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	✓	--	--	--