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Analysis of postural balance between two aquatic sports using vertical *vs.* horizontal body position

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Abstract. – OBJECTIVE: This study aims to analyze and compare the postural balance between two aquatic sports where vertical vs. horizontal body positions (i.e., windsurfing vs. swimming) are key techniques for both sports.

SUBJECTS AND METHODS: **Eight volunteer windsurfers and eight swimmers agreed to participate in this study. Each of the assessments was a 2D kinematic analysis of frontal and/or sagittal balance (i.e., in bipedal and/or unipedal stance) of the center of mass velocity on wobble board (Single Plane Balance Board) on hard and/or soft surface. Kinematic analysis was performed in 2D using two action-cams. Data were digitized using the video-based data analysis system SkillSpector.**

RESULTS: **The results showed that the ANOVA, with repeated measures on 1 factor, showed a significant difference (p<0.001) between groups (i.e., swimmers and windsurfers) in all variables and in the interaction between ground (i.e., hard and foam) and group (p<0.01) in all tests in sagittal plane. Furthermore, for the ground*group interaction, a study (i.e., paired t-test) of the difference between balance (i.e., in frontal and/or sagittal plane) on hard and soft ground for each group showed that windsurfers had no difference in body sway in frontal and/or sagittal plane between hard and soft surface in bipedal stance.**

CONCLUSIONS: **We concluded that the windsurfers showed better postural balance performances compared to swimmers in the bipedal posture on hard and soft ground. Also, the windsurfers presented a better stability level compared with the swimmers.**

Key Words:
Windsurfer, Swimmer, Kinematics, Postural balance, Body position.

Introduction

Postural balance is the act of maintaining the state control of balance while performing a specific training[1]. Staniszewski et al[2] argue that postural balance and stability are two characteristics of body position that have a very significant role in sports where athletes often use these to obtain the required results of their actions. In this study we establish the level of conserving postural stability of swimmers and windsurfers since swimming and windsurfing are two sports that equally require a very important capacity for balance and stability, differing only in the athlete's body position above the water.

Aspenes and Karlsen[3] mentioned that several aspects separate swimming from most other sports such as the prone position, water immersion, and propulsive forces that are applied against a fluctuant element. The swimmer acts in a nearly zero-gravity situation with buoyancy of water[4]. Here the athlete feels gravity horizontally and relies mainly on somatosensory inputs[5] on aquatic fields. So, a balanced swimmer uses simultaneous arms and legs for propulsion and lengthens the body line then glides in a long, slippery position[6]. Additionally, Laughlin and Mills[7] addressed the question of swimmers and their body balance and suggested that good swimmers swim high on the water. Although this is what generally people understand (i.e., to be high on the water), our bodies do not work like that, they contend. They rather tend to sink in a horizontal position.

Opposite to the swimmer, the windsurfer is in a vertical position, the movement is caused by

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external forces like the aerodynamic force of the wind and the gravity[8,9]. The athlete maintains a stable position during windsurfing by changing the direction of his movement by balancing his body, that is, by intentionally losing balance in the direction of the intended movement, and by opposing the external forces through proper control of the body position while turning[10]. Therefore, windsurfers make strong use of their anti-gravity muscles during training[11]. That is why the body balance is the key element of the technique of windsurfers moving on water[12].

Many researchers[5,13-15] showed a significant effect on postural balance for athletes training on specific activities progressed on different surfaces (i.e., hard ground such as grass fields and tartans, soft ground such as fall mats and the trampoline and aquatic environment where the athlete evolves in water). Also, Lackner and DiZio[16], Kioumourtzoglou et al[13] and Perrin et al[17] revealed that highly trained athletes demonstrated better postural control than sedentary subjects and induced specific postural adaptations, which are associated with the muscles involved and loads required to execute the specific movement in different body positions[18,19].

Nevertheless, fewer studies[2,6,14] have been conducted on how athletic training affects the balance control of swimming and windsurfing as two sports practiced on the water, the first in horizontal body position and the second in vertical body position. Mkaouer et al[14], in their study, proved that windsurfers presented the best postural control in terms of sway velocity of the center of mass (COM) followed by gymnasts, volleyball players, and monofin swimmers irrespective of the surface's nature (i.e., hard or foam) and postural stance (i.e., bipedal or unipedal). Moreover, Staniszewski et al[2] assess the changes of postural stability parameters among athletes who practice snowboarding and windsurfing activity. The research showed a significant (p<0.05) body stability in some measurement positions in dynamic conditions in both specialties and proved that the practice of this spatial sport influences the body balance sense. In this respect, it has been proved[20] that gymnasts tended to present better postural control followed by soccer players, swimmers, active control subjects, and basketball players.

Barone et al[11], however, employed a stabilometric analysis to measure the center of pressure (COP) sway path during dominant and nondominant one-legged stance with open and closed eyes among athletes practicing various sports (i.e., basketball, soccer, windsurfing, in addition to sedentary subjects). The results demonstrated that the best performance in relation to standing balance was attained by soccer players in the unipedal (nondominant leg) stance. This has been accounted for by the soccer drills that have been repeated by soccer players in this stance, with the left leg functioning as the pivot, which would lead to modification at the level of proprioceptive factors and neuromuscular control around the nondominant leg.

Furthermore, in another study[21], the kung-fu training developed the unipedal stability in open eyes; besides swimming practitioners developed a lower reliance on vision in the bipedal posture. Consequently, young adolescents improved equilibrium control task due to the specificity training of each sport[21].

Even so, swimming is characterized by leadless environment and the net vertical load was removed (i.e., horizontal body position)[16], the swimmers showed a better control of COM and more anticipatory postural adjustments than triathletes and control group[5]. This suggests that prolonged training in the absence of equilibrium constraints has more of an effect on postural balance than a prolonged general training.

To this end, this study aims to analyze and compare the dynamic postural balance (i.e., unipedal and bipedal on hard and soft surface) between two aquatic sports in vertical *vs.* horizontal body positions by using a single plane balance board (SPBB)[22] through a 2D kinematic analysis[23]. We hypothesize that the windsurfers develop their unipedal and bipedal balances better than swimmers.

Subjects and Methods

Participants

A minimum sample size of 16 participants (i.e., 8-windsurfers and 8-swimmers) was determined from an *a priori* statistical power analysis using G*Power software version 3.1 (Heinrich Heine University of Düsseldorf, Germany[24]). The power analysis was computed with an assumed power at 0.95 at an alpha level of 0.05 and a moderate effect size of 0.6. Therefore, eight volunteer windsurfers (age 21.57±1.47 years; height 1.87±0.02 m; weight 80.03±4.03 kg) and eight swimmers (age 20.48±1.04 years; height 1.80±0.03 m; weight 78.12±3.73 kg) agreed to participate in this study.

The inclusion criteria were to be ranked at a national level with participation in national cups and/or championships; average training time was 18±2 hours per week; healthy without any muscular, neurological or tendon injuries. All participants had the right leg as dominant following the Kicking Ball Test[25]. After being informed in advance of the procedures, methods, benefits, and possible risks of the study, each participant reviewed and signed a consent form to participate in the study. The experimental protocol was performed in accordance with the Declaration of Helsinki for human experimentation[26] and was approved by the local Ethical Committee of the National Sport Observatory.

Experimental Design and Procedures

This study is made up of four random assessments (i.e., randomized counterbalanced, Latin Square[27]); every assessment took place on a separate day successively. 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 was a 2D kinematic analysis of frontal and/or sagittal balance (i.e., in bipedal and/or unipedal stance) of the center of mass (COM) velocity on wobble board SPBB (length and width 420 × 420 mm; height 70 mm) (Figure 1) on hard and/or foam surface[22,28-31]. Kinematic analysis was performed in two-dimension (2D) using two cameras AEE PNJ camera SD18, HD 720 p, CCD 1,000,000 pixels, SSC 1/4,000 per second, minimum sensitivity 1 lux acquisition frequency 120 Hz, zoom angle 145°. They were arranged to capture the sway movement; the first camera was 2 m from the SPBB and the second was 2 m from the side of SPBB. Twenty reflective markers were affixed to every participant using the Hanavan model[32] modified by de Leva[33] digitized through the video-based data analysis system SkillSpector® version 1.3.2, (Odense SØ, Denmark)[34] with quantic-spline data filtering (Figure 1).

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

- On hard ground, 30-second frontal plane balance in bipedal stance on the SPBB [Hard ground, Frontal plane balance in Bipedal stance (HFB)].
- On soft ground (i.e., foam mat higher than 10 cm), 30-second frontal plane balance in bipedal stance on the SPBB [Soft ground, Frontal plane balance in Bipedal stance (SFB)].
- On hard ground, 30-second sagittal plane balance in bipedal stance on the SPBB [Hard ground, Sagittal plane balance in Bipedal stance (HSB)].
- On soft ground (i.e., foam mat higher than 10 cm), 30-second sagittal plane balance in bipedal stance on the SPBB [Soft ground, Sagittal plane balance in Bipedal stance (SSB)].
- On hard ground, 30-second sagittal plane balance in unipedal right stance on the SPBB [Hard ground, Sagittal plane balance in Unipedal Right stance (HSUR)].
- On soft ground (i.e., foam mat higher than 10 cm), 30-second sagittal plane balance in unipedal right stance on the SPBB [Soft ground, Sagittal plane balance in Unipedal Right stance (SSUR)].
- On hard ground, 30-second sagittal plane balance in unipedal left stance on the SPBB [Hard ground, Sagittal plane balance in Unipedal Left stance (HSUL)].
- On soft ground (i.e., foam mat higher than 10 cm), 30-second sagittal plane balance in unipedal left stance on the SPBB [Soft ground, Sagittal plane balance in Unipedal Left stance (SSUL)].

The participants were asked to fixate a black cross (20 x 25 cm) located 1.20 m away from the SPBB, at eye level. In all trials, subjects were instructed to keep their body straight, and their arms loosely hanging by their sides[35]. The kinematic analysis was performed over 10 seconds (i.e., between the 11th and the 20th second of the sway test). For each experimental condition, subjects performed two trials to be acquainted.

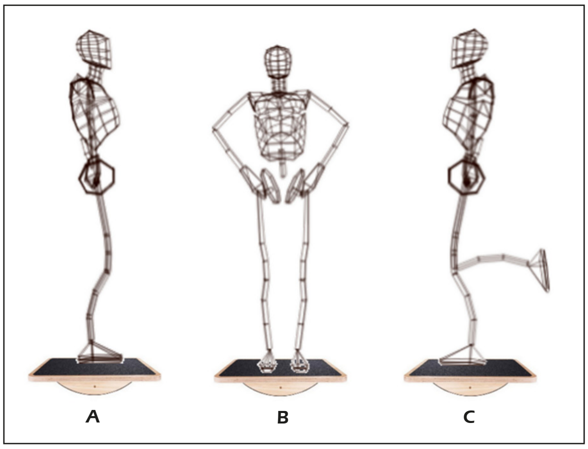

Figure 1. Experimental protocol: **A,** Bipedal sway, sagittal balance; **B,** Bipedal sway, frontal balance; **C,** Unipedal sway (i.e., right and/or left) sagittal balance.

Statistical Analysis

As part of statistical analysis, SPSS 20 package (IBM Corp., Armonk, NY, 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, (Heinrich Heine University of Düsseldorf, Germany[24]). 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[36]. The normality of distribution estimated by the Kolmogorov-Smirnov test was acceptable for all variables (p >0.05). Consequently, ANOVA with repeated measures on 1 factor was used to benchmark different balance strategies, Bonferroni's test was applied in post-hoc analysis for pairwise comparisons. Additionally, effect sizes (d) were determined from ANOVA output by converting partial eta-squared to Cohen's *d*. *A priori* level lower than or equal to 0.5% ($p \leq 0.05$) was used as a criterion for significance.

Results

The ANOVA with repeated measures on 1 factor showed a significant difference (p <0.001) between groups (i.e., swimmers and windsurfers) in all variables and in the interaction between ground (i.e., hard and foam) and group (p <0.01) in all tests in sagittal plane (Table I, Figure 2).

For the ground*group interaction, a study (i.e., paired t-test) of the difference between balance (i.e., in frontal and/or sagittal plane) on hard and soft ground for each group showed that windsurfers had no difference in body sway in frontal and/or sagittal plane between hard and soft surface in bipedal stance (Table II).

Figure 3 showed an example of COM velocity sway in sagittal plane, unipedal stance, on foam ground of swimmer (Figure 3a) *vs.* windsurfer athlete (Figure 3b).

Discussion

This study aims to analyze and compare the postural balance (i.e., unipedal and bipedal balance on hard and soft ground) between two aquatic sports involved in vertical *vs.* horizontal body positions (i.e., windsurfers and swimmers) by using a single plane balance board (SPBB)[22] through a 2D kinematic analysis[14,23].

The findings of this study in the COM sway velocity showed a significant difference (p <0.001) between windsurfers and swimmers' groups in all stances with a large effect size (d = 1.9).

We observed a large difference between the two groups in the frontal plane sway. The COM velocity on hard ground in bipedal stance of windsurfers is lower than swimmers' (5.54±0.43 cm/s and 7.73± 0.24 cm/s respectively). Additionally, on soft ground, the COM velocity in the same stance (i.e., frontal) revealed an enormous difference between the aquatic sports (Δ = 2.67 cm/s) in favor of windsurfers that showed the minimal sway velocity. Likewise, the difference still exists even during the sagittal sway in bipedal stance, and it is more accentuated on the soft ground between the two groups (i.e., windsurfers

Table I. ANOVA with repeated measures on 1 factor.

Source	Variable	df	Mean square	F	Sig.	Effect size	Power
Ground	FB	1	0.016	0.117	0.738	0.020	0.061
	SB	1	0.000	0.001	0.971	0.000	0.050
	SUR	1	0.010	0.180	0.679	0.030	0.068
	SUL	1	0.020	0.360	0.560	0.058	0.086
Group	FB	1	41.237	769.247	0.000**	1.970	1.000
	SB	1	36.526	555.022	0.000**	1.958	1.000
	SUR	1	36.571	662.383	0.000**	1.964	1.000
	SUL	1	34.743	835.155	0.000**	1.972	1.000
Ground *group	FB	1	0.413	3.106	0.103	0.412	0.368
	SB	1	1.152	12.693	0.004*	1.028	0.904
	SUR	1	1.303	24.330	0.000**	1.340	0.995
	SUL	1	1.514	27.126	0.000**	1.386	0.997

(FB) Frontal plane balance in bipedal stance; (SP) Sagittal plane balance in bipedal stance; (SUR) Sagittal plane balance in unipedal right stance; (SUL) Sagittal plane balance in unipedal left stance; *Significant at $p < 0.01$; **Significant at $p < 0.001$.

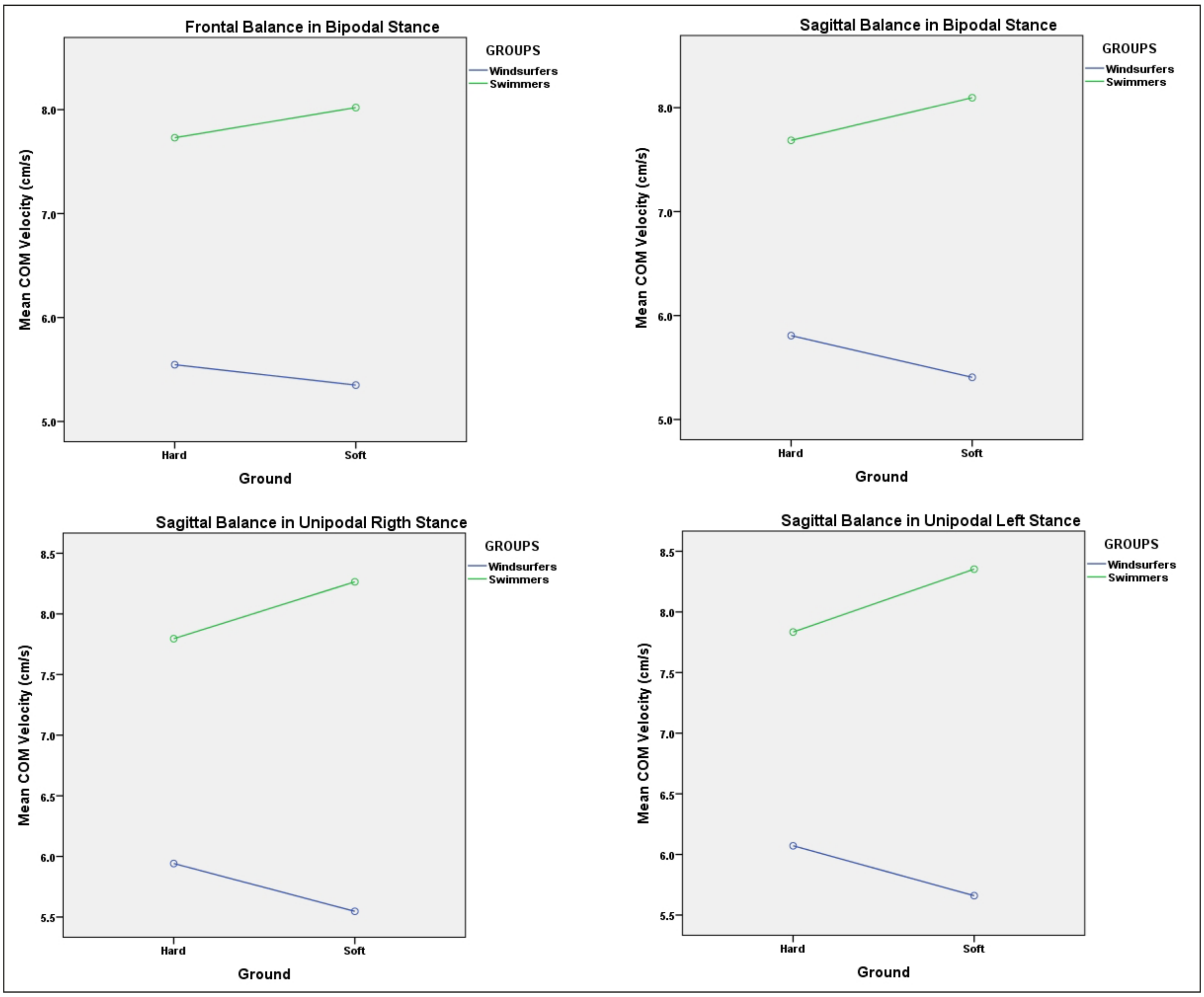

Figure 2. Mean COM velocity of the different balance tests.

Table II. Paired samples t-test between hard and foam ground.

Groupe	Variable	Mean difference	Std. difference	*t*	df	Sig.	Effect size
Windsurfers	HFB *vs.* SFB	0.196	0.659	0.786	7	0.462	0.457
	HSB *vs.* SSB	0.401	0.503	2.113	7	0.079	0.935
	HSUR *vs.* SSUR	0.394	0.295	3.537	7	0.012*	1.362
	HSUL *vs.* SSUL	0.411	0.316	3.444	7	0.014*	1.818
Swimmers	HBF *vs.* SBF	-0.290	0.313	-2.451	7	0.050*	1.046
	HSB *vs.* SSB	-0.410	0.332	-3.265	7	0.017*	1.236
	HSUR *vs.* SSUR	-0.469	0.357	-3.476	7	0.013*	1.318
	HSUL *vs.* SSUL	-0.519	0.351	-3.908	7	0.008**	1.529

(HFB) Hard ground, Frontal plane balance in Bipedal stance; (SFB) Soft ground, Frontal plane balance in Bipedal stance; (HSB) Hard ground, Sagittal plane balance in Bipedal stance; (SSB) Soft ground, Sagittal plane balance in Bipedal stance; (HSUR) Hard ground, Sagittal plane balance in Unipedal Right stance; (SSUR) Soft ground, Sagittal plane balance in Unipedal Right stance; (HSUL) Hard ground, Sagittal plane balance in Unipedal Left stance; (SSUL) Soft ground, Sagittal plane balance in Unipedal Left stance; *Significant at $p < 0.05$; **Significant at $p < 0.01$.

and swimmers) with a huge COM velocity difference equivalent to $\Delta = 2.69$ cm/s. We stated that windsurfers had a slower swing speed range of COM compared to swimmers, which proves

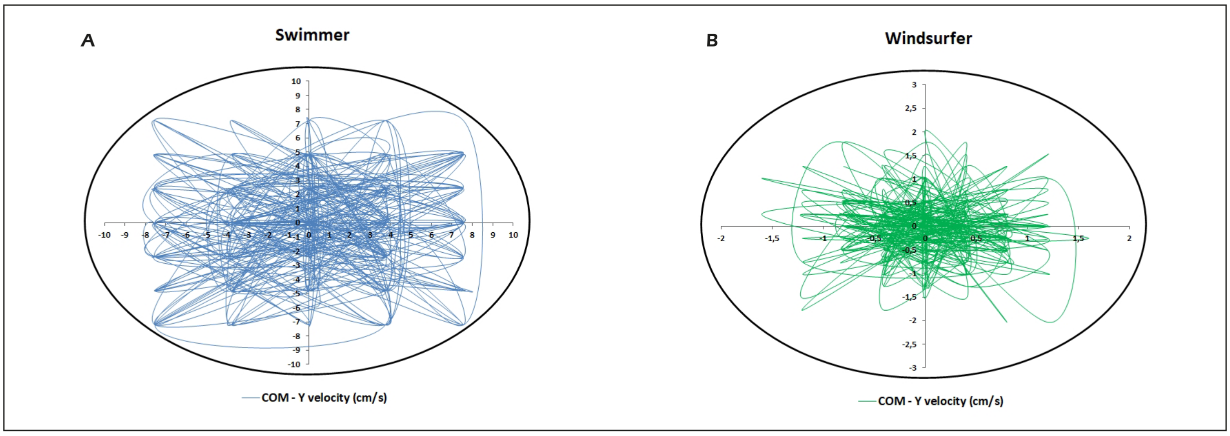

Figure 3. Example of COM velocity sway in sagittal plane, unipedal stance, on foam ground of swimmer (**A**) *vs.* windsurfer athlete (**B**).

that they have better postural stability in bipedal position. These results could be explained by the fact that the windsurf experts were trained to maintain and restore balance on a moving surface by leaning on both legs fixed on the board. That is why they excel in bipedal stance since this is considered to be a determining factor of success[37,38]. Zemková and Hamar[31] argue that stance symmetry in terms of weight distribution between the feet in a standing position plays a key role in maintaining balance.

Furthermore, swimmers were less stable than windsurfers practitioners when standing on one leg because the unipedal stance is an unusual and unexpected standing position for them. This supports the result of comparison between windsurfers and swimmers that showed a high displacement velocity of COM in unipedal stance (i.e., right, and left leg) in sagittal plane. Also, the edge of difference of COM velocity between the two groups on the soft surface is very remarkable in unipedal right stance (i.e., 5.54±0.16 cm/s *vs.* 8.26±0.28 cm/s). On the hard surface, this difference still exists between the windsurfers and the swimmers but with less significant values COM's oscillations in unipedal right stance (Δ = 1.85 cm/s *vs.* Δ = 2.72 cm/s respectively). Concerning the left leg stance, the value of the COM sway velocity reached 8.35 cm/s and is considered the highest velocity of oscillation in all positions. On the other hand, this difference between the two groups is less important when comparing the velocity sway value in unipedal left stance on hard ground (i.e., 6.07 cm/s *vs.* 7.83 cm/s). In addition, a comparative study[14] between windsurfers and gymnasts confirmed the better stability of windsurfers in bipedal and unipedal stance in the frontal and sagittal plan. Moreover, Debu and Woollacott[39] and Balogun et al[40] pointed out that the windsurfers proved good stability in unipedal stance due to the nature of their physical training (i.e., surface water sport, sailing on surfboard) which in particular develops equilibrium. Meanwhile, this advantage for the windsurfers may be explained by the fact that swimmers trained in horizontal position contrary to windsurfers who exercised drills in vertical position on the water.

The comparative study within group between balance (i.e., in frontal and/or sagittal plane) on hard and soft ground showed that windsurfers had no difference in body sway in frontal and/or sagittal plane between hard and soft surface in bipedal stance. The windsurfers presented good stability because they use both feet equally to maintain a state of balance for a long time on the water. This result can be explained by the fact that the windsurfers use both legs during sport practices, which may have minimized any difference in balance ability between the legs. Platzer et al[10] showed that windsurfers balance their body in different plane and oppose the external forces through proper control of the body position to keep stability above the water in bipedal stance.

Mkaouer et al[14] gave evidence that, compared to gymnasts, windsurfers showed better postural control performance when it comes to maintaining a dynamic stance using a bipedal base of support. However, the result revealed a significant difference (p <0.01) in the unipedal condition for the right and the left leg (i.e., in frontal and/or sagittal plane) on hard and soft ground. This result is inconsistent with what was presented by Matsuda et al[41] to the effect that windsurfers make strong use of their antigravity muscles during training, particularly in relation to the drills performed on the water using a windsurf board, they should have similar balance standing on both legs and improve the nondominant one-legged standing balance.

Besides, the swimmers group showed a significant difference (p <.001) in body sway on soft compared with hard ground in both stances (i.e., unipedal and bipedal) and in the two planes (i.e., in frontal and/or sagittal). This can be explained by the fact that swimmers adopt horizontal position contrary to other disciplines that perform in vertical position[21]. In addition, they were less stable when standing on one-leg because the unipedal stance is an unusual standing position for swimmers. Matsuda et al[41] discuss that the major position swimmers train on is the horizontal position in water, while they scarcely use their anti-gravity muscles during training, leading, as a result, to a less-developed stance stability.

Concerning the result of ANOVA between ground (i.e., soft, and hard), they do not have a significant value for all participants (i.e., windsurfers and swimmers). This shows that not only windsurfers exhibit postural balance but also swimmers revealed a certain stability developed through the potential of the buoyancy provided by water to facilitate postural control through a reduction in gravitational effects[42].

The interaction between ground (i.e., hard and foam) and group (i.e., windsurfers and swimmers) revealed that windsurfers have better stability than swimmers in sagittal plane. In fact, in unipedal stance, sagittal and frontal plane, windsurfers found no significant difference with ground (i.e., hard and foam). However, in unipedal stance there is a significant difference for all participants, but swimmers presented the highest COM velocity sway (8.35±0.25 cm/s). Then again, the windsurfers decrease their sway velocity in soft ground compared to hard ground in bipedal stance (5.807±0.34 cm/s and 5.40±0.22 cm/s) and unipedal stance (6.071±0.18 cm/s and 5.66±0.20 cm/s) respectively hard and soft ground with (p ≤0.05). Conversely, swimmers increase their sway velocity in soft ground in bipedal (7.68±0.25 cm/s and 8.09±0.28 cm/s) and unipedal stance (7.83±0.23 cm/s and 8.35±0.25 cm/s) respectively hard and soft ground with (p ≤0.05). These results are mainly on the sagittal plan. Psalman[43] proved that the expertise of windsurfers at keeping the right position still during difficult postures on unstable surface may explain their better stability on soft ground compared with swimmers.

Our results provide evidence that the windsurfers showed better postural balance performances compared to swimmers during bipedal stance on hard and soft ground, which is why windsurfers presented a better stability level. Artioli et al[37] argue that the posture is consistent with the training of the windsurf group and thus qualified as a specific posture.

Conclusions

Our findings prove that windsurfers developed a better postural balance compared to swimmers during bipedal stance on hard and soft ground balance. The interaction between ground (i.e., hard and foam) and group (i.e., windsurfers and swimmers) showed that windsurfers have better stability than swimmers in sagittal plane. Likewise, the windsurfers decrease their sway velocity in soft ground compared to hard ground in bipedal and unipedal stance. On the contrary, swimmers increase their sway velocity in soft ground in the two stances.

Thus, despite the same aquatic training environment for both groups, windsurfers develop greater postural balance. This has been explained by the difference in the position of the athlete's body during training, confirming that while on water, the vertical position of the body has a major effect on improving the athlete's stability.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Informed Consent

Informed consent was obtained from all individual participants included in the study.

Ethics Approval

The experimental protocol was performed in accordance with the Declaration of Helsinki for human experimentation and was approved by the local Ethical Committee of the National Sport Observatory.

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Authors' Contribution

SA drafted the initial manuscript; HEA and SA performed data acquisition; BM and SA performed the statistical analysis and interpreted the data; HEA, SA, BH, and BM were responsible for manuscript revision and preparation of this manuscript; SA, HEA and BM critically reviewed the manuscript. All authors read and approved the final version of the manuscript and agreed with the order of presentation of the authors.

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