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Effect of a Sensorimotor Training Program for Aerial Maneuvers in Junior Surfers

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Abstract: The purpose of this study was to examine the impact of a sensorimotor training program on maximum ankle dorsiflexion (ankle DF), coordination, dynamic balance and postural control, and lower-limb muscle power, in competitive junior surfers, and its relation to parameters of sensorimotor control required to perform aerial maneuvers. Twelve junior competitive surfers followed a 7-week sensorimotor training program, being assessed pre- and post-program with the knee-to-wall test (KW), Y-Balance test—lower quarter (YBT-LQ), and the countermovement jump test (CMJ). Post-training assessment revealed positive effects on the KW (ankle DF) distance, which increased approximately 2 cm ($p < 0.001$) for both ankles, and all scores for the YTB-LQ (coordination, dynamic balance, and postural control) variables increased, being significant ($p < 0.005$) for some reach distances (YBT-LQ—Anterior Left, YBT-LQ—Postero-medial Left, and YTB-LQ Anterior Right). YBT-LQ Anterior Reach Asymmetry also improved by decreasing 1.62 cm ($p < 0.001$) and the CMJ height (lower limb muscle power) increased 2.89 cm ($p < 0.001$). The training program proved to effectively enhance parameters of physical performance for this sample, including ankle DF, coordination, dynamic balance, postural control, and lower limb muscle power. This tailored-made task approach can help to optimize surfing performance capabilities and contribute to reducing the risk of injuries while performing aerials.

Keywords: surfing; sensorimotor training; aerial maneuvers; lower limbs; injury prevention

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1. Introduction

Surfing had an important turning point in terms of performance more than two decades ago, with the introduction of aerial maneuvers in competitions [1,2]. And since 2021, surfing has been an Olympic sport demanding from surfers a higher quality in their performances with a greater risk of injury due to the complexity of the maneuvers and the need for high scores.

To perform aerial maneuvers, the surfer needs to use speed and timing to project himself and the board above the wave's lip, control the board while airborne, and land back on the wave's surface [1–5] stable enough not to fall or to properly prepare for the next maneuver. Aerial maneuvers involve multiple performance variations (e.g., frontside, backside, rail grab/no grab, different heights and rotations, etc.), therefore presenting a high degree of difficulty [1,4,6–8], which contributes to increasing their scoring potential [4]. Over the years, the number of aerial maneuver attempts has been increasing in competition [1,9], as aerials have scored significantly higher than waves ridden without one [1,6]. In fact, regarding the 2018 and 2019 World Surf League Championship Tour, within the aerials performed by the men's top five (n = 185), the frontside air reverse with 360° rotation (FSAR360) presented the highest rate of frequency of completion (n = 68) and the backside air reverse with 360° rotation (BSAR360) the highest scoring potential (7.64 ± 0.85 points) [5].

However, the observed low aerial completion rate (45 to 55%) among elite surfers [4,6] also contributes to a high risk of sustaining lower limb injuries, mainly to the knee and ankle [4,10–12]. This low rate is because the successful completion of aerials involves the control of several factors, including an athlete's ability to control the anterosuperior displacement of their center of mass, to widen the support base (for frontside aerials) and triple-flexion of the lower limbs, which are more pronounced at landing [5], to absorb the generated forces during landing [3,13,14], and to react to the environments' constraints while maneuvering (e.g., moving wave; wave's surface instability at the moment of contact/landing; wind pushing the board; sunlight hitting the athlete's eyes).

The understanding of these movement principles, body actions, and critical features related to aerial maneuvers [5], as well as landing skills and postural control requisites [2,3,5], seems essential for the development of successful aerial landing programs. These programs should include dry-land training like jumping and/or landing tasks and addressing lower limb flexibility and range of motion to protect the musculoskeletal structures involved and to maintain performance while surfing [14,15].

Prioritizing injury prevention and implementing tailored training programs are vital for athlete well-being, and although surfing is a relatively safe sport when compared to other extreme sports, injury prevention has been mainly based on the use of protective personal equipment (e.g., helmets, botties, wetsuits, sunscreen) [16]. Even though cuts and lacerations to the skin (head, neck, face, and lower limbs) are the most frequent type of injuries (46%) [16–18], musculoskeletal injuries do occur (22.6%) [17] and have increased, mainly to the lower limbs [12–19], as surfing maneuvers have become more difficult and acrobatic [20]. However, the literature regarding injury prevention training programs is still very scarce [20].

A systematic review [19] of other sport modalities (e.g., soccer, cross-country, dodge ball, football, and basketball) identified that youth injury prevention programs can have a positive impact on modifiable risk factors for lower extremity injuries, such as strength, coordination, posture, and balance. In fact, it seems that these programs were able to reduce injury rates by up to 46%, with average improvements of 11.3% for force generation, 5.7% for coordination, and 5.2% for both posture and balance.

As to surfing specifically, resistance and plyometric/gymnastic-style training techniques have been previously applied to enhance surfing performance concerning landing skills [21,22]. In fact, it seems that this type of training may contribute not only to enhancing a surfer's capacity to absorb the impact during landing maneuvers, like aerials or floaters [22], but also to optimizing their sporting gestures and minimizing the risk of injuries [23]. Moreover, previous studies state that these interventions should be based on progressive multicomponent neuromuscular training exercises (e.g., strength, balance and coordination, agility, plyometrics) to improve physical performance characteristics as well as reduce lower-limb injury rates [24–28].

The goal of sensorimotor training is to enhance functional joint stability and postural stabilization for rehabilitation and injury prevention; by altering sensory feedback from the periphery to the central nervous system, it enables precise muscle stiffness regulation, improving task-specific muscle tone and optimizing intermuscular coordination [29].

Although Lundgren and colleagues described impact forces, accelerations, and ankle amplitude for different landing tasks in a controlled context (dry-land) in competitive surfers, there is still no evidence to define a complementary training program suitable for enhancing performance and preventing lower limb injuries associated with aerial maneuvers [30].

Therefore, the purpose of this study is to analyze the effects of a specific sensorimotor training program on ankle dorsiflexion (DF), coordination, dynamic balance and postural control, and lower limbs strength in relation to aerial maneuvers in Portuguese competitive junior surfers.

2. Materials and Methods

2.1. Participant Selection and Study Design

Twelve Portuguese junior competitor surfers (10 boys, 2 girls; age, 15.50 ± 2.11 years old; weight, 54.28 ± 9.77 kg; height, 1.64 ± 0.89 cm; body mass index (BMI), 19.99 ± 2.32) volunteered for this study.

All participants satisfied the inclusion criteria (competed in national and/or regional surfing contests for the 2022 competing season), and the exclusion criteria (not having sustained a musculoskeletal injury that would have prevented the surfer from completing any of the physical tests and training program required for this study; still recovering/rehabilitating from injury) were not satisfied by any of the participants.

This study used a single-group longitudinal design, comprising a seven-week sensorimotor training program with two training sessions per week on non-consecutive days, lasting approximately 60 min. The participants were assessed in baseline prior to the seven-week training program and immediately after the program. Pre- and post-testing assessments were related to the participant's ankle DF, coordination, dynamic balance and postural control, and lower limb strength.

2.2. Procedures

2.2.1. Testing Procedures

Pre-testing and post-testing data collection was conducted in a single session, one week before the program and 24 h after the last training session, respectively. Tests were performed under similar conditions for all participants: standard gym court, wooden floor, 20–25 °C, and in the afternoon (4–7 PM); athletes wore standard t-shirts, shorts, and were barefoot; the tests were carried out after a 10 min warm-up consisting of general body joint movements, dynamic stretching, and small jumps; the participants were strongly motivated to achieve their personal maximums on each test.

The same two evaluators tested all participants; they followed the same testing instructions and standard procedures for each assessment test.

The characterization sample variables in this study included anthropometrics in which body height and weight were measured to the nearest 0.5 cm (mobile stadiometer with integrated level Seca 213) and 0.1 kg (digital flat scale Seca 803), respectively, before the tests were performed. Body mass index (BMI) = body mass (kg)/body height (m^2) was also calculated for each athlete.

Dependent variables were defined according to physical performance tests variables, including ankle DF, coordination, dynamic balance and postural control, and lower limb muscle power. The selection of the tests was based on previous research, regarding not only their reliability and sensibility to junior populations [31–35], but also their applicability in assessing surf-related variables like balance, coordination, and strength [8,15,34,36]. With the exception of the countermovement jump with arm swing (CMJa), all the tests followed the specific procedures previously detailed in [15,31,32,36,37].

2.2.2. Maximum Ankle Dorsiflexion

Maximum ankle DF was assessed through the weight-bearing knee-to-wall test (KW) (expressed in centimeters), applying a minimum detectable change (MDC) of 1.0/1.5 cm between limbs to ensure validity ($p < 0.05$) and reliability (ICC: 0.93–0.99) [32]. Ankle ROM is an important measure as it is very useful not only for measuring one's ability to absorb forces while safely and successfully landing aerial maneuvers [3,5,14,22,30], but also for identifying flexibility-related risk injuries in jumping, balance, and agility tasks [38].

2.2.3. Coordination, Dynamic Balance, and Postural Control

Coordination, dynamic balance, and postural control were assessed using the Y-Balance Test Lower Quarter (YBT-LQ) with the Y Balance Test™ kit (Functional Movement Systems, Chatham, MA, USA), which has been demonstrated to have suitable validity [31] and intra-rater reliability (ICC: 0.85–0.91) [35]. This test indicates that an asymmetry equal or greater to 4 cm is associated with poor neuromuscular control and increased risk of lower-extremity injury [15,31,33]. Therefore, besides considering normalized scores (relative (normalized) reach distance (%) = absolute reach distance/limb length × 100) for analysis [15,31,37], limb reach asymmetry (difference between both legs reach distance in the anterior direction) was also calculated.

2.2.4. Lower Limb Muscle Power

Leg power was assessed with the countermovement jump (CMJ) with arm swing (CMJa), since it allows a higher degree of sports specificity [39,40] and mimics a more reliable surf aerial-specific performance. A contact platform (Chronojump Boscosystems®, Barcelona, Spain) was utilized to measure the jump height from flight time when performing the CMJa, which has been demonstrated to be valid and reliable (ICC: 0.93–0.98) [40].

After performing two submaximal CMJas with a 30 s inter-jump rest interval, the participants stepped on the previously calibrated contact platform, barefoot. Standing in an upright position with feet placed hip width to shoulder width apart, the athletes were instructed to perform a fast downward movement to approximately 90° of knee flexion, immediately followed by a maximal effort vertical jump with extended hips and knees, and land at approximately the same spot on the contact platform [39–42]. Each participant completed three maximal CMJas, with a resting interval of 60–120 s between consecutive CMJas [39–41] and the average of the three jumps from the first and second sessions was considered for analysis.

The independent variable was the proposed sensorimotor training program (Table 1), which aimed not only to improve the junior surfers' jump-landing technique related to aerial maneuvers in surfing, but also to contribute to decreasing their risk of sustaining lower-limb injuries according to the proposed tasks.

2.3. Sensorimotor Training Program

The training was held at the gymnastics hall of the Faculty of Human Kinetics of the University of Lisbon for 7 weeks (twice a week on non-consecutive days) and was performed on a wooden floor covered with gymnastics carpet-rubber mat. The materials used were limited to agility, training, and landing mats; training boxes (30, 40, 60, 80, 100, and 120 cm); and jumping barriers (30, 40, and 60 cm).

The program was supervised at the beginning by an experienced sports training coach, and then continued by the instructed physiotherapist. Athletes were barefoot, and all training sessions started with a standardized 10 min warm-up routine comprising general whole-body mobility exercises from head to toes and dynamic low aerobic intensity exercises like jogging, lateral shuffling, short changes of direction, and some quick and maximal jumps. Then, a 50 to 60 min exercises session was held, comprising 3 main exercise categories (Table 1): coordination (balance, rhythm, and spatial awareness); strength, power, and core (lower limb plyometrics and core stability); and endurance exercises (lower limbs jumping/landing tasks). These exercise categories were previously identified as performance and injury prevention indicators in surfing [2,22,36,37]. Athletes were specifically instructed to stay focused on the execution of exercises, and to perform all exercises at the highest movement quality possible. Rest between sets was not strict but varied from 1 to 3 min [21,38].

Table 1. Seven-week sensorimotor training program.

Week	Session	Coordination	Sets × Reps	Strength, Power, and Core	Sets × Reps	Endurance	Sets × Reps
1	1	Battement tendu w/hand grip	3 L + R	Double-Leg Lateral Hop	2 × 10	BW Squat	2 × 10
		CMJ w/arms UP	2 × 5	Double-Leg Lateral Hurdle	2 × 8	Lateral Squat	2 × 8 L + R
		CMJ w/arm SWING	5	Drop n Stick (from box 30)	8	Lateral Lunge	2 × 8 L + R
	2	Battement tendu w/hand grip	3 L + R	Plank	2 × 30 s	Split Squat	2 × 8 L + R
		CMJ w/arm SWING	5	Side Plank	2 × 20 s		
		CMJ w/arms UP (from box 30)	2 × 5				
		CMJ w/arms SWING (from box 30)	5				
2	3	Battement tendu	3 L + R	Double-Leg Lateral Hop	2 × 10	BW Squat	2 × 12
		CMJ w/arm SWING (to box 30)	5	Double-Leg Lateral Hurdle *	2 × 8	Lateral Squat	2 × 10 L + R
		CMJ + CMJ w/arm SWING (to box 30 to floor)	2 × 5	Drop n Stick (from box 30)	8	Lateral Lunge	2 × 10 L + R
		CMJ Hurdle w/arm SWING	2 × 5	Plank	2 × 30 s	Split Squat	2 × 10 L + R
	4	Battement tendu	3 L + R	Side Plank	2 × 20 s		
		CMJ Hurdle w/arm SWING	5				
		½ twist w/arms UP	2 × 5 L + R				
		½ twist w/arms SWING	2 × 5 L + R				
3	5	Battement tendu on Agility mat	3 L + R	Seated Box Jumps *	5	Forward Lunge	8 L + R
		½ twist w/arms UP	2 × 5 L + R	Drop n Split	2 × 8 L + R	Lateral Lunge	10 L + R
		½ twist w/arms SWING	5 L + R	1 Leg Lateral Hop	2 × 8 L + R	RF Elevated Squat	8 L + R
		½ twist w/arms UP (from box 30)	2 × 5 L + R	2 Leg Lateral Hurdle *	2 × 8 L + R		
		½ twist w/arms SWING (from box 30)	2 × 5 L + R	Plank Circuit	90 s		
	6	Battement tendu on Agility mat	3 L + R				
		½ twist w/arms UP	2 × 5 L + R				
		½ twist w/arms SWING (from box 30)	5 L + R				
		½ twist w/arms UP (to box 30)	2 × 5 L + R				
		½ twist w/arms SWING (from box 30)	2 × 5 L + R				

Table 1. *Cont.*

Week	Session	Coordination	Sets × Reps	Strength, Power, and Core	Sets × Reps	Endurance	Sets × Reps
4	7	Battement tendu on Landing mat ½ twist w/arms SWING (to box 30) Back ½ twist w/arms SWING (from box 30) ½ twist + ½ twist w/arms SWING (to box 30+ from box 30)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R	Seated Box Jumps * Drop n Split 1 Leg Lateral Hop 2 Leg Lateral Hurdle ** Plank Circuit	8 2 × 10 L + R 2 × 10 L + R 2 × 10 L + R 90 s	Forward Lunge Lateral Lunge RF Elevated Squat	10 L + R 12 L + R 10 L + R
	8	Airplane pose + leg side swing w/hand grip ½ twist + ½ twist w/arms SWING (to box 30+ from box 30) 1 twist w/arms UP 1 twist w/arms SWING	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R				
5	9	Airplane pose + leg side swing w/hand grip 1 twist w/arms SWING 1 twist w/arms UP (from box 30) 1 twist w/arms SWING (from box 30)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R	Seated Box Jumps * Drop n Split 1 Leg Lateral Hop 2 Leg Lateral Hurdle w/½ twist ** Plank Circuit	8 2 × 10 L + R 2 × 10 L + R 2 × 10 L + R 90 s	Forward Lunge Lateral Lunge RF Elevated Squat	10 L + R 12 L + R 10 L + R
	10	Airplane pose + leg side swing 1 twist w/arms UP (from box 30) 1 twist w/arms SWING (to box 30) 1 twist w/arms SWING (from box 30)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R				
6	11	Airplane pose + leg side swing 1 twist w/arms UP (from box 30) 1 twist w/arms SWING (to landing mat 30) 1 twist w/arms SWING (to box 40)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R	Single-Leg Box Squat (from box 40) Seated Box Jump + Broad Jump Plank Circuit Russian Twist 2-Leg Lateral Hurdle w/1 Twist *	8 L + R 10 120 s 2 × 10 2 × 8 L + R	Alternating Leg Lateral Bounds Scissor Jumps Single-Leg Jump w/½ twist	2 × 5 2 × 10 10 L + R
	12	Airplane pose + leg side swing on agility mat Back ½ twist w/arms SWING (from box 40) 1 twist w/arms SWING (to box 40+ from box 40) 1 twist w/arms SWING (from box 40)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R	Single-Leg Box Squat (from box 40) Seated Box Jump + 2 Broad Jumps Plank Circuit Russian Twist 2-Leg Lateral Hurdle w/1 Twist **	8 L + R 10 120 s 2 × 10 2 × 8 L + R	Alternating Leg Lateral Bounds Scissor Jumps Single-Leg Jump w/1 Twist	2 × 5 2 × 10 8 L + R

Table 1. *Cont.*

Week	Session	Coordination	Sets × Reps	Strength, Power, and Core	Sets × Reps	Endurance	Sets × Reps
7	13	Airplane pose + leg side swing on agility mat 1 twist w/arms SWING (from box 40) 1 twist w/arms SWING (from box 60) 1 twist w/arms SWING (from box 80)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R	Single-Leg Box Squat (from box 60) Seated Box Jump + 2 Broad Jumps Plank Circuit Russian Twist 2-Leg Lateral Hurdle w/1 twist **	6 L + R 10 120 s 3 × 10 2 × 8 L + R	Alternating Leg Lateral Bounds Scissor Jumps Single-Leg Jump w/1 Twist	2 × 5 2 × 10 8 L + R
	14	Airplane pose + leg side swing on landing mat 1 twist w/arms SWING (from box 80) 1 twist w/arms SWING (from box 100) 1 twist w/arms SWING (from box 120)	3 L + R 5 L + R 2 × 5 L + R 2 × 5 L + R	Single Leg Box Squat (from box 60) Seated Box Jump + 2 Broad Jumps Plank Circuit Russian Twist 2-Leg Lateral Hurdle w/1 Twist ***	6 L + R 10 150 s 3 × 10 2 × 8 L + R		

Abbreviations: CMJ: Countermovement Jump; L: Left; R: Right; * 30 cm; ** 40 cm; *** 60 cm; BW: Back Wall; RF: Rear-foot.

The training program and its components (types of exercise, sets, repetitions, height of the boxes and obstacles, etc.) were designed based on previous studies conducted with youth sport athletes [24,25,27,28,42,43], also including surfing [44,45].

The volume of the training was gradually increased over the course of the study (e.g., from 40 min per training session in first 2 weeks up to 60 min after the 3rd week, with more exercises and/or repetitions being added). The sensorimotor training intensity and difficulty were also gradually manipulated within each session, either by the number of repetitions (1 to 2 sets per exercise, with 5 to 10 repetitions in each set) [28,46] and/or by the selection of exercises (e.g., two legs to one leg) [46].

For the coordination category, a wide variety of exercises was used, from simple to complex tasks, aiming at the progression of the athletes: from stable to unstable surfaces; introducing arm swing to jumping techniques; changing jumping techniques performed from the forward to backward direction and with increasing full body rotations; using boxes with increasing jump heights. The strength, power, and core category basically used the same set of exercises through the whole program, increasing its difficulty from 2-leg to single-leg exercises, and increasing the duration and/or sets and repetitions and the height of the boxes used for some of the exercises. For the endurance category, exercises increased in complexity over the course of the program, requiring more control while changing directions and increasing the speed and load during jumping/landing tasks.

3. Results

The effects of the 7-week sensorimotor training are reflected on the measures of maximum ankle dorsiflexion (KW test—Figure 1); coordination, dynamic balance, and postural control (YBT-LQ—Table 2); and lower-limbs muscle power (CMJa—Figure 2).

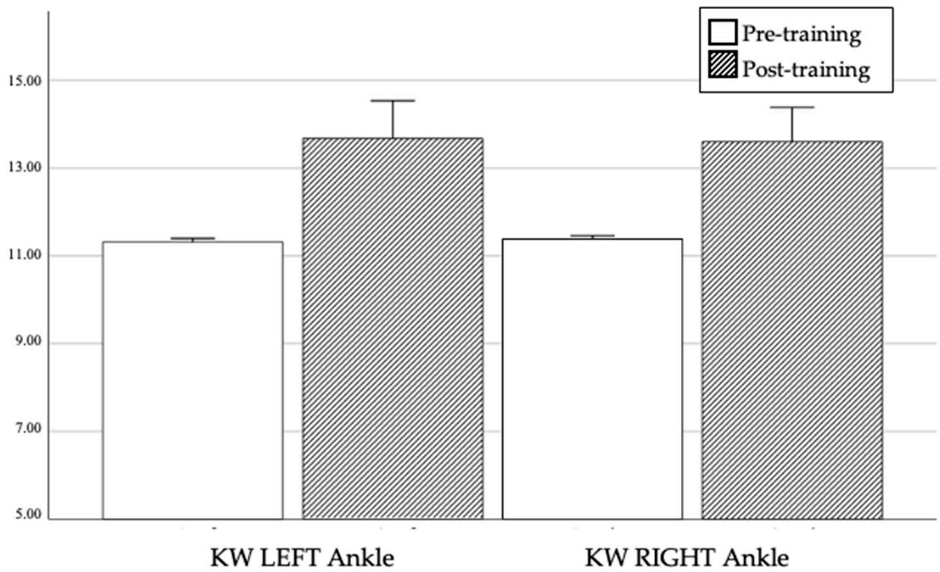

Figure 1. Pre- and post-training means and standard deviation values of ankle dorsiflexion (cm) with knee-to-wall (KW) test.

Table 2. Y-Balance test—Lower Quarter (YBT-LQ) pre- and post-training mean, median, and standard deviation (SD) values and differences.

	Pre-Training Program		Post-Training Program		Differences (Post–Pre)
YBT-LQ (cm)	**Mean ± SD**	**Median**	**Mean ± SD**	**Median**	***t***
YBT-LQ—Anterior Left	62.62 ± 5.73	63.00	65.37 ± 6.87	63.50	2.75 ± 4.08 *
YBT-LQ—Postero-medial Left	104.75 ± 11.72	102.50	108.54 ± 12.90	105.75	3.79 ± 6.55 *
YBT-LQ—Postero-lateral Left	111.75 ± 16.69	105.50	112.45 ± 12.90	109.00	0.70 ± 7.05
YBT-LQ—Anterior Right	63.91 ± 6.01	65.00	66.12 ± 6.41	65.00	2.20 ± 3.89 *
YBT-LQ—Postero-medial Right	106.04 ± 12.32	104.00	106.45 ± 11.88	102.75	0.41 ± 7.07
YBT-LQ—Postero-lateral Right	110.45 ± 13.89	105.50	112.50 ± 10.07	114.50	2.0.4 ± 7.69
YBT-LQ Anterior Asymmetry	3.37 ± 2.04	3.00	1.75 ± 1.48	1.25	−1.62 ± 2.73 *

Abbreviations: YBT-LQ: Y-Balance Test—Lower Quarter; SD: standard deviation; * $p < 0.05$.

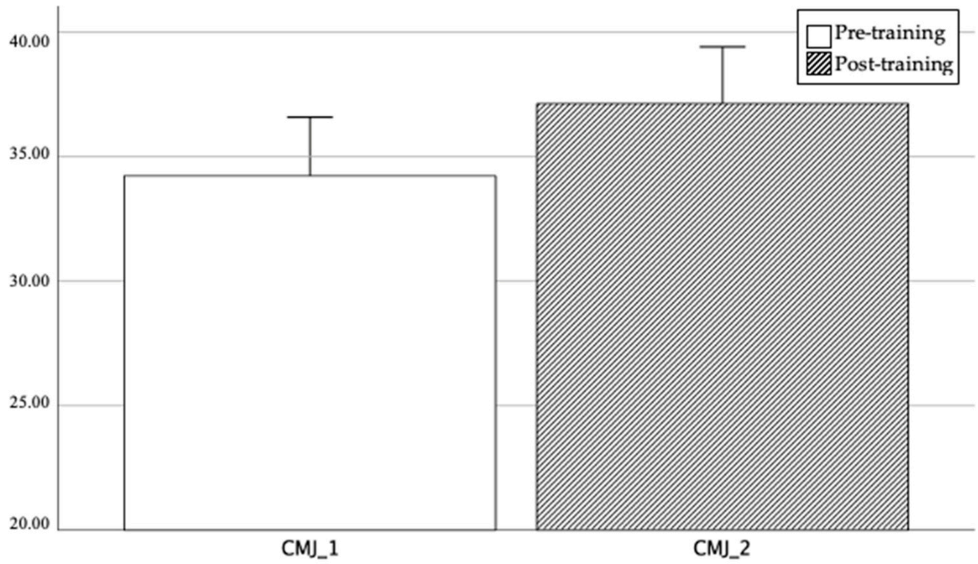

Figure 2. Pre and post-training measures of lower limb muscle power, assessed with the CMJa test (cm).

Figure 1 shows the mean KW test distance increased significantly, 2.36 cm (11.31 ± 0.28 cm to 13.67 ± 2.99 cm; $p < 0.001$) for the left ankle and 2.22 cm (11.38 ± 0.26 cm to 13.60 ± 2.71 cm; $p < 0.001$) for the right ankle.

Post-training assessment revealed the program reduced lower limb asymmetry, as it increased scores for some of the YBT-LQ variables, showing a positive and significant ($p < 0.05$) increase, mainly in the values of YBT-LQ—anterior left, YBT Postero—medial left, and YBT-LQ—anterior right.

The YBT-LQ anterior reach distance asymmetry also showed a positive evolution with a decrease of approximately 1.62 cm (3.37 ± 2.04 cm to 1.75 ± 1.48 cm; $p < 0.05$).

As for the CMJ, Figure 2 highlights the average and significant increase of approximately 8.44% (34.24 ± 8.25 cm to 37.13 ± 7.90 cm; $p < 0.001$) in jumping height for all athletes.

4. Discussion

Lower limb injuries are the most common in surfing competitors [12] and among elite junior surfers [15], and seem to be related to landing tasks [12,47]. Therefore, physical performance outcome measures are important baseline screening tools for detecting initial deficits in young athletes and tracking their progress following the implementation of programs [19,41,42]. In fact, Lundgren and colleagues highlight the need for a multifactorial approach to evaluating landing skills (e.g., ankle dorsiflexion range of motion, isometric midthigh pull, lower body strength, time to stabilization during a drop-and-stick (DS) landing, relative peak force during a DS landing), recognizing that multiple factors contribute to both the success and safety in these tasks. [30]

According to Steele and Sheppard [48], normal ankle DF, assessed with the KW test, should be over 12 cm for surfers. The KW test revealed that junior surfers presenting pre-test borderline lower scores for ankle DF achieved a higher (13.67 ± 2.99 cm to 13.60 ± 2.71 cm) and significant ($p < 0.001$) post-program increase of more than 2 cm, which is higher than or similar to previous junior elite surfer studies addressing ankle ROM, like Dowse et al. [49] (10.0 ± 2.0 cm to 11.0 ± 3.0 cm), Seixas et al. [15] (11.5 ± 3.2 cm to 11.6 ± 2.7 cm), and Lundgren et al. [8] (13.9 ± 2.8 cm to 14.3 ± 3.9 cm).

Previous research has highlighted the importance of increased ankle dorsiflexion and the proficient landing ability of competitive surfers, as well as a positive link between ankle proprioception and competitive achievement, which differentiates senior from junior elite and recreational surfers [47,49]. It has also been suggested that the ability to attenuate energy to reduce the landing force may be developed through long-term training that aligns with the demanding tasks of competitive surfing [47].

Coordination, *dynamic balance*, *and postural control*, assessed through the YBT-LQ, revealed post-program increased scores for all measured variables. Although some of them (YBT-LQ—Anterior Left, YBT-LQ—Postero-medial Left and YBT-LQ—Anterior Right) showed a statistically significant difference ($p < 0.05$), its increase is not considered clinically relevant due to the associated measuring error (SD), as the variations were lower than 5%. This increase in the previous great SD measuring error might be because not all athletes achieved the same degree of neuromuscular adaptations regarding the implemented training program, which might be explained by the different experience and dry-land training routines among them.

However, the fact that both limbs present similar post-program YBT-LQ scores due to a greater increase in YBT-LQ left scores shows that the proposed program, centered on bilateral exercises and/or bilateral motor patterns, induced symmetry between limbs, having a positive effect on movement control and balance in segmental actions, therefore seeming to mitigate pre-program inter-limb asymmetry.

The post-program results show that both the right and left anterior reach distance differences (YBT-LQ anterior asymmetry) decreased significantly ($p < 0.05$) with a reduction of 56%, which is relevant as an YBT-LQ anterior asymmetry greater than 4 cm is commonly associated with up to a 2.5 times higher risk of lower extremity injury [33].

Many studies also utilize the normalized composite reach distance (composite reach distance (%) = sum of the 3 reach directions/3 times the limb length × 100) since its score being below specific cut points is associated with impaired neuromuscular control and an elevated likelihood of lower extremity injuries [31,33,34]. However, the composite score could not be applied in this study because cutting points regarding the age, gender, and sport/activity of the individual have yet to be researched in surfing.

Nevertheless, the YBT-LQ improved results might also be associated with the verified ankle DF improvements, as it has been previously demonstrated that limited ankle dorsiflexion affects balance control [50], and balance deficits and flexibility asymmetry are linked with a higher risk of lower-limb injuries [51]. Therefore, the improved results of our post-program assessments on these variables may indicate a reduction in these athletes' injury risk level.

As to lower limb muscle power, assessed with the CMJa test, another study [36] suggests that top-ranked surfers display a higher vertical jump performance (49.00 ± 5.00 cm) when compared to lower-ranked or non-elite surfers (42.00 ± 7.00 cm). Our post-program results, despite being lower (37.13 ± 7.90 cm), revealed a significant increase of 8.44% ($p < 0.001$), which supports the effectiveness of our program in terms of jump height potential development. Our significant but modest results might be explained by the fact that, although this is a sensorimotor program with incremental increases in strength, it is not exclusively a strength training program. In addition, other studies [21,30] probably included more experienced junior surfers in terms of their training physical performance when compared to our athletes, who potentially needed a higher frequency of training, either more time/an extended training program, and/or a more focused lower limbs strengthening program to achieve the same physical level.

In fact, lower body strength and power seem to be determinants in competitive surfing and overall performance [37,52,53], as stronger surfing athletes seem to be able to develop significantly greater eccentric peak velocity [36], to brake more effectively, and to better use the landing/eccentric phase, optimizing their jumping performance [44]. This load absorption optimization while landing an aerial is also related to increased ankle dorsiflexion [14], which confirms the importance of the assessment of the three variables analyzed (ankle DF, YBT-LQ, and CMJa), also supported by our results.

A previous study of junior surfing athletes' physical performance level [15,51] also revealed some degree of un-structured training strategies (e.g., type, frequency, intensity of training), which might not fully address the physical needs of the surfers, considering the tasks to be performed. It is also clear that for junior surfing athletes, failing to maintain a consistent regimen of resistance training alongside their surf training may result in detrimental reductions in power, strength, and sensorimotor ability, ultimately diminishing their physical performance [54]. These findings underscore the inadequate existing physical training regimen for adolescent competitors, emphasizing the necessity for a more comprehensive training program that involves structured dry-land training to optimize their athletic potential. Adding on this, other authors [54] suggest that surfing alone does not provide a sufficiently potent stimulus to sustain optimal performance parameters, and that young surfers should incorporate training strategies with respect to their strength, power, and sensorimotor abilities to avoid the negative consequences of detraining.

Therefore, a specific sensorimotor training program was created, comprising coordination (balance, rhythm, and spatial awareness); strength, power, and core (lower limb plyometrics and core stability); and endurance exercises. These exercise categories were previously identified as performance and injury prevention indicators in surfing [2,38,43,44].

Coordination exercises are related to the ability to control fundamental movement skills (locomotor, manipulation, and stability skills), increasing one's capacity to react to unanticipated situations, optimize sport-specific movements, and ultimately reducing the risk of injuries in young athletes [28]. Therefore, when surfers possess the ability to stabilize and control their posture, it increases their chance of executing successful landings and smoothly transitioning to the next maneuver rapidly and effectively [54]. The coordination exercises were also defined taking into consideration the specificity of the aerial tasks, like arm swing during jumping and landing while controlling the body's trajectory (e.g., one twist w/arms swing (to landing mat 30)).

Strength, power, and core exercises are part of any sensorimotor training program, since they focus on the activation of deep trunk muscles, leading to improved muscle control and enhanced coordination both within and between muscles [55]. It has also been observed that greater physical performance characteristics such as strength and power are positively linked to improved surfing performance [54], being critical for force absorption while landing aerials or floaters [36].

As strength deficits have been frequently associated with diminished neuromuscular control and a higher susceptibility to injuries among the younger population [28,54], this training program incorporated the development of athletes' stretch shortening cycle ability (e.g., plyometric exercises—"seated box jump + broad jump") and agility exercises (e.g., "2-Leg Lateral Hurdle w/½ twist"), which involved enhancing skills at maximum speed and integrating changes of direction [28].

Enhanced muscular endurance in a surfing athlete reduces the likelihood of fatigue, leading to increased chances of heat wins and overall success in competitions [56]. This type of training is characterized by incorporating a range of exercises that target core and lower limb stability, as well as upper body and lower body movements, including both pushing and pulling strength exercises [28]. This programs' endurance exercises aimed more specifically at the lower limbs (squats, lunges, and jumps) since their action is crucial to guarantee effectiveness of jumping/landing tasks for aerials.

According to our research results, all three parameters measured had a positive improvement, which shows a trend that needs to be confirmed with larger sample studies and a control group in order to strengthen the study's internal validity and make it possible to generalize the main conclusions (external validity). In fact, due to the size and variability of our sample, despite all twelve being junior surfers and similar in age (15.50 ± 2.11 years-old), they presented a wider range of anthropometric characteristics (weight: 54.28 ± 9.77 kg; height: 164.29 ± 8.97 cm), which can probably be explained by unconfirmed different maturational profiles. Therefore, pre-program physical performance capacities and adaptations to new and/more demanding exercises as the program followed through might not have been equal for all participants, which also explains their low pre-program variables scores.

Supporting this idea, a recent study [57] analyzed the impact of age and maturation on physical performance capacities in junior surfing competitors. Their results revealed that physical performance capacities were similarly influenced by both maturity and age, except for general athletic abilities, which displayed a significant correlation with maturation level but not age.

However, the post-training changes on ankle dorsiflexion, balance, and lower limb strength suggest that the proposed program can improve not only those variables but also positively influence the surfer's ability to control their posture and effectively absorb eccentric forces while landing an aerial maneuver. We can also theorize that practice and repetition of the suggested analytical tasks will also benefit surfing performance [14], as some of the movements (e.g., one twist w/arms swing) are similar to the proposed surfing task (e.g., 180° frontside aerial). Being a high-risk maneuver, dry-land aerials training is presented as an option to optimize a surfer's landing technique and improve completion rates [7], making the surfer more prepared for the task, and therefore reducing the risk of lower limb injury while performing one of these maneuvers.

Previous research [55] demonstrated that an 8-week land-based training program improved core muscle strength, power, countermovement jump performance, peak power, and rotational flexibility in young surf athletes. Whilst engaging in this kind of training is clearly advantageous for the health and psychological well-being of adolescents, it also plays a crucial role in their growth and motor skill development [54].

The training duration (7 weeks), frequency (two-times/week), duration (60 min session), and resting time (1 to 3 min) are in line with a systematic review on neuromuscular training for young athletes that points to four weeks as the minimal necessary period to generate neuromuscular adaptations, with an exercise program's duration ranging between 6 weeks to 8 months, two times per week, and with an average training duration of 60 min, varying from 30 to 90 min [28]. These ideas are also supported by the American Academy of Pediatrics guidance document [38,46].

In terms of the required materials, this training would be easy to implement, as it only requires agility, training, and landing mats, training boxes, and jumping barriers.

As a recommendation for coaches, all surfers should be assessed at the beginning of each competitive season regarding their physical performance indicators, since the results can be used as a base to improve their limitations; and the YBT-LQ and KW tests results should be considered as reference for lower limb injury risk. Other important aspects are the following: (1) the utilization of initial dry-land training to ensure the surfer's control of body segments with simple exercises which can later be used for technical aerial training tasks; and then (2) to verify the performance of movements similar to the aerial, but in a simplified context and with a greater number of repetitions, which will allow the surfer to evolve in the execution of aerials in the water.

It is our understanding that this type of multicomponent and progressive sensorimotor training will allow not only athletes to improve aerial tasks in a more controlled and stable environment (dry-land), but also coaches to identify main tasks pertaining to key components requiring improvement, therefore optimizing training for better performance.

Moreover, considering a double-periodization competitive season programming scheme [58], and depending on the available time on the competitive calendar, this sensorimotor training program can be applied twice: initially as proposed here, and reinforced mid-season with more complex and demanding exercises, according to the surfer's indoor and on-water performance evolution.

Surfers should also seek to prevent lower limb injuries, not only through the inclusion of pre-surf warm up exercises on their surfing routines (as performed before each training session), but also by focusing on flexibility training to prevent lower limb injuries.

As to limitations, with this small and heterogeneous sample, and without a control group, it is not possible to generalize these findings to the junior surfer population, and studies with larger samples are necessary to prove the effects of the proposed training program; and it was not possible to standardize the complementary training that each surfer's coach was responsible for, making it difficult to assess if that also contributed to the improved post-program results. For example, younger/less experienced/less trained athletes, who never performed any type of complementary training before, might have had more difficulties following the progression of the proposed sensorimotor training program multicomponent when compared to older/more experienced/trained athletes, therefore presenting lower post-program results. It is also important to verify if, with different performance indicators and longer programs, the improvements obtained with this dry-land training program would also apply to in-water aerial maneuver performance, and its relationship with injury prevention.

5. Conclusions

To the best of our knowledge, this research is the first to present structured training activities specifically designed to address aerial maneuver performance. The proposed intervention training program effectively enhanced clinical measures of sensorimotor control (maximum ankle dorsiflexion; coordination, dynamic balance, and postural control; and lower limb muscle power) that can contribute to aerial maneuver performance. In addition, the improvements in ankle dorsiflexion, balance, and anterior reach asymmetry suggest that this 7-week sensorimotor training program might also be seen as an active protection strategy for lower limb injuries while performing aerial maneuvers.

These findings emphasize the importance of consistent training for adolescent surfers with a relatively low training age to maintain and enhance their power, strength, and sensorimotor abilities, which are essential for optimal surfing performance and minimizing injury risk.

More research should be carried out with different performance indicators and longer programs to verify if the improvements obtained with dry-land training programs also apply to in-water aerial maneuver performance, and if they are related to injury prevention.

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