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# Acute effect of short-duration static stretching exercises on dynamic balance in U-14 female athletes

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**Abstract**

*Purpose:* The acute effects of static stretching (SS) on dynamic balance, a key fitness component that contributes to injury prevention, has been and is still a subject of significant debate. This study aimed to investigate the acute effect of short-duration SS exercises on dynamic balance following different recovery durations in youth female volleyball players. *Methods:* Thirteen volunteers U-14 female players were included. Eight random assessments were carried-out on separate days. They consisted of 2D-kinematic analysis of frontal and/or sagittal balance of the center of mass (COM) displacement, velocity, and acceleration on wobble board conducted without SS, immediately after and following 2 and 10 minutes of SS. *Results:* Repeated-measures ANOVA showed a significant difference between conditions in the velocity ($p$=0.002 to 0.049; $d$=0.844 to 2.200) and the acceleration ($p$=0.014 to 0.021; $d$=1.532 to 1.657) of the COM in both frontal and sagittal planes sway. Post-hoc analysis revealed decreased COM velocity ($p$=0.001 to 0.030; $d$=2.501 to 6.750) and acceleration ($p$=0.001 to 0.030; $d$=2.501 to 6.750) in the frontal plane, regardless of the recovery time. The most prominent decrease in both parameters was observed immediately after SS ($p$=0.001 to 0.013; $d$=2.907 to 6.750). However, in the sagittal balance, we observed an immediate increase in COM acceleration following SS ($p$<0.001; $d$=4.223). *Conclusion:* Short-duration SS leads to improved dynamic balance, particularly on the frontal plane, with the most favorable effect observed immediately after stretching. Practically speaking, short-duration SS appears to be an effective exercise modality for inducing acute enhancements in dynamic balance among youth female volleyball players.


**Keywords:** Passive stretching, postural control, kinematic analysis, youth females, short-term effect.

**Introduction**

Stretching and more particularly static stretching (SS) is a prevalent practice in sports and exercise. In fact, integrating a comprehensive stretching routine into the training regimen of athletes can positively impact their physical performance and promote the development of strength and power [2, 23]. Particularly, for athletes, engaging in SS is vital, as it can improve the range of motion (ROM) around joints and decrease the risk of injuries [5, 7].

While the chronic effects of SS on various measures of physical fitness such as muscle strength and power can generally be considered positive [2], the acute effects remain a topic of significant debate [7, 41]. In this sense, although earlier studies advised against performing SS before strength- and power-related tasks [27, 37], more recent investigations have shown that the duration of SS does matters. For instance, Chaabene et al. [9] reviewed the acute effects of SS on muscle strength and power. Their findings indicated that prolonged SS, exceeding 60 seconds per muscle group, tends to lead to noteworthy and practically relevant decreases in strength and power performances. On the other hand, short-duration SS with an accumulated duration per muscle group does not surpass 60 seconds causes only no-to-trivial negative effects on subsequent strength and power performances [9]. This is because neuromuscular activation and musculotendinous stiffness appear not to be significantly impaired after short-duration SS ($\leq$ 60 seconds) compared to long-duration SS (> 60 seconds) [5, 9, 23].

Unlike muscle strength and power where a sort of consensus on the acute effect of SS exists [4, 10], the immediate effects of SS on dynamic balance, a key fitness component that contributes to injury prevention in a wide range of sports disciplines [7], including volleyball [22], has been a subject of significant contention [7, 10]. There are conflicting outcomes pertaining to the acute effects of SS on dynamic balance. The differing results can be attributed to a range of factors including the subjects' training status [11], age, and sex [20], as well as the duration and intensity of the stretching protocol [6]. For instance, Behm et al. [7] noted in their review that the acute effects of SS on balance remain inconclusive, yet consistent SS training could potentially enhance balance and contribute to mitigating the risk of falls and injuries. Additionally, Behm et al. [4] demonstrated that 3 sets of SS with 45 sec duration targeting the lower limbs resulted in reduced subsequent dynamic balance scores compared to the control condition in healthy male student. This is consistent with the results reported by Nagano et al. [31] who showed that dynamic balance performance was decreased after a single 3 min SS of the calf muscle in healthy physically active males. Furthermore, the findings of Chatzopoulos et al. [10] showed that a total of 7 min SS generated significant balance performance deterioration in female high-school athletes. However, in a recent study, Oba et al. [34] demonstrated that intermittent SS with four sets, each lasting 30 seconds, had no adverse impact on postural control in recreational athletes. Moreover, Costa et al. [11] indicated that performing two sets of SS, 45 seconds each, had no detrimental impact on balance, whereas two sets of SS, 15 seconds each, resulted in a notable improvement dynamic balance in healthy, recreationally active women. Besides, Handrakis et al. [20] and Nelson et al. [32] demonstrated enhancements in dynamic balance (i.e., single leg balance on a Balance System SD movable platform) and postural sway (i.e., time to maintain a stabilometer horizontal over two 30-second periods) following 10 to 30 minutes of total SS exercises in male and female collegiate students. Nonetheless, the duration of SS plays a pivotal role in enhancing the effects on dynamic balance. Earlier studies, such as those conducted by Costa et al. [11], Ghaffarinejad et al. [17], and Denerel et al. [14], indicate that short-duration SS (≤ 60 seconds per muscle group) may enhance subsequent balance performance in physically active athletes of both sexes. Indeed, such exercises may have positive effects on joint position sense and proprioception [14, 17]. However, short-duration SS can also result in decreased subsequent balance performance [10].

In light of the marked heterogeneity in the literature, there is a need for further studies to bring forth more clarity to this topic. Additionally, dynamic balance is crucial in volleyball for injury prevention [22]. Despite SS being a common practice in volleyball, its acute effects on dynamic balance are not well understood. Therefore, this study aims to investigate the acute effect of short-duration SS on dynamic balance after different recovery periods (i.e., immediately after and following 2 and 10 minutes) in youth female volleyball players. We hypothesized that, regardless of the recovery period, short-duration SS would benefit dynamic balance [11]. We also hypothesized that the largest effect on dynamic balance would be observed immediately after short-duration SS [7].

## Methods

### *Participants*

A minimum sample size of 13 participants was determined from an a priori statistical power analysis using G*Power software (Version 3.1, University of Dusseldorf, Germany [16]). The power analysis was computed with an assumed power at 0.80 at an alpha level of 0.050 and a moderate effect size ($d$ = 0.70 and critical $F$ = 2.866) [18]. Therefore, thirteen volunteers U-14 female volleyball players (age = 13.42 ± 0.32 years; maturity offset (MO) = 0.34 ± 0.01 years; body height = 1.68 ± 0.04 m; body mass = 57.03 ± 4.02 kg) agreed to participate in this study. The inclusion criteria were to be female volleyball players U-14 years ranked at a national level with participation in national cups and/or championships; average training time was 10 ± 2 hours per week; accustomed to dynamic balance exercises on single plane balance board and/or Freeman plate; healthy without any muscular, neurological, or tendon injuries. After being informed in advance of the procedures, methods, benefits, and possible risks of the study, participants as well as their parent/legal representatives reviewed and signed a consent form to participate in the study. The experimental protocol was performed per the declaration of Helsinki for human experimentation and was approved by the local Ethical Committee of the National Observatory of Sport (ONS/UR/18JS01).

***Experimental design and procedures***

This study is made up of eight random assessments [i.e., randomized counterbalanced, Latin Square]; each assessment took place on a separate day with 24 hours interval between sessions. All assessments were carried out in the gymnasium at the same time of the day (between 10:00 PM and 12:00 PM). Each of the assessments involved a 2D kinematic analysis of frontal and/or sagittal balance (i.e., in bipedal standing upright) of the center of mass (COM) displacement, velocity, and acceleration on wobble board (i.e., single plane balance board (SPBB), length and width 420 × 420 mm; height 70 mm [1, 15, 28, 30]) (Figure 1). These assessments were conducted both without and after a SS exercises session (i.e., 15 min, Table 1), with different recovery durations (i.e., immediately after and following 2 and 10 minutes).

Kinematic analysis was performed in two-dimension (2D) using two cameras AEE PNJ camera SD18, HD 720 p, CCD 1000000 pixels, SSC 1/4000 per second, minimum sensitivity 1 lux acquisition frequency 120 Hz, zoom angle 145°. They were arranged to capture the swaying movement; the first camera was facing 2 m from the SPBB and the second was 2m from the side of the SPBB. Twenty reflective markers were affixed to every participant using the Hanavan model [19] modified by de Leva [13] digitized through the video-based data analysis system SkillSpector® (Version 1.3.2, Odense SØ – Denmark [8]) with quantic-spline data filtering. Sway velocity, displacement, and acceleration of the COM were recorded in frontal and sagittal planes (i.e., $FBvx_{COM}$, $SBvx_{COM}$, $FBdx_{COM}$, $SBdx_{COM}$, $FBax_{COM}$, and $SBax_{COM}$, respectively).


**Figure 1. Experimental protocol: (a) Bipedal sway, sagittal balance; (b) Bipedal sway, frontal balance.**

Table 1. Stretching session.

| Exercise | Description | Stretch | Sketch |
|---|---|---|---|
| Standing Quad Stretch | Stand with your feet together.<br>Bend your left knee and use your left hand to pull your left foot toward your butt. Keep your knees together. | 15s held/<br>30s rest /<br>3 repetitions |  |
| Pike Stretch | Sit in the ground with your legs stretched out in front of you.<br>Gently lean over, pulling your core in as you do so, and reach for your toes. | 15s held/<br>30s rest /<br>3 repetitions |  |
| Piriformis Stretch | Cross your right leg over your left and place your right foot flat on the floor.<br>Place your right hand on the floor behind your body.<br>Place your left hand on your right quad and press | 15s held/<br>30s rest /<br>3 repetitions |  |

| | | | |
|---|---|---|---|
| | your right leg to the left as you twist your torso to the right. | | |
| Straddle Stretch | Seated on a mat, extend your legs out to the side. Lengthen your spine to sit up tall and extend your arms up, then drop forward. | 15s held/ 30s rest / 3 repetitions |  |
| Calf Stretch | Stand at arm's length from a wall. Place your right foot behind your left foot. Hold your back straight and your hips forward. | 15s held/ 30s rest / 3 repetitions |  |
| Knees to Chest Stretch | Lie on your back and pull your knees into your chest with both hands. Keep your lower back on the floor. | 15s held/ 30s rest / 3 repetitions |  |

The postural performance was evaluated across a range of several balance tests mentioned as follows:

- Without stretching session, 30-second frontal plane balance in bipedal stance on the SPBB (WSFB).
- Without stretching session, 30-second sagittal plane balance in bipedal stance on the SPBB (WSSB).
- Immediately after the stretching session, 30-second frontal plane balance in bipedal stance on the SPBB (ISFB).
- Immediately after the stretching session, 30-second sagittal plane balance in bipedal stance on the SPBB (ISSB).
- Two minutes recovery after stretching session, 30-second frontal plane balance in bipedal stance on the SPBB (2RFB).
- Two minutes recovery after stretching session, 30-second sagittal plane balance in bipedal stance on the SPBB (2RSB).

- Ten minutes recovery after stretching session, 30-second frontal plane balance in bipedal stance on the SPBB (10RFB).
- Ten minutes recovery after stretching session, 30-second sagittal plane balance in bipedal stance on the SPBB (10RSB).

The participants were asked to fixate a black cross (20 x 25 cm) located on a wall 1.20 m away from the SPBB, in front of participants. In all trials, athletes were instructed to keep their bodies straight, and their arms loosely hanging by their sides [39]. The kinematic analysis was performed over 10 seconds (i.e., between the $11^{th}$ and the $20^{th}$ second of the sway test) [15, 30]. For each experimental condition, subjects performed two trials to become acquainted.

### *Statistical analyses*

As part of the statistical analysis, the SPSS 20 package (SPSS, Chicago, IL, USA) program was used for the data analysis. Descriptive statistics (i.e., means ± SD) were performed for all variables. The effect size was conducted using G*Power software (Version 3.1, University of Dusseldorf, Germany). The following scale was used for the interpretation of *d*: < 0.2, trivial; 0.2 – 0.6, small; 0.6 – 1.2, moderate; 1.2 – 2.0, large; and > 2.0, very large [21]. The normality of distribution was assessed using the Kolmogorov-Smirnov test. ANOVA with repeated measures on 1 factor (i.e., condition) was used. Post hoc analysis was conducted using the Bonferroni test. Additionally, effect sizes (*d*) were determined from ANOVA output by converting partial eta-squared to Cohen's *d*. A priori level less than or equal to 0.5 % ($p \leq 0.050$) was used as a criterion for significance.

## Results

The results of the ANOVA analysis showed significant effects of the factor conditions (i.e., control [without SS], immediately after SS, and following 2 and 10-minutes rest) in the velocity and acceleration of the COM in both frontal and sagittal planes sway (Table 2).

Table 2. ANOVA with repeated measures on 1 factor.

| Source | Sum of Squares | df | Mean Square | $F_{(1,12)}$ | *p* | Effect Size (*d*) | Power |
|---|---|---|---|---|---|---|---|
| $SBdx_{COM}$ | 0.000 | 1 | 0.000 | 0.275 | 0.609 | 0.300 | 0.077 |
| $SBvx_{COM}$ | 0.000 | 1 | 0.000 | 1.590 | 0.231 | 0.728 | 0.213 |
| $SBax_{COM}$ | 0.523 | 1 | 0.523 | 7.034 | 0.021* | 1.532 | 0.683 |
| $FBdx_{COM}$ | 0.036 | 1 | 0.036 | 4.060 | 0.067 | 1.108 | 0.458 |
| $FBvx_{COM}$ | 0.170 | 1 | 0.170 | 14.523 | 0.002** | 2.200 | 0.937 |
| $FBax_{COM}$ | 0.002 | 1 | 0.002 | 8.228 | 0.014* | 1.657 | 0.750 |

** (SB) Sagittal balance; (FB) Frontal balance; (dx) Horizontal displacement; (vx) Horizontal velocity; (ax) Horizontal acceleration; (COM) Centre of mass; (*) Significant at p < 0.050; (**) Significant at p < 0.010.*

The post-hoc analysis revealed decreased COM velocity ($p$ = 0.001 to 0.030; $d$ = 2.501 to 6.750) and acceleration ($p$ = 0.001 to 0.030; $d$ = 2.501 to 6.750) in the frontal plane, regardless of the recovery time. The most prominent decrease in both parameters was observed immediately after SS ($p$ = 0.001 to 0.013; $d$ = 2.907 to 6.750). However, in the sagittal balance, we observed an immediate increase only in COM acceleration following SS ($p$ < 0.001; $d$ = 4.223). The sway velocity did not display any significant difference between conditions and recovery periods (i.e., control [without SS], immediately after SS, and following 2 and 10-minutes rest), (Table 3; Figure 2).

Table 3. Pairwise comparison between no-stretching/stretching and different recovery periods.

| Measure | | Mean Difference | Std. Error | *p* | Effect Size (*d*) |
|---|---|---|---|---|---|
| SB $ax_{COM}$ | WS vs. IS | 0.283 | 0.067 | 0.001** | 4.223 |
| | WS vs. 2R | 0.330 | 0.125 | 0.022* | 2.640 |
| FB $vx_{COM}$ | WS vs. IS | 0.157 | 0.054 | 0.013* | 2.907 |
| | WS vs. 2R | 0.176 | 0.065 | 0.020* | 2.707 |
| | IS vs. 10R | 0.071 | 0.029 | 0.029* | 2.448 |
| FB $ax_{COM}$ | WS vs. IS | 0.027 | 0.004 | 0.000** | 6.750 |
| | IS vs. 2R | 0.021 | 0.008 | 0.020* | 2.625 |
| | IS vs. 10R | 0.030 | 0.012 | 0.030* | 2.501 |

** (SB) Sagittal balance; (FB) Frontal balance; (vx) Horizontal velocity; (ax) Horizontal acceleration; (COM) Centre of mass; (WS) Without stretching; (IS) Immediately after stretching; (2R) Two minutes recovery after stretching session; (10R) Ten minutes recovery after stretching session; (*) Significant at p < 0.050; (**) Significant at p < 0.010.*



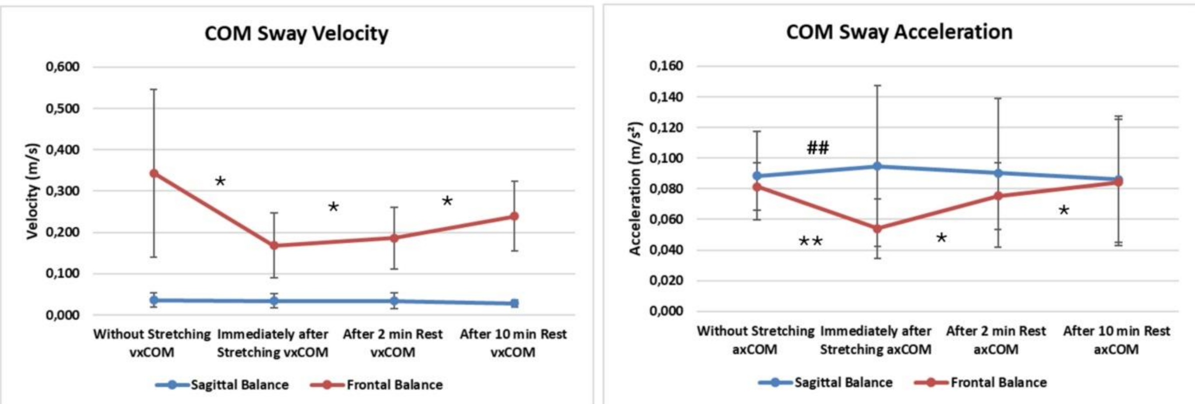


Figure 2. Center of mass (COM) sway velocity and acceleration. [(*) Significant at p<0.05 in frontal balance; (**) Significant at p<0.001 in frontal balance; (#) Significant at p<0.05 in sagittal balance. (##) Significant at p<0.001 in sagittal balance]

**Discussion**

This study aimed to investigate the acute effects of short-duration SS on dynamic balance performance of young female volleyball players across different recovery times. The main findings indicated decreased COM velocity and acceleration in the frontal plane, regardless of the recovery time. Of note, the most prominent decrease in both parameters (i.e., COM velocity and acceleration) was observed immediately after SS. In the sagittal plane, however, we observed an immediate increase in COM acceleration following SS.

Our results indicated that short-duration SS can result in beneficial effects on dynamic balance performance in youth female volleyball players. More specifically, results showed decreased COM velocity and acceleration in the frontal plane, regardless of the recovery times. This is reflective of an improved dynamic balance performance, which was notably greater immediately after short-duration SS compared to 2 and 10-minutes after. These findings align with the studies conducted by Nelson et al. [32] and Costa et al. [11], where both demonstrated that the short-duration SS exercises (i.e., 15 seconds) resulted a dynamic balance improvement in frontal plane. Nelson et al. [32] suggested that enhanced flexibility, especially in individuals unaccustomed to dynamic balance tasks, results in a greater increase in balance performance. This implies that heightened balance instability may be associated with increased joint stiffness [32]. Consequently, the enhanced ability to sustain dynamic balance after improved flexibility may be connected to a desensitized stretch reflex [32]. In addition, Ghaffarinejad et al. [17] have demonstrated that short-duration SS can enhance joint position sense, resulting in increased proprioceptive feedback. This enhancement in proprioception could serve as a mechanism that, consequently, contributes to improved balance [11]. However, Behm et al. [5] carried out a systematic review on the acute effect of short-duration SS on dynamic balance performance. They revealed a decrease in balance following 45-second SS. Similarly, Lewis et al. [26] reported that short-duration SS of lower extremity muscles (i.e., 3 sets, 45 seconds each) did not influence dynamic balance.

In contrast, the data revealed a significant decrease of COM acceleration in sagittal plane and an improvement in dynamic postural control just following the control (without SS) and after 10-minutes rest of SS session. In simpler terms, short-duration SS did not positively contribute to enhancing dynamic balance in the sagittal plane. It appears that the sagittal plane condition may have a more significant impact on sensory functions compared to the motor functions engaged in task-oriented balance exercises that rely on visual feedback [42]. This indicates that alterations in the sagittal plane, potentially related to somatosensory inputs, play a crucial role in affecting sensory aspects during balance tasks, particularly when visual feedback is a factor. Furthermore, the results imply, in accordance with Szczepanowska-Wołowiec et al. [38], that once a certain threshold of deterioration in proprioceptive function is reached, there is no further decrease in balance parameters. This suggests a non-linear relationship between the decline in proprioceptive function and its impact on balance, indicating that beyond a specific point, balance parameters do not further deteriorate despite ongoing degradation in proprioception. Furthermore, no significant effects were observed in the displacement of the COM parameter in both the frontal and sagittal planes following short-duration SS. This implies that the brief SS did not induce measurable changes in the displacement of the COM, suggesting a limited immediate impact on this balance parameter under the given experimental conditions.

In addition, our results suggest that the most favorable effects of short-duration SS on dynamic balance occurred immediately after. This is supported by the significant difference favoring immediately after SS over 2-minutes rest (i.e., 0.054 ± 0.0193 m/s² vs. 0.075 ± 0.021 m/s², respectively with $p < 0.050$ and $d = 2.625$) and 10-minutes rest (i.e., 0.054 ± 0.0193 m/s² vs. 0.084 ± 0.041 m/s², respectively with $p < 0.050$ and $d = 2.501$) for acceleration in the frontal plane. Despite this, there was a significant difference in sway velocity after a 10-minutes rest compared to immediately after SS (i.e., 0.167 ± 0.078 m/s vs. 0.238 ± 0.084 m/s, respectively with $p < 0.050$ and $d = 2.448$) in frontal balance. These results support the previous [32] in that SS can improve subsequent dynamic balance performance. Generally, there is a lack of studies exploring the effect of different recovery times on dynamic balance following short-duration SS. The majority of the available studies [11, 14, 32] have outlined in their experimental protocols that the assessment of postural balance is carried out immediately after the stretching session. Additionally, these studies [11, 14, 32] have demonstrated positive effects of short-duration SS on dynamic balance performance.

Nevertheless, the data indicated a notable increase in the COM acceleration across the sagittal plane immediately after SS session (i.e., 0.094 ± 0.052 m/s² vs. 0.088 ± 0.028 m/s², respectively with $p < 0.010$ and $d = 4.223$) and following a 2-minutes rest (i.e., 0.090 ± 0.048 m/s² vs. 0.088 ± 0.028 m/s², respectively with $p < 0.050$ and $d = 2.640$) compared to control (without SS) session. Among all the noted significant outcomes, the lower COM acceleration values, in sagittal balance condition, are observed in to control condition (without SS). Unlike the frontal plane, short-duration SS does not yield any positive effect on dynamic balance in the sagittal plane among youth female athletes. Likewise, Behm, Bambury, Cahill and Power

[4] noticed that the control groups (i.e., without stretching) showed a significant enhancement in balance, contrasting with the findings of Costa et al. [11], who reported no significant effects for the control groups. In contrast, our study reveals a different outcome regarding the impact of short-duration SS on postural balance concerning the body sway planes (i.e., FB or/and SB) on SPBB. Accordingly, the variations in these responses observed in different sway planes can be explained by Latash et al. [25] and Cusumano and Dingwell [12], in their motor control theories, that maintaining an upright posture is a primary goal during standing. This is accomplished through various combinations of joint moments and muscle activation patterns that stabilize the COM in an inverted pendulum configuration [36]. This underscores the idea that the body's position above SPBB (i.e., FB or/and SB) influences postural sway differently, highlighting that the objective and spatial characteristics of a task dictate how individuals manage redundant degrees of freedom [25]. In addition, Raffegeau et al. [35] affirm that sustaining stability is the outcome of meticulous coordination between the muscular and nervous systems. As a result of the harmonious coordination involving balance organs, vision, proprioceptive receptors, and the central nervous system. The regulation of body posture under appropriate conditions becomes a naturally occurring dynamic process. This, in turn, provides consequential evidence that changes in body position (i.e., FB or/and SB) impact the velocity and acceleration of postural sway in dynamic balance [35].

Ultimately, earlier modeling and human experimentation have suggested that human locomotion demonstrates passive stability in the sagittal plane, indicating that active balance control is primarily focused on managing instability in the frontal plane [3, 24]. This theory finds support in experiments involving perturbations of visual feedback [33] and oscillation of the support surface [29] during treadmill walking. These studies illustrate that individuals with intact neurological function exhibit a more pronounced volitional response to discrete perturbations in the frontal plane compared to the sagittal plane when maintaining dynamic balance [40].

This study has some limitations that warrant discussion. First, the sample size is rather small. Unlike male athlete population, the overall female athlete population is relatively limited, making it particularly challenging to recruit a large sample size, especially within specific age groups. Nevertheless, future studies with larger sample sizes are needed to strengthen the findings of the current investigation. Second, the analysis system used in this study could be considered a limitation. This is because it is a semi-automatic analysis system. Future studies should prioritize using a real-time motion analysis system (e.g., Vicon) coupled with triaxial force plates.

## Conclusion

Short-duration SS leads to improved dynamic balance in youth female volleyball players, particularly on the frontal plane. Of note, the most favorable effects on dynamic balance in the frontal plane were observed immediately after the SS tasks. From a practical standpoint, short-duration SS can be considered among the effective exercise tools that result in acute improvement in dynamic balance in youth female volleyball players. However, whether the acute effects translate to long-term effects is a question yet to be explored in future longitudinal studies. Furthermore, it is important to note that these findings are specific to female volleyball players. Therefore, further research involving males is warranted to enhance the generalizability of the results. Finally, to improve players' postural stability, volleyball coaches should integrate short duration SS exercises into training routine of female players.

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**Table captions:**

Table 1. Stretching session.

Table2. ANOVA with repeated measures on 1 factor.

Table 3. Pairwise comparison between no-stretching/stretching and different recovery periods.

**Figure captions:**

Figure 1. Experimental protocol: (a) Bipedal sway, sagittal balance; (b) Bipedal sway, frontal balance.

Figure 2. Center of mass (COM) sway velocity and acceleration.

[(*) Significant at $p < 0.050$ in frontal balance; (**) Significant at $p < 0.001$ in frontal balance; ($^{\#}$) Significant at $p < 0.050$ in sagittal balance. ($^{\#\#}$) Significant at $p < 0.001$ in sagittal balance]