet remain stationary and the knees extended. To reflect the lower extremity positioning during the forward lean directions of the LOS, we measured WBDF of the backward LE in the lunge position with the knee straight. Prior studies utilized the SEBT as a measure of dynamic balance. During the SEBT, maximal reach of the non-stance LE is attained by dorsiflexing the ankle while flexing the knee of the stance leg. We found the WBDF measurement method to result in the greatest amount of ankle DF of the three methods examined. The amount of ankle DF measured in WB may have exceeded the amount used to perform forward leaning directions of the LOS test, resulting in lower correlations of WBDF to LOS performance. Future studies should include both the SEBT and LOS test as measures of dynamic balance when examining the relationship of ankle DF ROM method to balance performance.

Despite the significant correlation between maximal excursion and NWB DF for young adults and WBDF for older adults, there does not appear to be a correlation between ankle DF and end point excursion for either age group. This is not surprising given the definition of each LOS parameter. End point excursion is the percentage of distance achieved on the first movement toward a target placed at 100% of LOS based on height whereas, maximal excursion is the maximum distance attained toward the target placed at 100% LOS. The significant positive correlation between maximal excursion and NWB DF for young adults and WBDF for older adults indicates that as ankle DF ROM increases there is an increase in the maximal distance one's center of pressure (COP) can move toward a target during the leaning movement without loss of balance. The little to no correlations between end point excursion and each method of ankle DF measurement, suggests that the initial movement of COP movement toward a target is not dependent upon the amount of ankle DF available.

A limitation of this study is the measurement of ankle DF ROM in the right LE only. While the findings of the study show ankle DF of one LE is associated with select parameters of balance and gait performance, additional research should be conducted to examine the association of unilateral ankle DF ROM of both lower extremities as well as the association of combined bilateral ankle DF ROM on gait and balance performance.

For older adults, the correlations between WBDF and gait parameters of velocity and step length of the left lower extremity were approaching statistical significance. Increasing the number of older participants may have achieved the a priori p-value for the correlations between these parameters and WBDF (cadence r=0.45, p=0.09; SLL r=0.48, p=0.07).

Conclusion

The method of assessing ankle mobility impairments of dorsiflexion is an important determinant of balance and gait performance in young and older adults. Available motion at the ankle measured using non-weight bearing methods contributes to dynamic standing balance in young adults, while available motion at the ankle measured using weight bearing methods contributes to dynamic standing balance in older adults. Non-weight bearing measurement of ankle DF contribute to temporal parameters of gait performance in young adults but not older adults. Available motion at the ankle measured using weight bearing methods does not contribute to spatiotemporal parameters of gait in either age group. Clinicians may use this information when selecting testing methods to identify ankle mobility impairments that may be associated with alterations in balance and gait performance.

List of abbreviations

DF: Dorsiflexion
ROM: Range of motion
NWB: Non-weight bearing
WB: Weight bearing
WBDF: Weight bearing dorsiflexion
NWB-AROM: Non-weight bearing active range of motion
NWB-PROM: Non-weight bearing passive range of motion
MXE: Maximal excursion
EPE: End point excursion

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Authors' contributions	EN	EH	AF	WA
Research concept and design	✓	✓	✓	✓
Collection and/or assembly of data	--	✓	✓	✓
Data analysis and interpretation	✓	✓	✓	✓
Writing the article	✓	✓	--	--
Critical revision of the article	✓	--	--	--
Final approval of article	✓	✓	✓	✓
Statistical analysis	✓	--	--	--