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Article

Exploring the Effect of Prolonged Ankle Plantar-Flexed Standing on Postural Control, Balance Confidence, Falls Efficacy, and Perceived Balance in Older Adults

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Abstract: Background/Objectives: Postural control describes our ability to maintain an upright position. This study explored the impact of prolonged ankle plantar-flexed standing on postural control variability and strategy in an older adult population. The ability to perceive balance change was also assessed via subjective balance-related variables. **Methods:** Twenty-four community-dwelling older adults were recruited via convenience sampling. Each participant completed a balance confidence and falls efficacy questionnaire at baseline. Five barefoot quiet standing trials on a force plate then followed (Timepoint 1). After this, the participants stood with their ankles in a plantar-flexed position for up to 7.5 min before completing another quiet standing trial on the force plate. Four further ankle plantar-flexed standing trials of 2 min were then completed, interspersed with quiet standing trials on a force plate (Timepoint 2). The balance confidence and falls efficacy questionnaires were then completed again. For measures of postural control variability (sway path length, root mean square [RMS], sway area) and strategy (fractal dimension), mean values for the five trials were calculated for Timepoints 1 and 2 separately. **Results:** The sway path length and RMS measures were significantly increased ($p < 0.05$) at Timepoint 2. However, the fractal dimension did not change. There was also no change in balance confidence or falls efficacy. **Conclusions:** The findings suggest that prolonged standing can impact measures of postural variability without a change in postural control strategy. Postural control change also occurred without a change in subjective balance measures, suggesting that the altered balance may not be practically significant or perceptible to the individual.

Keywords: postural variability; postural strategy; fatigue; older people

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1. Introduction

Human postural control has been modelled as an inverted pendulum with muscular forces acting about the ankle joints to control the centre-of-mass movement [1,2]. Older adults who engage in prolonged activity involving the ankle plantar flexors may experience muscular fatigue, leading to increased postural sway area and sway path [3]; this is indicative of an increased fall risk [4,5].

The sway area and path length variables are linear measures of postural control that offer insight into postural variability [6]. A complimentary non-linear analysis, such as the calculation of fractal dimension, provides additional insight into postural control strategies [7,8]. However, previous studies of prolonged standing with older adult populations have not explored changes in control strategy. These studies, therefore, miss important insight into control mechanisms. Similarly, they tend to study the effect of volitional fatigue, which is less likely to be experienced by older adults. Furthermore, postural control data are inherently instable [9], which can impact the data's absolute and relative reliability [10]. Studies fail to offer interpretations of their findings in relation to the data's reliability, especially the Minimum Detectable Change (MDC), considered the smallest real difference that reflects true change rather than measurement error [11]. Consequently, these factors can impact the previous conclusions drawn.

The practical significance of postural control change is also missing in previous research. It is, therefore, unclear whether prolonged plantar-flexed standing leads to a perceptible change in balance, balance confidence, or falls efficacy. This is important given that a change in these subjective states relates to fear of falling, physical activity avoidance [12,13], and quality of life [14]. In fact, it is not clear whether there is a relationship between a change in these measures and a change in postural control variables.

This study sought to understand the effect of prolonged activity on the postural control variability and strategy of older adults. Furthermore, it aimed to evaluate whether there was any subjective balance change experienced and whether there were any relationships between changes in postural control and subjective balance measures. It was hypothesised that postural control will decrease following prolonged standing. It was also thought that balance confidence and falls efficacy will decrease following prolonged standing. Finally, it was hypothesised that a change in postural control measures will be positively associated with a perceived change in balance and falls efficacy and negatively associated with balance confidence.

2. Materials and Methods

A convenience sample of 24 healthy, community-living older adults (73.7 $\pm$ 6.8 years; Male/Female = 9/15) meeting the inclusion and exclusion criteria was recruited from the West London area of the United Kingdom. The inclusion criteria required participants (1) to be at least 60 years old and (2) to independently stand without an assistance device (e.g., cane and walkers). Older adult residents with cognitive impairment, deteriorated musculoskeletal or neurological function, and any medical disease history that impaired walking and balance (e.g., arthritis, diabetes, visuospatial deficits) were excluded. This study was approved by the Brunel University of London ethics committee (42477-A-Feb/2024-49776-1) in accordance with the Declaration of Helsinki. The number of participants was calculated based on the need to reach a statistical power of 0.8 with $p = 0.05$ and $d = 0.75$ [15]. A Cohen's d of 0.75 was chosen since it is considered large in gerontology [16], and these changes are described as 'grossly perceptible' [15] and, thus, could be considered important from a practical perspective.

At baseline, the participants undertook five barefoot quiet standing trials (20 s each) upon a force plate (Kistler, Winterthur, Switzerland; 100 Hz), standing with their feet shoulder width apart and arms by their sides, with visual fixation on a cross marked approximately 1.8 m in distance and 1.8 m in height on a wall. The participants then stood with their ankles plantar-flexed so that their heels were off the floor, for up to 7.5 min. After the completion of this time period or when they could not continue any longer, the participants stood on the force plate again for another 20 s quiet standing trial in the same stance. Plantar-flexed standing was then repeated four further times, each lasting two minutes, with a quiet standing trial collected after each. Each plantar-flexed stand was conducted next to the force plate to minimise the duration taken between the end of the task and the collection of postural control data. This, along with the quiet standing trial duration and conducting the plantar-flexed standing before each quiet standing trial, followed recommendations made to ensure fatigue remained present [17]. A chair was also placed in front of the participant so that the participants could use this to remain plantar-flexed standing for as long as possible.

Postural control variability was measured using the anterior–posterior (A-P), medio-lateral (M-L), and total sway path lengths; the A-P and M-L RMS and the RMS radius. and sway area (95% confidence area) were also calculated. These measures are all associated with the risk of falls and calculated using the position of the centre of pressure (COP) along with published formulae [18]. The fractal dimension was also calculated, using the 95% confidence area and total sway path length (Equation (1)), where N is number of sample points. A value of 1 indicated a completely stationary postural control signal, and a value of 2 indicated completely random postural control data [19]. The data were not filtered since this can remove natural variability, resulting in a loss of complexity [19]. The COP data were calculated within BioWare software (version 5.3, Kistler, Winterthur, Switzerland), and then all the postural control calculations were performed within Microsoft Excel (Microsoft Corporation, Redmond, WA, USA).

$$\frac{\log \mathrm{N}}{\log \mathrm{N} + \log \sqrt{\frac{4}{\pi} \times 95\%\ \text{confidence area}} - \log \text{total sway path length}} \quad (1)$$

Before baseline quiet standing trials and following the 5th plantar-flexion quiet standing trial, the participants completed the English Falls Efficacy Scale (FES-I) [13], which consists of 16 questions about the participants' concern of falling. The FES-I has excellent test–retest reliability and good internal consistency [13]; it also possesses good sensitivity in community-dwelling older adults [20], including for changes in physical function [21]. The sum of the ordinal data is calculated and interpreted as follows: those with scores of 16–19 have a low concern of falling; 20–27 indicates a moderate concern of falling; and above 28 indicates a high concern of falling [22]. The participants' balance confidence was also assessed using the Activity-Specific Balance Confidence short-version questionnaire (ABC) [12]. This consists of 6 questions with outcome scores presented as ordinal data. The scale possesses excellent test–retest reliability [23] and also has high internal consistency [24]. The ABC is related to physical function in community-dwelling older adults. The average score for the questions was determined and interpreted as follows: a score lower than 50 was indicative of low functioning, 50–80 was moderate functioning, and above 80 was high functioning [12].

Along with the FES-I and ABC, the participants also rated their perceived change in balance on a 15-point Generalised Rating of Change (GRC) question [25]. The self-report GRC is a single-item, recall-based questionnaire of global well-being and pain, based on change since an initial treatment encounter. The participants scored their global rating of change in balance compared with their baseline standing on a 15-point self-report Likert scale (from −7 to 7). A score of 1 to 7 suggests improvement; 0 suggests no change; and −1 to −7 indicates deterioration. The larger the value, the greater the degree of change. The outcome scores are ordinal and considered to have high face reliability [26]; they are also often used as an external standard of change in functional status [27]. The order for completing these questionnaires was varied across participants.

The effect of the prolonged standing was explored for each postural control variable by averaging the five baseline trials and comparing these with the average of the five trials collected post plantar-flexed standing; the averaging of multiple trials substantially improves the reliability of the data [28]. These were compared using paired sample t-tests. Similarly, Wilcoxon-signed rank tests were used to explore the differences in ABC and FES-I. The association between the change in postural control data and the change in balance confidence and falls efficacy (gain score) was determined using a Spearman's Rank Correlation Coefficient; these analyses were performed within SPSS software 29.0 (Version 29, IBM

Corp., Armonk, NY, USA). The size of the relationships was identified as weak when r = 0 to 0.3 or 0 to −0.3 (positive and negative relationship, respectively), moderate when r = 0.3 to 0.7 and −0.3 to −0.7 (positive and negative relationship, respectively), and strong when r = 0.7 to 1 and −0.7 to −1 (positive and negative relationship, respectively) [29]. Missing data were omitted from the calculations and reflected in the overall count of responses. Statistical significance was accepted at $p < 0.05$.

The relative reliability of the postural control data was assessed using the 5 baseline trials by calculating the average measures two-way random absolute agreement Intraclass Correlation Coefficient ($ICC_{2,5}$). These ICCs were interpreted using the following criteria: ICC of 0 to 0.5 indicates poor reliability; 0.5 to 0.75 is considered moderate reliability; 0.75 to 0.9 is considered good reliability; and above 0.9 is considered excellent reliability [30]. The standard error of the measurement (SEM) was determined using Equation (2), where SD was determined using Equation (3); the sum of squares total (SS_{total}) was provided within the ANOVA table provided by SPSS along with the ICC data [31].

$$\mathrm{SEM} = \mathrm{SD}\sqrt{1 - \mathrm{ICC}_{2,5}} \tag{2}$$

$$\sqrt{\mathrm{SS}_{\mathrm{total}}/(\mathrm{n}-1)} \tag{3}$$

To assess whether any individual change in postural control data was real or due to chance, the MDC_{95} was determined using Equation (4).

$$\mathrm{MDC}_{95} = \mathrm{SEM} \times 1.96\sqrt{2} \tag{4}$$

3. Results

Based on the ABC, 15 participants were considered high functioning; 2 were low functioning; and 7 possessed a moderate level of functioning. Furthermore, 14 participants had a low concern about falling; 9 possessed moderate concern, and 1 participant had high concern.

All the participants performed five plantar-flexed standing trials, although seven participants could not sustain standing for the full 7.5 min duration for trial 1. However, all completed trials two to four, each lasting two minutes.

Prolonged standing resulted in a significantly greater A-P ($t(23) = -3.39$, $p = 0.003$, $d = 0.54$) and total sway path length (t (23) = −3.35, $p = 0.003$, $d = 0.39$); however, the sway length in the M-L direction did not change ($t(23) = -1.53$, $p = 0.140$, $d = 0.12$) (Figure 1).

The RMS in the A-P direction also significantly increased following plantar-flexed standing ($t(23) = -2.057$, $p = 0.051$), as did the RMS radius ($t(23) = 2.034$, $p = 0.054$). Conversely, the M-L RMS ($t(23) = -0.68$, $p = 0.50$) and sway area ($t(23) = -1.553$, $p = 0.134$) did not change, neither did the fractal dimension ($t(23) = -3.13$, $p = 0.757$) (Table 1).

Table 1. Mean, standard deviation, and Cohen's *d* for postural control measures taken at baseline (pre) and after plantar-flexed standing (post).

	Pre-Mean (SD)	Post-Mean (SD)	Cohen's *d*
RMS A-P (m) *	0.049 (±0.0009)	0.058 (±0.0021)	5.6
RMS M-L (m)	0.059 (±0.0009)	0.035 (±0.0012)	0.9
RMS radius (m) *	0.009 (±0.0124)	0.011 (±0.0141)	0.2
95% ellipse area (m^2)	0.0003 (±0.0001)	0.0004 (±0.0002)	0.6
Fractal dimension	1.72 (0.08)	1.73 (0.09)	0.1

* Significance < 0.05; A-P = anterior–posterior; M-L = medio-lateral; RMS = root mean square.

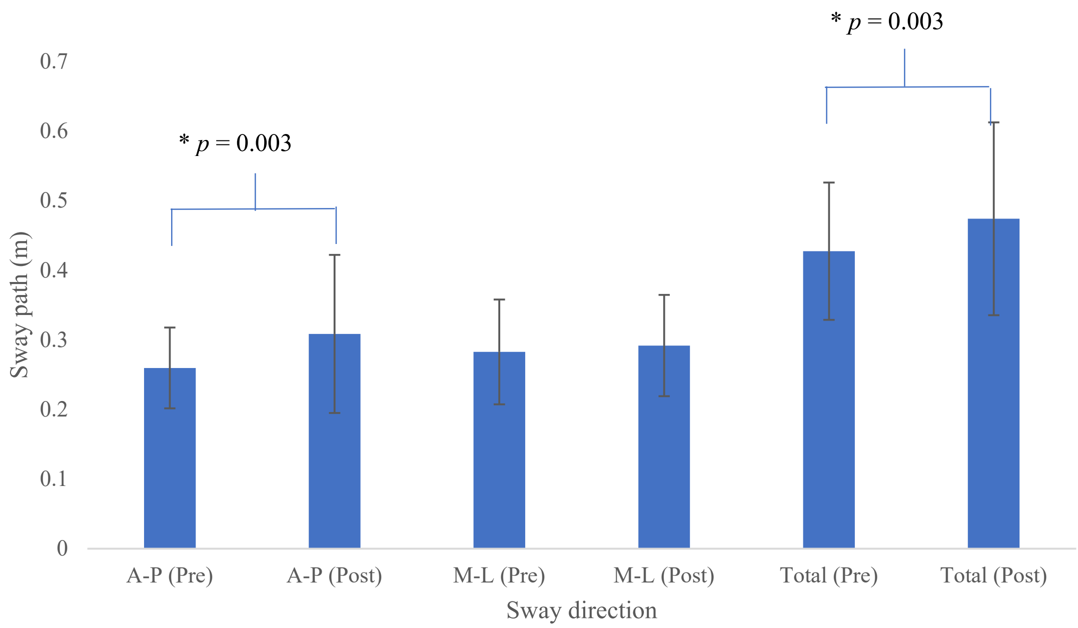

Figure 1. Comparison of total, medio-lateral (M-L), and anterior–posterior (A-P) sway path at baseline (pre) and after planar-flexed standing (post).

There was no difference in ABC when comparing baseline (median = 87.92, IQR = 22.92) with after plantar-flexed standing (median = 88.33, IQR = 26.04), (z = −1.253, $p = 0.210$); this was also true for FES-I (baseline median = 19, IQR = 3, after plantar-flexion standing median = 19, IQR = 4, z = −1.190, $p = 0.234$).

The GRC was 0 for 12 individuals, suggesting no perceived general change in balance. Seven individuals experienced a negative change in perceived balance (e.g., poorer balance), and five rated an improved balance (at least 1-point movement on the scale in either direction). Table 2 shows that the GRC was moderately and positively correlated with the change in A-P and total sway path length and RMS A-P. There were no other significant correlations for GRC nor were there any between sway data and ABC or falls efficacy gain scores.

Table 2. Correlation between postural control measurements and General Rating of Change in balance (GRC), Activity-Specific Balance Confidence (ABC), and Falls Efficacy Scale (FES-I).

		A-P Sway Length	M-L Sway Length	Total Sway Length	RMS A-P	RMS M-L	RMS Radius	Sway Area	Fractal Dimension
GRC	*R*	0.59	0.25	0.61	0.42	0.28	0.35	0.32	−0.13
	P	<0.01 *	0.25	<0.01 *	0.04 *	0.19	0.10	0.12	0.55
FES-I	*R*	0.02	0.18	0.07	−0.07	−0.08	−0.15	−0.02	0.05
	P	0.92	0.41	0.77	0.76	0.73	0.50	0.93	0.82
ABC	*R*	−0.31	−0.15	−0.32	0.14	−0.06	0.19	0.002	−0.16
	P	0.15	0.48	0.13	0.51	0.79	0.36	0.99	0.47

* Significance < 0.05; A-P = anterior–posterior; M-L = medio-lateral; RMS = root mean square.

The reliability ($ICC_{2,5}$) of the postural control measurements ranged between moderate ($ICC_{2,5} = 0.68$) to excellent ($ICC_{2,5} = 0.98$), except for A-P RMS which was poor and non-significant ($ICC_{2,5} = 0.27$). The MDC_{95} was represented as a percentage of the baseline average and ranged from 5.9% to 100% (Table 3).

Table 3. Relative and absolute reliability for postural control measurements.

	$ICC_{2,5}$	SS_{Total}	SD	SEM	MDC_{95}	$\%MDC_{95}$	Participants Exceeding MDC_{95} (n)
A-P sway path length	0.92 *	0.516	0.07	0.2	0.05	19.3%	9
M-L sway path length	0.98 *	0.685	0.08	0.1	0.03	10.6%	2
Total sway path length	0.96 *	1.265	0.10	0.2	0.06	14.0%	9
A-P RMS	0.27	0.0004	0.002	0.002	0.004	8.2%	9
M-L RMS	0.68 *	0.0002	0.001	0.0008	0.002	5.9%	10
RMS radius	0.95 *	0.21	0.013	0.003	0.008	88.9%	10
Sway area	0.69 *	0.000005	0.0002	0.0001	0.0003	100%	0
Fractal dimension	0.80 *	1.29	0.10	0.05	0.13	7.6%	0

* Significance < 0.01; ICC = Intraclass Correlation Coefficient; SS_{Total} = Sum of $squares_{Total}$; SD = standard deviation; SEM = standard error of measurement; MDC_{95} = Minimal Detectable $Change_{95}$; $\%MDC_{95}$ = Minimal Detectable $Change_{95}$ as a percentage of baseline mean average; A-P = anterior–posterior; M-L = medio-lateral; RMS = root mean square.

4. Discussion

This study explored the effect of prolonged activity on postural control. In partial agreement with the study hypothesis, prolonged activity decreased older adults' postural control for some measures, supporting previous observations [3,32]. The greater total sway path length and RMS radius along with greater movement in the A-P direction suggests decreased postural steadiness [33] and a greater risk of falling [18].

A decreased function of the plantar flexor muscles due to fatigue may underpin the observed changes in postural stability. These muscles control movement in the sagittal plane, across which stability changed. Conversely, in the M-L direction, the sway path length did not change, which is understandable given that the protocol did not target muscles that control movement in this direction. During prolonged standing, individuals can experience reduced blood flow [34], contributing to oxygen and nutrient depletion and the accumulation of lactic acid in the muscles [35]. Furthermore, during eccentric contraction, muscle fibres can experience high mechanical stress [36]; all of this can lead to muscle damage [35] and fatigue [37,38]. As a consequence, the muscles have a reduced mechanical power and force output [39], leading to a diminished ability to ensure postural stability. This peripheral fatigue can also impair motor control through weakened sensory integration and proprioception [40], important for effective postural control [41]. Whilst fatigue was not directly measured, the postural control changes observed are consistent with other studies in which individuals were fatigued [3,17,32]. However, it is also important to acknowledge that the prolonged standing may have also led to increased sway in response to pain or discomfort. Similarly, the fear of falling may have offered a psychological explanation for the change in sway [42], yet there were no differences in the subjective measures collected to suggest this.

The increase in sway paths and RMS was not accompanied by an increased sway area, an observation that is in contrast to those of Boyas et al. [3]. This may suggest that the ankle-stabilising muscles were able to retain sufficient joint stiffness to maintain the area in which the increased sway occurs. The difference in findings is likely due to greater fatigue induced by Boyas and colleagues, who used isokinetic contractions until failure. Isokinetic contractions can lead to fatigue more quickly than the isometric contractions used in the current study [43]. Sustaining activity until complete exhaustion is unlikely to occur in an older population, and, thus, this study provides evidence of a change in postural control under fatigue conditions more likely experienced in older adult populations.

Despite changes in postural variability, the signal complexity as indicated via the fractal dimension, was unchanged, suggesting that there was no reorganisation of afferents and no use of a new postural control strategy [19,44]; this is consistent with other studies in which increased postural variability has been observed [40,45]. Consequently, any change in proprioception due to the prolonged standing was insufficient for sensory reweighting to be required. Similarly, there was no need for increased activity from other ankle muscles or for a switch to a hip or multi-joint postural control strategy [1], which can occur when perturbations increase [46].

Whilst changes in the postural stability were shown, the prolonged activity also did not significantly change balance confidence or falls efficacy, measures considered important since they impact daily physical activity participation, fear of falling [12,13], and quality of life [14]. Practically, this suggests that postural control change did not impact the overall perception of balance, which may be because the postural control change was insufficient in magnitude. Consequently, the practical significance of the change in postural control is questionable, which is commonly not demonstrated in similar studies.

It is also important to consider the individual response to the task, which may somewhat account for the inconsistency between group postural control and perception changes. For various measures (sway area, A-P sway length, total sway length, and RMS A-P), there were significant moderate correlations with the GRC, which suggests that postural control change is responsive to changes in this subjective measure [47]. Therefore, for some individuals, the size of change in postural control was notable, whereas, for others, it was not. However, these postural control changes were not related to a change in confidence or efficacy, suggesting that other factors may be more important when evaluating the perception of fall risk or movement confidence.

Group differences may have also been influenced by variability within the data, affecting their reliability. The relative reliability of the sway path data was excellent, whilst that of sway area was good and larger than that presented previously by some (ICC = 0.22, [10]) but by not others using similar populations (ICC = 0.92, [48]). The RMS radius also had excellent reliability, which was larger than that previously presented (ICC = 0.82, [48]). The RMS in the ML direction had moderate reliability; this was higher than the reliability presented by Lafond et al. [10] and similar to that by Swanenburg et al. [49]. In general, this suggests that there was confidence in these data measured. Conversely, the RMS-AP data showed poor reliability, which is in line with other studies [10,49] but which may impact the ability to draw faithful conclusions from these data.

Despite generally good-to-excellent reliability, fewer than half of the individuals experienced a change that was beyond the MDC_{95}. Therefore, the group difference may have resulted from a number of individual changes that were real, combined with others that were the result of chance. Consequently, this may explain why a corresponding change in the ABC and FES-I data was not observed. The reasons for inter-individual differences may include differences in frailty or sensory system functionality that were either insufficient for clinical diagnosis or were undiagnosed or unreported by the participants. Differences in body mass index are shown to impact postural control [50], which, along with differences in muscle fatigue tolerance, may also be influential. Differences in the baseline ABC and FES-I may also suggest that individual function and confidence may influence the postural control and perceptions reported. These factors are rarely considered in the study of postural control; thus, future studies should be more considerate of these factors when studying change.

Collectively, these results indicate the importance of measuring perceptual data alongside reliability data when interpreting postural control in older adults. Furthermore, for measures deemed responsive, future research should determine the Minimal Important Change (MIC) for each [47], which will allow the assessment of the meaningfulness of individual changes. It is important to note that this is not the same as the MDC, which is the minimum change required to be real; instead, it is the size of change considered important for the individual.

A study limitation is that the relative fatigue of each participant was not measured. This can be determined using dynamometry or electrical stimulation, yet this was not practically possible given the recommendations to ensure fatigue is present [17]. The RPE could have also been measured although the maximum RPE at fatigue is often not 20 (i.e., maximum score) and can be dependent on the individual and the exercise; recording the RPE to make comparisons of individuals within and between studies is, therefore, problematic, and there is also generally no correlation between fatigue-induced RPE and change in balance [51]. The angle of the plantar-flexion stance was also not monitored, which may impact the fatigue generated; thus, motion analysis could be used to monitor this in future research. Electromyography could also be used to explore a change in muscle activation that may be indicative of peripheral muscle fatigue [52]. A larger sample size and greater task intensity may have also resulted in differences and correlations being shown for those variables observed as insignificant.

5. Conclusions

In conclusion, older adults undertaking prolonged activity can experience increased postural variability without a change in sway area or control strategy. This change in variability also occurred without a group change in balance confidence or falls efficacy. The change in postural control variability was related to a perceived change in balance but not in balance confidence or falls efficacy. This study also shows the importance of understanding individual change when interpreting postural control data in group comparisons, which is often missing in similar research.

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Institutional Review Board Statement: This study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of Brunel University London (protocol code 42477 and 2nd February 2024).

Informed Consent Statement: Informed consent was obtained from all the subjects involved in this study.

Data Availability Statement: The datasets presented in this article are not readily available because this was not a feature of the ethical approval.

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

A-P	Anterior–posterior
M-L	Medio-lateral
RMS	Root mean square
GRC	Generalised Rating of Change
ICC	Intraclass Correlation Coefficient
SS_{total}	Sum of squares total
MDC	Minimal Detectable Change

References

1. Winter, D.A. Human balance and posture control during standing and walking. *Gait Posture* **1995**, *3*, 193–214. [CrossRef]
2. Winter, D.A.; Patla, A.E.; Rietdyk, S.; Ishac, M.G. Ankle muscle stiffness in the control of balance during quiet standing. *J. Neurophysiol.* **2001**, *85*, 2630–2633. [CrossRef] [PubMed]

3. Boyas, S.; Medd, E.R.; Beaulieu, S.; Boileau, A.; Lajoie, Y.; Bilodeau, M. Older and young adults adopt different postural strategies during quiet bipedal stance after ankle plantarflexor fatigue. *Neurosci. Lett.* **2019**, *701*, 208–212. [CrossRef] [PubMed]
4. Howcroft, J.; Lemaire, E.D.; Kofman, J.; McIlroy, W.E. Elderly fall risk prediction using static posturography. *PLoS ONE* **2017**, *12*, e0172398. [CrossRef]
5. Merlo, A.; Zemp, D.; Zanda, E.; Rocchi, S.; Meroni, F.; Tettamanti, M.; Recchia, A.; Lucca, U.; Quadri, P. Postural stability and history of falls in cognitively able older adults: The Canton Ticino study. *Gait Posture* **2012**, *36*, 662–666. [CrossRef]
6. Smith, B.A.; Stergiou, N.; Ulrich, B.D. Lyapunov exponent and surrogation analysis of patterns of variability: Profiles in new walkers with and without down syndrome. *Motor Control* **2010**, *14*, 126–142. [CrossRef]
7. Kiefer, A.W.; Armitano-Lago, C.N.; Cone, B.L.; Bonnette, S.; Rhea, C.K.; Cummins-Sebree, S.; Riley, M.A. Postural control development from late childhood through young adulthood. *Gait Posture* **2021**, *86*, 169–173. [CrossRef]
8. Doyle, T.L.; Newton, R.U.; Burnett, A.F. Reliability of traditional and fractal dimension measures of quiet stance center of pressure in young, healthy people. *Arch. Phys. Med. Rehabil.* **2005**, *86*, 2034–2040. [CrossRef]
9. Rhea, C.K.; Silver, T.A.; Hong, S.L.; Ryu, J.H.; Studenka, B.E.; Hughes, C.M.; Haddad, J.M. Noise and complexity in human postural control: Interpreting the different estimations of entropy. *PLoS ONE* **2011**, *6*, e17696. [CrossRef]
10. Lafond, D.; Corriveau, H.; Herbert, R.; Prince, F. Intrasession reliability of center of pressure measures of postural steadiness in healthy elderly people. *Arch. Phys. Med. Rehabil.* **2004**, *85*, 896–901. [CrossRef]
11. Salehi, R.; Ebrahimi, T.I.; Esteki, A.; Maroufi, N.; Parnianpour, M. Test-retest reliability and minimal detectable change for center of pressure measures of postural stability in elderly subjects. *Med. J. Islam. Repub. Iran* **2010**, *23*, 224–232.
12. Myers, A.M.; Fletcher, P.C.; Myers, A.H.; Sherk, W. Discriminative and evaluative properties of the activities-specific balance confidence (ABC) scale. *J. Gerontol. A Biol. Sci. Med. Sci.* **1998**, *53*, M287–M294. [CrossRef] [PubMed]
13. Yardley, L.; Beyer, N.; Hauer, K.; Kempen, G.; Piot-Ziegler, C.; Todd, C. Development and initial validation of the Falls Efficacy Scale International (FES-I). *Age Ageing* **2005**, *34*, 614–619. [CrossRef] [PubMed]
14. Legters, K.; Verbus, N.B.; Kitchen, S.; Tomecsko, J.; Urban, N. Fear of falling, balance confidence and health-related quality of life in individuals with postpolio syndrome. *Physiother. Theory Pract.* **2006**, *22*, 127–135. [CrossRef]
15. Cohen, J. *Statistical Power Analysis for the Behavioural Sciences*, 2nd ed.; Erlbaum: Hillsdale, NJ, USA, 1988.
16. Brydges, C.R. Effect size guidelines, sample size calculations, and statistical power in gerontology. *Innov. Aging* **2019**, *3*, igz036. [CrossRef]
17. Vuillerme, N.; Forestier, N.; Nougier, V. Attentional demands and postural sway: The effect of the calf muscles fatigue. *Med. Sci. Sports Exerc.* **2002**, *34*, 1907–1912. [CrossRef]
18. Quijoux, F.; Nicolaï, A.; Chairi, I.; Bargiotas, I.; Ricard, D.; Yelnik, A.; Oudre, L.; Bertin-Hugault, F.; Vidal, P.P.; Vayatis, N.; et al. A review of center of pressure (COP) variables to quantify standing balance in elderly people: Algorithms and open-access code. *Physiol. Rep.* **2021**, *9*, e15067. [CrossRef]
19. Doyle, T.L.; Dugan, E.L.; Humphries, B.; Newton, R.U. Discriminating between elderly and young using a fractal dimension analysis of centre of pressure. *Int. J. Med. Sci.* **2004**, *1*, 11–20. [CrossRef]
20. Hauer, K.A.; Kempen, G.I.; Schwenk, M.; Yardley, L.; Beyer, N.; Todd, C.; Oster, P.; Zijlstra, G.A. Validity and sensitivity to change of the Falls Efficacy Scales International to assess fear of falling in older adults with and without cognitive impairment. *Gerontology* **2011**, *57*, 462–472. [CrossRef]
21. McColl, L.; McMeekin, P.; Poole, M.; Parry, S.W. Is fear of falling key to identifying gait and balance abnormalities in community-dwelling older adults? Protocol of a mixed-methods approach. *BMJ Open* **2022**, *12*, e067040. [CrossRef]
22. Delbaere, K.; Close, J.C.; Mikolaizak, A.S.; Sachdev, P.S.; Brodaty, H.; Lord, S.R. The Falls Efficacy Scale International (FES-I). A comprehensive longitudinal validation study. *Age Ageing* **2010**, *39*, 210–216. [CrossRef] [PubMed]
23. Schepens, S.; Goldberg, A.; Wallace, M. The short version of the Activities-specific Balance Confidence (ABC) scale: Its validity, reliability, and relationship to balance impairment and falls in older adults. *Arch. Gerontol. Geriatr.* **2010**, *51*, 9–12. [CrossRef] [PubMed]
24. Peretz, C.; Herman, T.; Hausdorff, J.M.; Giladi, N. Assessing fear of falling: Can a short version of the Activities-specific Balance Confidence scale be useful? *Mov. Disord.* **2006**, *21*, 2101–2105. [CrossRef]
25. Wright, A.A.; Abbott, J.H.; Baxter, D.; Cook, C. The ability of a sustained within-session finding of pain reduction during traction to dictate improved outcomes from a manual therapy approach on patients with osteoarthritis of the hip. *J. Man. Manip. Ther.* **2010**, *18*, 166–172. [CrossRef] [PubMed]
26. Kamper, S.J.; Maher, C.G.; Mackay, G. Global rating of change scales: A review of strengths and weaknesses and considerations for design. *J. Man. Manip. Ther.* **2009**, *17*, 163–170. [CrossRef]
27. Low, D.C.; Walsh, G.S. The minimal important change for measures of balance and postural control in older adults: A systematic review. *Age Ageing* **2022**, *51*, afac284. [CrossRef]
28. Rafał, S.; Janusz, M.; Wiesław, O.; Robert, S. Test-retest reliability of measurements of the center of pressure displacement in quiet standing and during maximal voluntary body leaning among healthy elderly men. *J. Hum. Kinet.* **2011**, *28*, 15–23. [CrossRef]

29. Ratner, B. The correlation coefficient: Its values range between +1/−1, or do they? *J. Target. Meas. Anal. Mark.* **2009**, *17*, 139–142. [CrossRef]
30. Koo, T.K.; Li, M.Y. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J. Chiropr. Med.* **2016**, *15*, 155–163. [CrossRef]
31. Weir, J.P. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *J. Strength. Cond. Res.* **2005**, *19*, 231–240.
32. Freitas, S.M.; Wieczorek, S.A.; Marchetti, P.H.; Duarte, M. Age-related changes in human postural control of prolonged standing. *Gait Posture* **2005**, *22*, 322–330. [CrossRef] [PubMed]
33. Sozzi, S.; Ghai, S.; Schieppati, M. Incongruity of geometric and spectral markers in the assessment of body sway. *Front. Neurol.* **2022**, *13*, 929132. [CrossRef] [PubMed]
34. Waters, T.R.; Dick, R.B. Evidence of health risks associated with prolonged standing at work and intervention effectiveness. *Rehabil. Nurs.* **2015**, *40*, 148–165. [CrossRef] [PubMed]
35. Allen, D.G.; Lamb, G.D.; Westerblad, H. Skeletal muscle fatigue: Cellular mechanisms. *Physiol. Rev.* **2008**, *88*, 287–332. [CrossRef]
36. Hody, S.; Croisier, J.L.; Bury, T.; Rogister, B.; Leprince, P. Eccentric Muscle Contractions: Risks and Benefits. *Front. Physiol.* **2019**, *10*, 536. [CrossRef]
37. Acaster, S.; Dickerhoof, R.; DeBusk, K.; Bernard, K.; Strauss, W.; Allen, L.F. Qualitative and quantitative validation of the FACIT-fatigue scale in iron deficiency anemia. *Health Qual. Life Outcomes* **2015**, *13*, 60. [CrossRef]
38. Hepple, R.T. The Role of O_2 Supply in Muscle Fatigue. *Can. J. Appl. Physiol.* **2002**, *27*, 56–69. [CrossRef]
39. Nocella, M.; Colombini, B.; Benelli, G.; Cecchi, G.; Bagni, M.A.; Bruton, J. Force decline during fatigue is due to both a decrease in the force per individual cross-bridge and the number of cross-bridges. *J. Physiol.* **2011**, *589*, 3371–3381. [CrossRef]
40. Penedo, T.; Polastri, P.F.; Rodrigues, S.T.; Santinelli, F.B.; Costa, E.C.; Imaizumi, L.F.I.; Barbieri, R.A.; Barbieri, F.A. Motor strategy during postural control is not muscle fatigue joint-dependent, but muscle fatigue increases postural asymmetry. *PLoS ONE* **2021**, *16*, e0247395. [CrossRef]
41. Lee, J.W.; Park, J.S. The Correlation between Proprioception and Postural Control in Healthy Adults. *Iran. J. Public Health* **2022**, *51*, 2360–2361. [CrossRef]
42. Adkin, A.; Frank, J.S.; Jog, M.S. Fear of falling and postural control in Parkinson's disease. *Mov. Disord.* **2003**, *18*, 496–502. [CrossRef] [PubMed]
43. Bisson, E.J.; Remaud, A.; Boyas, S.; Lajoie, Y.; Bilodeau, M. Effects of fatiguing isometric and isokinetic ankle exercises on postural control while standing on firm and compliant surfaces. *J. Neuroeng. Rehabil.* **2012**, *9*, 39. [CrossRef] [PubMed]
44. Doherty, C.; Bleakley, C.; Hertel, J.; Caulfield, B.; Ryan, J.; Delahunt, E. Postural control strategies during single limb stance following acute lateral ankle sprain. *Clin. Biomech.* **2014**, *29*, 643–649. [CrossRef] [PubMed]
45. Boyas, S.; Hajj, M.; Bilodeau, M. Influence of ankle plantarflexor fatigue on postural sway, lower limb articular angles, and postural strategies during unipedal quiet standing. *Gait Posture* **2013**, *37*, 547–551. [CrossRef]
46. Horak, F.B.; Shupert, C.L.; Mirka, A. Components of postural dyscontrol in the elderly: A review. *Neurobiol. Aging* **1989**, *10*, 727–738. [CrossRef]
47. Terwee, C.B.; Peipert, J.D.; Chapman, R.; Lai, J.S.; Terluin, B.; Cella, D.; Griffiths, P.; Mokkink, L.B. Minimal important change (MIC): A conceptual clarification and systematic review of MIC estimates of PROMIS measures. *Quality Life Res.* **2021**, *30*, 2729–2754. [CrossRef]
48. Lin, D.; Seol, H.; Nussbaum, M.A.; Madigan, M.L. Reliability of COP-based postural sway measures and age-related differences. *Gait Posture* **2008**, *28*, 337–342. [CrossRef]
49. Swanenburg, J.; de Bruin, E.D.; Favero, K.; Uebelhart, D.; Mulder, T. The reliability of postural balance measures in single and dual tasking in elderly fallers and non-fallers. *BMC Musculoskelet. Disord.* **2008**, *9*, 162. [CrossRef]
50. Ku, P.X.; Abu Osman, N.A.; Yusof, A.; Wan Abas, W.A. Biomechanical evaluation of the relationship between postural control and body mass index. *J. Biomech.* **2012**, *45*, 1638–1642. [CrossRef]
51. Jo, D.; Bilodeau, M. Rating of perceived exertion (RPE) in studies of fatigue-induced postural control alterations in healthy adults: Scoping review of quantitative evidence. *Gait Posture* **2021**, *90*, 167–178. [CrossRef]
52. Kallenberg, L.A.C.; Schulte, E.; Disselhorst-Klug, C.; Hermens, H.J. Myoelectric manifestations of fatigue at low contraction levels in subjects with and without chronic pain. *J. Electromyogr. Kinesiol.* **2007**, *17*, 264–274. [CrossRef]