Full length article

# Can arm movements improve postural stability during challenging standing balance tasks?

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## ABSTRACT

*Background:* There is growing evidence that arm movements make a substantial and functionally relevant contribution to dynamic balance. Additional insight of the important role of arm movements may be gained by quantifying the effects of arm restriction on the performance of commonly recommended static balance tasks of increasing difficulty.

*Research question:* The purpose of the present study was to determine whether restricting/permitting arm movements influences postural sway during tasks of various levels of difficulty.

*Methods:* A total of 20 healthy and physically active adults (females; n = 10; age, 20.7 ± 1.3 years) randomly completed (a) quiet standing postural control tasks of increasing difficulty (bipedal, tandem, unipedal) on a fixed and foam surface, and (b) a dynamic postural control task (Y balance test), under two different verbally conveyed instructions of arm position; (1) restricted arm movement and (2) free arm movement. Centre of pressure outcomes measured during quiet standing served as a measure of static balance performance.

*Results:* The results showed that restricting movements of the arms elicited large magnitude (Cohen's $d = 0.97 – 1.28$) increases in mediolateral postural sway ($P < 0.05$) but not anteroposterior ($P > 0.05$) sway. These effects were only observed during challenging (tandem and unipedal) standing balance tasks. Restricting arm movements elicited a marked reduction in the Y Balance reach distance (all directions, $P < 0.001$, $d = -0.53$ to $-1.15$).

*Significance:* The findings from the present study suggest that the contribution of the arms only become relevant when frontal plane balance is challenged. Moreover, the data indicate that arm movements are vital for the control of mediolateral postural sway.

## 1. Introduction

Meta-analytic evidence suggests that balance training programmes that involve a high challenge to postural equilibrium elicit the greatest fall-prevention effects [1]. To sufficiently challenge the sensorimotor system during balance training it is appropriate to progressively increase the training intensity [2,3]. Increasing the level of difficulty of balance exercises can be achieved by various combinations of sensory modulation (i.e. foam surface, eyes closed) and stance manipulation (single limb, tandem), which will be reflected by varying degrees of postural sway [4,5]. In their recent systematic review and meta-analysis, Sherrington and colleagues [1] recommended restricted arm movements during balance exercises. Manipulating task difficulty by restricting/permitting arm movements during challenging balance tasks (i.e. those commonly employed in best-practice balance training programs) is an obvious and logical exercise variation. However, the effects of arm movements on postural sway remains to be empirically tested.

During challenging balance scenarios, we spontaneously outstretch our arms in an attempt to increase postural stability [6,7]. Accordingly, a growing body of literature has developed regarding the effects of arm contributions to postural control. Restricting movements of the arms decreases performance in functional mobility tasks (i.e. timed-up and go) [8], reduces dynamic postural control (i.e. Y Balance test) [9,10], impairs recovery of balance when standing on a balance board [11] and reduces stability during tandem walking [12]. Taken together, these findings suggest that the arms make a substantial and functionally relevant contribution to dynamic balance. To our knowledge, only one study has examined the effects of arm movement on static balance control. Patel et al. [13] reported that restricting arm movements impaired mechanisms to minimise postural sway during quiet tandem standing [13]. Given the paucity of previous research, additional insight may be gained by quantifying the effects of arm restriction on the

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performance of commonly recommended balance tasks of increasing difficulty.

Thus, the present study sought to determine whether restricting/permitting arm movements influences postural sway during quiet standing tasks of varying levels of difficulty. Based on findings from dynamic balance scenarios [12], it was hypothesised that the contribution of arm movements to postural performance increases with task difficulty. Since arm movements are likely to be more important when frontal plane balance regulation is challenged (i.e. tandem or unipedal stance) [10], it was further hypothesised that the effects of arm restriction on balance would be more profound in the mediolateral than the anteroposterior direction. Such findings will be influential in providing the practical evidence base to guide future efforts to incorporate/exclude upper body movements into balance training and rehabilitation protocols designed to reduce fall-risk.

## 2. Methods

### 2.1. Participants

An a priori power analysis (power = 0.80, alpha = 0.05, effect size = 0.70) was conducted for the Y Balance test (effects ranged from $d$ = 0.62–1.13 [10]) and revealed that 19 participants would be sufficient for finding statistically significant effects of arm restriction on balance performance. A total of 20 healthy and physically active adults (females; n = 10; age, 20.7 ± 1.3 years; height 1.73 ± 0.09 m; mass 72.8 ± 16.5 kg) volunteered in the study. Participants completed the Physical Activity Readiness Questionnaire (PAR-Q) to detect potential factors that might affect their balance. None of the participants had any known neurological diseases, musculoskeletal dysfunction or orthopaedic pathology and no history of ankle injury in the past 12 months. The study was approved by the institutional research ethics committee and all procedures were carried out in accordance with the guidelines outlined in the Declaration of Helsinki (1964). Written informed consent was obtained from each participant prior to involvement in the study.

### 2.2. Experimental design

This study employed a repeated measures, within-subject design. During a single visit to the biomechanics laboratory, participants randomly completed (a) quiet standing postural control tasks of increasing difficulty (bipedal, tandem, unipedal) on a firm and foam surface, and (b) a dynamic postural control task, under two different verbally conveyed instructions of arm position; (1) arms placed flat across the chest touching the contralateral shoulder (i.e., restricted arm movement) and (2) arm movement without restriction (i.e., free arm movement) [10]. To ensure adequate habituation to balance tasks and to remove potential learning effects, participants completed three practice trials and two recorded trials for each test condition (i.e. free arms vs. restricted arms). The order of balance tasks was randomised, as were the arm position instructions. For the free arm movement, participants were instructed to be able to move their arms freely to their advantage during the tasks. For the restricted arm position, compliance to the instructions was monitored visually by the investigator.

### 2.3. Posturography

Postural sway measured during quiet standing served as a measure of static balance performance [14]. Each participant performed quiet stance trials while standing on a force platform (AMTI, AccuGait, Watertown, MA) for 30 s. Data were sampled at 100 Hz (AMTI, Netforce, Watertown, MA) and the maximal displacement (i.e. distance between the maximum and minimum COP displacement) of centre of pressure (COP) in the anteroposterior and mediolateral directions (both cm), and COP path length (cm) (i.e. total distance travelled) were subsequently

calculated (AMTI, BioAnalysis, Version 2.2, Watertown, MA). The validity and reliability of these parameters have previously been established for this sampling duration [15]. After three familiarisation trials for each task, participants performed two trials (an average was used in the subsequent analysis) of each of the following balance tasks: standing on a firm surface in a (1) bipedal, (2) tandem, and (3) unipedal stance, and standing on an foam surface (Balance-pad Plus, Alcan Airex AG, Switzerland) in a (4) bipedal, (5) tandem, and (5) unipedal stance. To ensure continuity during bipedal trials, unshod foot position was standardised by instructing participants to stand with the feet together. During tandem stance, participants stood with the right foot in front of the left (all participants were right foot dominant). Foot dominance was defined as the foot used to kick a ball [10]. For continuity, the great toe of the left foot was required to touch the most posterior part of the calcaneus on the right foot. For the unipedal trials, participants maintained a single-leg stance with the dominant limb. Participants were instructed that the unloaded leg should not touch the supporting leg and the knee should be flexed to 90˚. Termination of the test was recorded if; (1) the foot touched the support leg, (2) hopping occurred, (3) the foot touched the floor.

Unsuccessful trials were discarded and repeated until two trials were successfully recorded. During all quiet standing trials, participants were asked to stand as still as possible on the force platform while gazing at a target 1.5 m from the force platform, which was adjusted to the eye level of each individual. Participants could step off the plate and rest between tests ( ± 60 s).

### 2.4. Dynamic postural stability

The Y Balance Test Kit™ was used to determine dynamic postural control. We also used this test to confirm that restricted arm movements impaired balance performance [9,10]. As described by Plisky et al. [16], the Y Balance Test Kit™ consists of a stance platform to which three pieces of plastic pipe are attached in the anterior, posteromedial, and posterolateral reach directions. The posteromedial and posterolateral pipes are positioned 135 degrees from the anterior pipe with 45 degrees between the posterior pipes. Participants were asked to stand on the centre of a foot plate with the most distal point of the great toe at the starting line. While maintaining a single-leg stance with the dominant limb, participants were asked to push a reach indicator along the pipe with the contralateral limb (i.e., non-dominant limb) in each of the reach directions. The trial was discarded and repeated if the participant (1) failed to maintain single limb stance (i.e., touch the floor with the reach limb), (2) failed to remain in contact with the reach indicator at the most distal point (i.e., kicked the reach indicator to achieve greater distance), (3) used the reach indicator to support weight (i.e., mechanical support) or (4) failed to return to the reach foot at the centre of the foot plate [10]. Although the reach direction was randomised, to improve reproducibility of the testing protocol, participants performed three consecutive reach attempts for each direction. The greatest reach distance for each direction was used for subsequent analysis. Reach distance was normalised to limb length (reach distance / limb length * 100) [16]. Each participant's dominant limb length was measured in centimetres from the anterior superior iliac spine to the most distal portion of the medial malleolus using an anthropometric measuring tape [17]. Additionally, the composite reach score was also calculated as the sum of the three reach directions divided by three times limb length, and then multiplied by 100 [16].

### 2.5. Statistical analysis

Data were analysed using SPSS version 25.0 (IBM Inc., Chicago, IL). Paired t-tests were carried out to determine differences in dynamic balance between free arm and restricted arm movements. Recognising that gender may influence the performance of balance assessments, as part of our initial exploratory analyses we conducted a 2 (gender; male

and female) $\times$ 2 (arm contribution; free and restricted) $\times$ 3 (stance; bipedal vs. tandem vs. unipedal) way ANOVA, to determine the effects of gender as a between-subject factor. There were no significant interactive or main effects of gender for any of the outcome measures. Therefore, separate two-way analysis of variance (ANOVA) with repeated measures on both factors (e.g. stance; bipedal vs. tandem vs. unipedal $\times$ arm position; free arm-movement vs. restricted arm-movement) were conducted to examine changes in dependent variables. Firm and foam surface conditions were analysed separately. For all analyses, normality (Shapiro–Wilk Test) and homogeneity of variance/sphericity (Mauchly Test) were performed and confirmed prior to parametric analyses. Post hoc analyses with the Bonferroni-adjusted $\alpha$ for multiple comparisons were conducted to follow up significant effects. For ANOVA, effect sizes are reported as partial eta-squared value ($\eta^2$) where appropriate. Cohen's d magnitude of effect size is reported for pairwise comparisons and were interpreted as trivial ($< 0.20$), small (0.2), moderate (0.6), large (1.2) and very large ($> 2.0$) (Hopkins et al., 2009). All values are expressed as mean $\pm$ SD. Statistical significance was accepted at $P \leq 0.05$.

## 3. Results

### 3.1. Postural sway

Fig. 1 illustrates the effects of arm restriction on postural sway during bipedal, tandem and unipedal stance on a firm surface. The 3 (stance) $\times$ 2 (arm movement) way ANOVA revealed a significant interaction for the mediolateral COP displacement ($F_{(2,38)} = 28.390$, $P < 0.001$, $\eta^2 = .599$). Main effects of stance were found for anteroposterior COP displacement ($F_{(2,38)} = 39.556$, $P < 0.001$, $\eta^2 = .676$) and COP path length ($F_{(2,38)} = 45.352$, $P < 0.001$, $\eta^2 = .705$). Further main effects of arm movement were found for the COP path length ($F_{(1,19)} = 5.566$, $P < 0.001$, $\eta^2 = .227$). Follow up *post-hoc* analysis revealed a significantly greater mediolateral COP displacement with the restricted arm-movements for tandem ($P < 0.001$, d = 1.15) and unipedal ($P = 0.001$, d = 1.28) stance. In contrast, the mediolateral COP displacement was significantly smaller during the arm-restricted condition during bipedal stance ($P = 0.007$, d = 0.37).

Fig. 2 illustrates the effects of arm restriction on postural sway during bipedal, tandem and unipedal stance on a foam surface. The 3 (stance) $\times$ 2 (arm movement) way ANOVA revealed a significant interaction for the mediolateral COP displacement ($F_{(2,38)} = 15.609$, $P < 0.001$, $\eta^2 = .451$). Main effects of stance were found for anteroposterior COP displacement ($F_{(2,38)} = 18.981$, $P < 0.001$, $\eta^2 = .500$) and COP path length ($F_{(2,38)} = 37.342$, $P < 0.001$, $\eta^2 = .663$). Further main effects of arm movement were found for the COP path length ($F_{(1,19)} = 4.802$, $P = 0.041$, $\eta^2 = .202$). Follow up *post-hoc* analysis revealed a significantly greater mediolateral COP displacement with the restricted arm-movements for tandem ($P = 0.002$, d = 0.97) and unipedal ($P = 0.002$, d = 1.08) stance. As with the firm surface condition, the mediolateral COP displacement was significantly smaller during the arm-restricted condition during bipedal stance ($P = 0.005$, d = 0.98).

### 3.2. Dynamic postural stability

Fig. 3 illustrates the effects of arm restriction on dynamic balance performance of the right and left limbs. Separate paired *t*-test revealed significant differences between free and restricted-arm conditions for the anterior (right limb; d = 0.70, left limb; d = 0.63), posteromedial (right limb; d = 1.15, left limb; d = 0.81), posterolateral (right limb; d = 0.56, left limb; d = 0.70) and composite (right limb; d = 0.56, left limb; d = 0.53) reach distance (all P < 0.001). For all directions, reach distance was significant greater during free arm-movement compared to restricted arm-movement.
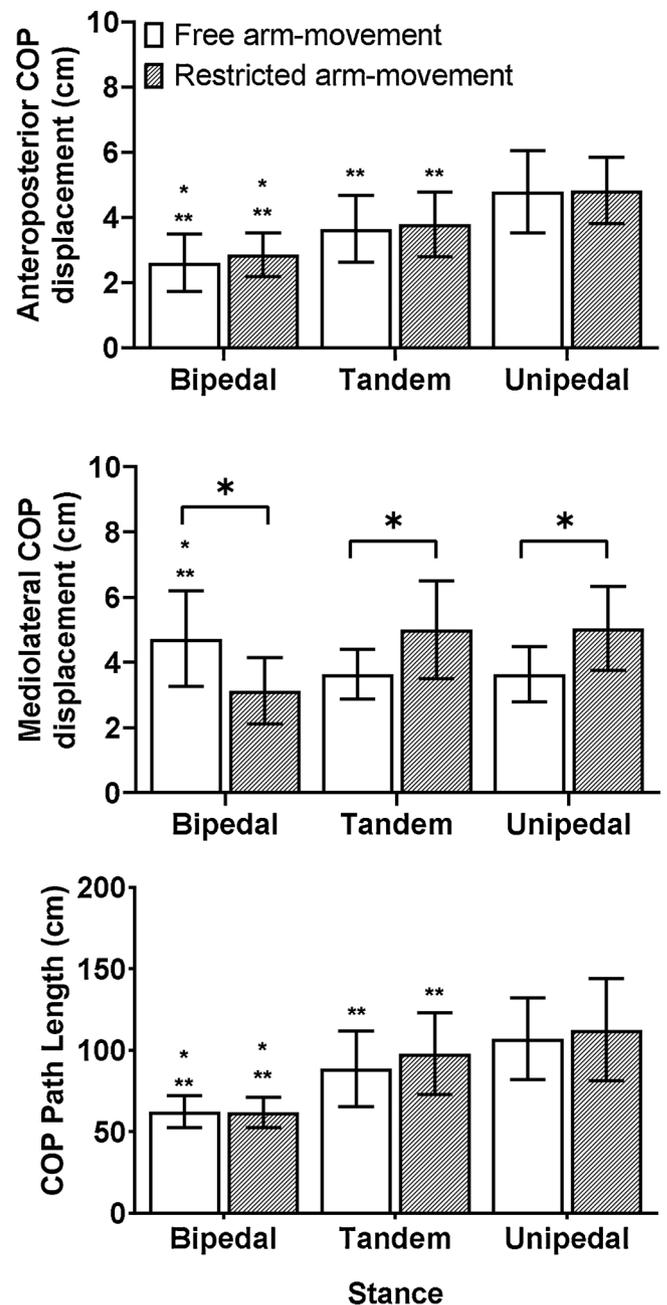


**Fig. 1.** Mean $\pm$ SD anteroposterior and mediolateral COP displacement and COP path length with free (white) and restricted (lines) arm movements during bipedal, tandem and unipedal stance on a firm surface. *Post hoc comparisons*; *significantly different to tandem stance (P < 0.05). **significantly different to unipedal stance (P < 0.05). Main effect of arm movement is illustrated by large asterisks (P < 0.05).

## 4. Discussion

The research presented here is the first to quantify the effects of arm restriction on measures of postural sway during standing balance tasks of increasing difficulty. In accordance to the hypotheses, restricting movements of the arms elicited large magnitude increases in postural sway in the mediolateral, but not anteroposterior direction during challenging (tandem and single limb stance) standing balance tasks.

Replicating previous research, we showed that reducing the base of support (i.e. tandem and unipedal) [4,18,19] and altering the support surface (i.e. foam) [5,20], increased postural sway displacement and total path length. Although human upright standing is inherently
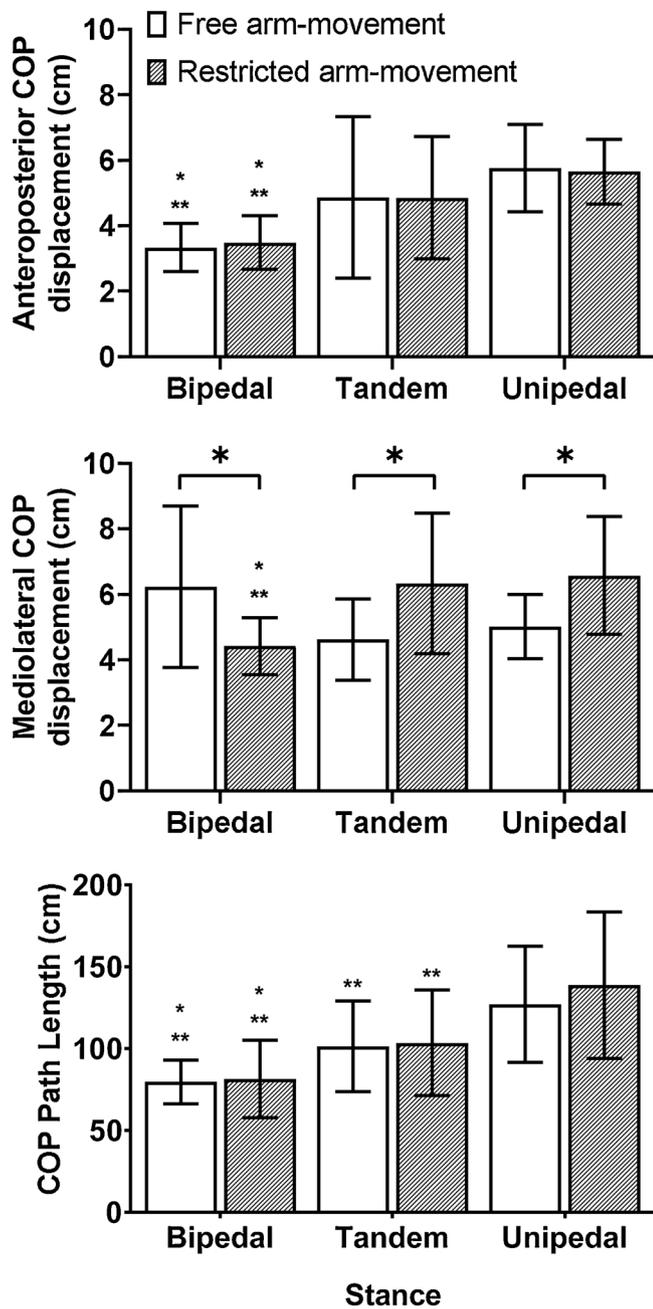
**Fig. 2.** Mean ± SD anteroposterior and mediolateral COP displacement and COP path length with free (white) and restricted (lines) arm movements during bipedal, tandem and unipedal stance on a foam surface. *Post hoc comparisons*; *significantly different to tandem stance (P < 0.05). **significantly different to unipedal stance (P < 0.05). Main effect of arm movement is illustrated by large asterisks (P < 0.05).



**Fig. 3.** Mean ± SD anterior, posteromedial, posterolateral and composite reach distance for the right (A) and left (B) limb with free (white) and restricted (lines) arm movements. *Significant main effect of arm restriction.

unstable [21], the postural control system uses two distinct modes of operation to maintain upright stance, referred to as the ankle and hip strategies [22]. Ankle mechanisms (single segment inverted pendulum) are predominantly used during bipedal stance [23] while the hip strategy (double-segment inverted pendulum) is expected to be employed when the support surface is narrow (i.e. tandem or unipedal) where little ankle torque can be applied [22]. However, it has been suggested that control of upright stance is multivariate [24,25] as opposed to bivariate in nature. Although an upright posture can be maintained by the ankle and hip mechanisms during most scenarios, movements of the upper body are not considered by these two control strategies.
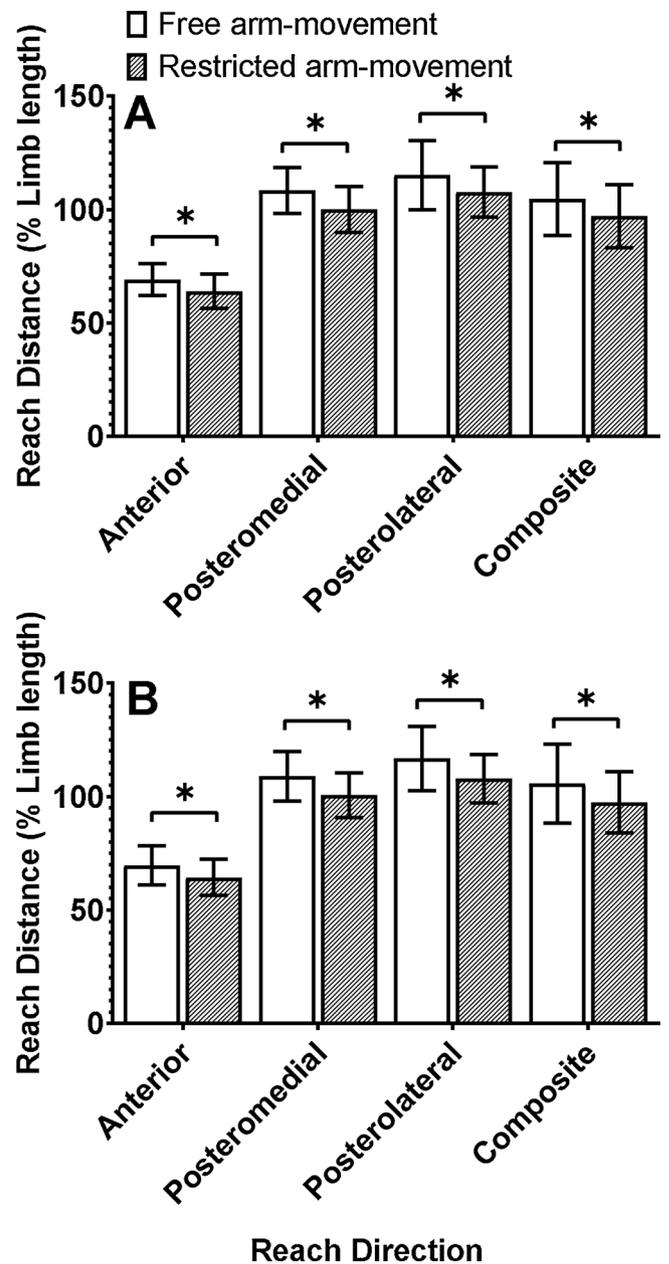
Results of the present study suggest a relationship between standing task difficulty and reliance on arm movements. These findings provide an important extension to the current postural control literature by providing the scientific evidence base that using the arms freely helps postural stability during challenging situations. Such findings align with prior work which showed that outstretching the arms reduces postural sway during tandem standing [13]. By comparing three different postural tasks of increasing difficulty (bipedal, tandem, unipedal), our results showed a reduction in mediolateral, but not anteroposterior sway with free arm movements, confirming our hypothesis. These findings are important because mediolateral aspects of postural control are predictive of future falls [26]. Overall, several mechanical mechanisms may account for the lower postural sway observed during the free arm movement conditions. Specifically, greater dispersion of body mass in the frontal plane increases the moment of inertia, which should theoretically increase stability of the postural control system

[10]. Further, in stance conditions where the support surface has been changed only in the mediolateral direction (i.e. during tandem or unipedal stance), we would have expected only mediolateral sway would change. Accordingly, arm movements may have been used to generate restoring torques to reduce angular momentum of the body [13,27] and act as counterweight to shift the centre of mass away from the direction of instability [28].

It was interesting to observe that participants' postural sway increased during bipedal stance with free arm movements. The most likely explanation for this finding may be the presence of a ceiling effect. For example, during bipedal stance, body oscillations will be close to the "physiological minimum". Thus, raising the arms during this task may cause instability in an already stable position. In contrast, postural stability in challenging situations has more room to improve, and therefore changes are more noticeable. As evidence, the greatest effect of restricting arm movement on postural sway was observed when participants stood in unipedal stance (both foam and firm surface), compared to bipedal and tandem stance.

Given the exploratory nature of this study, we sought to use the Y balance test to confirm the effects of arm restriction of performance with previous studies. The observed deterioration in Y balance reach performance is consistent with previous findings [9,10]. In the present study, we found moderate to large magnitude reductions ($d = 0.53$–$1.15$) in the anterior, posteromedial and posterolateral reach scores when arm movements were restricted. Importantly, this is the first study to show that restricting arm movements elicits a similar magnitude of effect (Cohen's d) for both static and dynamic tasks. Although it was not the aim of this study to compare the effects of arm movement on static and dynamic postural stability, these findings offer an important first step before additional exploration in relation to the effects of arm movements during functional balance tasks (i.e. stepping, turning, obstacle crossing) could be undertaken.

An important clinical implication from the present study is that postural control during challenging stance conditions (tandem and unipedal) is affected by arm position and movements. Therefore, specific instructions regarding arm position would be necessary to avoid misinterpretation of balance performance and to facilitate experimental replication. Studies directly investigating effects of arm movements on static balance are rare. Therefore, current guidelines concerning the manipulation of arm movements during balance training lacks scientific validation. Based on our findings, we suggest that; (a) permitting arm movements may be valuable in acting as a starting point as part of a continuum of balance training to progress to more challenging scenarios, (b) restricting arm movements may promote more effective control of the centre of mass by focusing on ankle, knee and hip postural strategies.

## 5. Conclusion

The findings from the present study suggest that the contribution of the arms to improve postural stability only become relevant when frontal plane balance is challenged. Moreover, the data indicate that arm movements are vital for mediolateral control of postural sway. This is an important finding because mediolateral aspects of postural control are prospectively associated with increased fall-risk [26]. Consequently, balance training programmes should focus on restricting arm movements to challenge mediolateral postural stability, which in turn might reduce the risk of falls. Collectively, these findings can be used to select balance exercises of suitable difficulty to match individual's balance ability and to implement progression, variability and novelty in balance training.

## Declaration of Competing Interest

None

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