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Acute Impact of Proprioceptive Exercise on Proprioception and Balance in Athletes

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Featured Application: Both proprioceptive exercise and non-specific exercise, like cycling on a static bike for 10 min, improve knee position sense and balance. Yet, the responders to the exercise session showed greater knee position sense improvement after the proprioceptive exercise session.

Abstract: This study aimed to compare the acute effect of a proprioceptive exercise session and a non-specific exercise session on knee position sense, and the static and dynamic balance of athletes. Sixty male athletes (19.4 ± 1.2 years) participated in a within-subjects repeated-measures study. Knee position sense in closed kinetic chain, and static (BESS test) and dynamic balance (Y-balance test) were measured before and after two exercise sessions, consisting of 10 min of non-specific exercise in a cycle-ergometer or proprioceptive exercise with an unstable platform. Overall, both exercise sessions significantly improved knee position sense, BESS score, and YBT composite score, and no differences were detected between proprioceptive and non-specific sessions (knee position sense, −6.9 ± 65.2% vs. −11.5 ± 75.0%, $p = 0.680$; BESS, −19.3 ± 47.7% vs. −29.03 ± 23.5%, $p = 0.121$; YBT, 2.6 ± 2.7% vs. 2.2 ± 2.2%, $p = 0.305$). Twenty athletes did not improve knee position sense after the exercise session (non-responders). When analyzing only the exercise responders, both sessions improved knee position sense, but the improvement was greater after the proprioceptive exercise session (56.4 ± 25.6% vs. 43.8 ± 18.9%, $p = 0.023$). In conclusion, a single proprioceptive, as well as non-specific, exercise session increased knee position sense and balance. The proprioceptive exercise seems to be more effective in improving joint position sense when considering only athletes who respond to the intervention.

Keywords: exercise; proprioception; balance

Citation: Harry-Leite, P.; Paquete, M.; Teixeira, J.; Santos, M.; Sousa, J.; Fraiz-Brea, J.A.; Ribeiro, F. Acute Impact of Proprioceptive Exercise on Proprioception and Balance in Athletes. *Appl. Sci.* **2022**, *12*, 830. https://doi.org/10.3390/app12020830

Academic Editor: Domenico Lombardo

Received: 21 December 2021
Accepted: 9 January 2022
Published: 14 January 2022

1. Introduction

The visual, vestibular, and somatosensory systems act to maintain balance, which is considered a dynamic process of body posture to prevent falls, by maintaining the line of gravity within the base of support. The maintenance of balance requires constant adjustments of muscle activity and joint positioning, based on visual, vestibular, and somatosensory information [1]. Accurate detection and control of the joint position, orientation and movement, and an efficient postural balance not only reduce the risk of body imbalance, fall, or subsequent injuries, but also contributes to the optimization of motor performance in several athletic disciplines [2,3]. Optimized balance and proprioception are particularly useful to decrease the risk of injury in sports with constant physical contacts and high-intensity complex movements in small spaces, such as football [4–8] or basketball [9–11].

Previous studies showed that physical exercise changing the functional state of the muscle can affect proprioception, namely joint position sense. Studies have shown that exercise-induced fatigue acutely decreases the accuracy of the position sense [12,13], while warm-up exercise or a single session of unspecific exercise not inducing fatigue [14–17] increases joint position sense. For instance, Bouët and Gahéry [14] showed an increase in knee joint position sense after 10 min of moderate exercise (warm-up without any fatigue) on a cycle ergometer. Despite using different exercises and different protocols to measure proprioception, most of the previous studies reported an increase in joint position sense immediately after the exercise session. However, less is known whether the acute effects of an unspecific exercise session are similar to the effects promoted by a session composed of proprioceptive exercises. Regarding balance, Yong and Lee [18] assessed the acute influence of proprioceptive exercise on static and dynamic balance in 28 adults and found an increase in dynamic balance immediately after exercise.

The immediate benefits of both proprioceptive and non-specific exercise in the proprioceptive feedback and balance are acknowledged, yet it is not clearly documented which one is the most effective in the short term. The rationale behind the study of the acute effect of these two exercise sessions lies in the potential positive effects on proprioception, postural stability, and balance, which may decrease the risk of injury when the subject starts a therapeutic exercise session or a recreational/competitive game. It seems particularly relevant to determine if a simple exercise, such as pedaling on a cycle ergometer, is as effective as a more complex exercise session composed of a series of exercises most of the time performed on/with specific materials/equipment. Hence, our study aimed to compare the acute effects of a proprioceptive exercise session versus a non-specific exercise session on knee position sense, and static and dynamic balance in young athletes. We hypothesized that both exercise sessions would increase the accuracy of position sense and balance and that this increase would be higher after the proprioceptive exercise session.

2. Materials and Methods

2.1. Study Design

This quantitative study consisted of a within-subjects repeated-measures design. The independent variables are the exercise session (proprioceptive exercise versus non-specific exercise), and joint position sense, and dynamic and static balance as the dependent variables. Joint position sense and balance measures were obtained before and immediately after the exercise sessions. Data collection was performed at the teams' facilities, in a quiet room, from January 2019 to April 2019. The exercise sessions were separated by seven days and its order was randomly determined by the selection of one of two sealed, non-translucent, envelopes.

2.2. Participants

A convenience sample of 68 semi-professional, male, soccer and basketball players, were assessed for eligibility. Inclusion criteria: ≥18 years of age, normal knee range of motion, play soccer or basketball at a semi-professional level, and uninterrupted sports practice for the last 5 years. Athletes were excluded according to the following criteria: history of lower back and lower limb injuries in the last 6 months; history of neurological and vestibular disorders [19]; history of lower limb surgery [20]; history of cardiac/respiratory, or neuromuscular disorders. The participants were previously familiarized with the procedures of the experimental protocol and were advised to avoid intense or exhaustive exercise in the 2 days preceding the data collection. Appropriate ethical approval from the institutional board of Jean Piaget Higher School of Health of Vila Nova de Gaia, Portugal, was granted prior to the study. Written informed consent was provided by the participants and all procedures were conducted according to the Declaration of Helsinki.

2.3. Assessment of Joint Position Sense

Knee joint position sense was evaluated in the dominant lower limb in closed kinetic chain using an ipsilateral technique of active knee positioning of an actively determined position. The dominant limb was defined as the limb used to kick a ball. Joint position sense measurements were performed without visual input using a video-recorded 2D motion analysis. The camera was positioned 7 m away from the participant on a tripod, in the sagittal plane, and at knee level.

Before the assessment, four markers were fixed to the skin of the apex of the greater trochanter, the iliotibial tract (level with the posterior crease of the knee when flexed to 80°), the head of the fibula, and the prominence of the lateral malleolus; these two pairs of markers represent the axis of the thigh and the axis of the leg (Figure 1).

Figure 1. Assessment of knee joint position sense. The blue points represent the placement of the markers for position sense assessment of individual joints using a video analysis system.

The participants stood on the test leg, with both hands placed lightly on a stable object in front of them [21]. A small heel wedge (height: 5 cm) was used to decrease the passive tension generated in the triceps sural muscle of the dominant limb [22]. The contralateral limb was relaxed on a step, with slight knee flexion.

One test position at the midrange of knee range of motion was tested as follows: the participants were instructed by the examiner to slowly (at approximately 10/s) and actively move the lower limb from the starting position of 0° of knee flexion to the test position, which was determined as a knee joint angle between 40° and 60° of flexion. Then, the participant maintained the test position actively (isometrically) for 5 s to identify/memorize the position. After that, the participant was instructed by the examiner to actively return the lower limb to the starting position. Then, the participant actively flexed the knee in an attempt (upon the command "reposition") to reproduce the test position using the same lower limb. The participant then returned to the position perceived as the test position and reported "target" to the examiner. This position was held for 3 s, and on the command "return" the participant returned to the initial position [15]. The procedure was repeated three times.

To determine the knee angles, a sequence of 10 frames of the target and the repositioning joint positions were analyzed with the Postural Assessment Software (PAS/SAPO) [23]. Joint position sense is reported using the absolute angular error (AAE, defined as the absolute difference between the target position and the test position reproduced by the participant) and relative angular error (RAE, defined as singed arithmetic difference between the target position and position reproduced by the participant). This method of joint position sense assessment showed an intraclass correlation coefficient (ICC) of 0.81 and 0.69 for absolute and relative angular errors, respectively, in a sample of young athletes;

the standard error of measurement and smallest real difference were 0.30° and 0.83° for absolute and 0.90° and 2.94° for relative angular error [15].

2.4. Assessment of Balance (Static and Dynamic)

Static balance was determined by assessing the performance on the Balance Error System Score (BESS). BESS is a clinical test used by clinicians and researchers to assess postural stability and balance [24,25]. Assessments were conducted with bare feet, allowing three practice trials before testing. The BESS consists of three stances: double-leg stance with hands on the iliac crests, single-leg stance (nondominant lower limb) with hands on the iliac crests, and tandem stance (nondominant foot behind the dominant foot) in a heel-to-toe fashion. Participants were asked to maintain static balance with eyes closed under 6 different conditions (3 stances on a firm surface and 3 stances on a foam surface) for 20 s each [26]. For scoring, an error is defined as: (1) hands lifted off the iliac crests; (2) opening eyes; (3) a step, stumble or fall; (4) moving the hip into more than 30° of abduction or flexion; (5) lifting the forefoot or heel or (6) remaining out of the test position for more than 5 s. The maximum possible number of errors in each trial was 10 and the maximum possible number of errors for the total test score was 60 [27]. Dynamic balance was assessed with the Y-balance test. The test was demonstrated and the participants were given four practice trials before the three assessment trials [28]. Each participant performed the Y-balance test barefoot to eliminate additional support. The testing was performed with the participant standing with the heel of the weight-bearing foot in the center of the grid, maintaining the base of support. The participant was instructed to slide the box, reaching as far as possible in the anterior, posteromedial, and posterolateral directions and to return to the initial upright position without losing balance. The reach distance was recorded (foot length was removed in the anterior direction since the heel was aligned with the middle of the grid) [29], and normalized to the participant's leg length (anterior superior iliac spine to inferior medial malleolus) providing a measure of performance [30]. The overall performance of the test, i.e., the composite reach distance, was computed using the greatest reach distance from each direction. The best trial of each direction was considered for analysis. Invalid attempts were considered when the participant: (1) removed his hands from the hip; (2) did not return to the initial position; (3) applied sufficient weight through the reaching foot to gain an increase in reach distance; (4) placed his foot on either side of the tube; (5) lifted or moved the support foot during the test; or (6) pushed or kicked the attachment with the reaching foot to achieve better results. In these cases, the test was discarded and the participant was asked to repeat the test [31].

2.5. Proprioceptive/Non-Specific Exercise Sessions

The exercise sessions lasted 10 min and were supervised by a physiotherapist. The non-specific exercise session consisted of cycling in a mechanically braked cycle ergometer, at 60 rpm, with a fixed load of 50 watts. This non-specific exercise session was selected because it showed in a previous study to improve proprioception [14]. The proprioceptive exercise session consisted of a set of exercises, performed on a BOSU, focusing on the awareness and control of the lower limb. The session was composed of 10 exercises (Table 1), adapted from a previously tested proprioceptive training protocol [32].

Table 1. Proprioceptive exercise session.

Exercise	Duration [1]
1. Squat in Bosu	10 x
2. Bipodal support in Bosu	60 s
3. Throw and catch the ball in bipodal support in Bosu	60 s
4. Unipodal support in bosu	60 s
5. Throw and catch the ball in unipodal support in Bosu	60 s
6. Jump to Bosu with bipodal support	10 x

Table 1. *Cont.*

Exercise	Duration [1]
7. Jump to Bosu with unipodal support	10 x
8. Jump to Bosu with bipodal support with 90° trunk rotation	10 x
9. Bipodal support in Bosu with eyes closed	60 s
10. Unipodal support in Bosu with eyes closed	60 s

[1] s—seconds; x—repetitions.

2.6. Statistical Analysis

Statistical analyses were performed using SPSS version 26.0 (SPSS Inc., Chicago, IL, USA). The normality of data distribution was tested with the Shapiro–Wilk test and histogram analysis. Data are expressed as mean ± SD or median (interquartile range); mean differences are expressed with their two-sided 95% confidence interval (CI). The percentage of change in each outcome from baseline to post-session was calculated as follows: ((post-session value − baseline value)/baseline value) × 100. Between sessions differences at baseline and in the change from baseline to the end of the study were tested with paired Student's *t* tests. Paired Student's *t* tests were also performed for within-session comparisons from baseline to the end of the exercise session. Between-group (sport modalities: soccer versus basketball) differences at baseline and in the change from baseline to the end of the study were tested with independent *t*-tests. The effect size was calculated and an effect size of 0.2, 0.5, and 0.8, respectively, interpreted as small, medium, and large. Paired Student's *t* tests were also conducted to compare baseline from first and second sessions (irrespective of the exercise type that followed) to determine whether there were within-session learning effects. The intraclass correlation coefficient (ICC) was calculated to determine the reliability of the baseline assessments from the first and second sessions (irrespective of the exercise type that followed). The level of significance was set at $\alpha < 0.05$.

3. Results

From the 68 athletes who agreed to participate in the study, 8 did not meet the inclusion criteria. Thus, a total of 60 semi-professional male athletes (age, 19.7 ± 1.9 years; height, 180.6 ± 0.1 cm; weight, 74.0 ± 9.9 kg; body mass index, 22.6 ± 1.9 kg/m^2), 30 soccer players and 30 basketball players participated in the study. There were no significant differences for age (19.4 ± 1.2 versus 20.1 ± 2.4, $p = 0.01$), height (176.5 ± 0.1 versus 184.7 ± 0.1, $p = 0.01$), weight (67.4 ± 7.9 versus 80.7 ± 6.7, $p = 0.01$), and body mass index (21.6 ± 1.3 versus 23.7 ± 1.9, $p = 0.01$) between soccer and basketball players, respectively.

At baseline, there were no statistically significant differences for knee position sense and balance between sessions (Table 2). When comparing the baseline data from first and second sessions (irrespective of the exercise type that followed) we did not find significant differences in any variable; there was no indication of within-session learning effects for joint position sense (AAE 1st session 1.78 ± 1.14° vs. 2nd session 1.55 ± 1.06°, $p = 0.148$), static (BESS 1st session 7.32 ± 2.35° vs. 2nd session 7.18 ± 2.40°, $p = 0.566$) and dynamic (YBT 1st session 106.6 ± 11.7° vs. 2nd session 106.4 ± 12.5°, $p = 0.689$) balance. The reliability of our methods of joint position sense assessment showed an ICC of 0.628 and 0.629 for absolute and relative angular errors between baseline levels of both sessions. Y-balance test and BESS test showed an ICC of 0.969 and 0.835, respectively, between baseline levels of both sessions.

Table 2. Pre–post differences in the variables.

	Non-Specific Exercise			Proprioceptive Exercise			Comparison between Sessions in the Difference (95% CI)	*p* Value #
	Before	After	Difference to Before (%)	Before	After	Difference to Before (%)		
AAE (°)	1.83 ± 0.88	1.41 ± 0.78 *	−6.9 ± 65.2	1.71 ± 0.81	1.22 ± 0.81 *	−11.5 ± 75.0	4.5% (−17.3–26.3)	0.680
RAE (°)	1.21 ± 1.69	1.01 ± 1.36	4.7 ± 150.6	1.08 ± 1.62	0.85 ± 1.29	−10.5 ± 132.4	20.0% (−25.0–55.2)	0.454

Table 2. *Cont.*

	Non-Specific Exercise			Proprioceptive Exercise			Comparison between Sessions in the Difference (95% CI)	p Value #
	Before	After	Difference to Before (%)	Before	After	Difference to Before (%)		
YBT (%)	106.4 ± 12.8	109.1 ± 13.3 *	2.6 ± 2.7	106.7 ± 11.4	109.1 ± 12.4 *	2.2 ± 2.2	0.37% (−0.35–1.08)	0.305
BESS	7.35 ± 2.48	5.33 ± 1.80 *	−19.3 ± 47.7	7.15 ± 2.27	4.92 ± 1.84 *	−29.0 ± 23.5	9.7% (−2.63–22.03)	0.121

* Significantly different from before the session, $p < 0.05$; # test value for comparison between groups of differences for before the session.

Both proprioceptive exercise and non-specific exercise sessions significantly improved knee joint position sense (by decreasing absolute angular error) (effect size: 0.51 and 0.47, respectively, for proprioceptive and non-specific), and the performance in the Y-balance test (effect size: 1.00 and 0.95, respectively, for proprioceptive and non-specific) and BESS test (effect size: 1.38 and 0.98, respectively, for proprioceptive and non-specific) (Table 2). There were no statistically significant differences between sessions in the percentage of change in knee position sense and balance, i.e., both sessions induced similar improvements (Table 2). There were no statistically significant differences in relative angular error after both sessions; the participants underestimated the target position before and immediately after both exercise sessions. The results were similar when analyzing soccer and basketball players separately (Table 3).

Table 3. Pre–post differences in proprioception and balance by modality.

		Non-Specific Exercise			Proprioceptive Exercise			Comparison between Groups in the Difference (95% CI)	p Value #
		Before	After	Difference to Before (%)	Before	After	Difference to Before (%)		
AAE (°)	Soccer	1.93 ± 0.89	1.61 ± 0.85 *	−4.50 ± 63.04	2.03 ± 0.79	1.45 ± 0.87 *	−22.58 ± 42.61	18.08% (−9.58–45.74)	0.192
	Basketball	1.72 ± 0.89	1.22 ± 0.67 *	−9.38 ± 68.34	1.40 ± 0.71	0.98 ± 0.68 *	−0.35 ± 96.77	−9.03% (−43.76–25.69)	0.599
RAE (°)	Soccer	1.33 ± 1.69	1.18 ± 1.56	24.8 ± 179.8	1.17 ± 1.95	0.92 ± 1.58	1.67 ± 163.75	23.13% (−48.78–95.05)	0.516
	Basketball	1.10 ± 1.73	0.85 ± 1.14	−15.5 ± 113.8	1.00 ± 1.23	0.77 ± 0.92	−22.57 ± 92.35	7.07% (−33.29–47.42)	0.723
YBT (%)	Soccer	110.02 ± 15.72	113.25 ± 16.30 *	2.96 ± 3.43	109.68 ± 13.89	112.85 ± 15.19 *	2.81 ± 2.82	0.15% (−1.21–1.51)	0.823
	Basketball	102.74 ± 7.63	105.03 ± 7.52 *	2.26 ± 1.59	103.67 ± 7.37	105.38 ± 7.32 *	1.67 ± 0.99 **	0.59% (0.23–1.15)	0.040 *
BESS	Soccer	7.00 ± 2.6	5.03 ± 1.96 *	−15.17 ± 64.9	6.67 ± 2.79	4.23 ± 2.01 *	−32.52 ± 27.8	17.35% (−6.77–41.47	0.152
	Basketball	7.70 ± 2.29	5.63 ± 1.61 *	−23.48 ± 16.64	7.63 ± 1.47	5.60 ± 1.38 *	−25.53 ± 18.1	2.06% (−4.83–8.94)	0.546

* Significantly different from before the session, $p < 0.05$; # trial value for comparison between groups of differences for before the session; ** significantly different from football, $p = 0.044$.

One third of the athletes did not improve knee position sense (absolute angular error) after the exercise sessions (proprioceptive: n = 20, 33.3%; non-specific: n = 20, 33.3%). Of these 20, 9 athletes (15%) were non-responders to both sessions. When only the responders (n = 30) were analyzed, both sessions improved knee position sense, but the magnitude of the improvement was significantly higher in the proprioceptive exercise session (mean difference 12.6%, 95%CI: 1.8–23.5, $p = 0.023$; effect size: 0.44). Regarding the Y-balance test and BESS, the number of non-respondents was lower (n = 10 and n = 17, respectively), and the improvement in both sessions was not different when considering only the responders.

4. Discussion

The main findings of this study confirm our hypothesis that both exercise sessions increase proprioception and static and dynamic postural balance. The two exercise sessions induced immediate effects of the same magnitude, hence our results did not support the assumption that the proprioceptive exercise would present better immediate results than the non-specific exercise. However, the proprioceptive exercise session increased the position sense of the knee to a larger extend in comparison to the non-specific exercise session when considering only the responders.

The significant improvements in the proprioceptive function after the exercise sessions are in agreement with previous studies [33,34]. Several studies showed that non-specific, warm-up exercise may increase proprioception. For instance, Bartlett & Warren [35] evaluated knee joint position at rest and after a 4-min warm-up (jogging and stretching exercises) in 12 adult male rugby players and found an improved joint position sense after the warm-up. The authors suggested that the improvement in accuracy of knee joint position could be related to an increase in the sensitivity of the mechanoreceptors or a more central mechanism. In the same way, Magalhães et al. [15] evaluated the influence of a warm-up session on knee position sense in open and closed kinetic chain in 10 karate athletes, and reported positive effects only in closed chain. It should be noted that the session lasted 10 min and included slow running, stretches, and jumps. The authors also suggested that central and peripheral elements may contribute to improving proprioception after warm-up exercises, but they did not establish the relative contribution of each one. Likewise, Salgado et al. [13] found significant increases in knee joint position sense in 14 soccer players after a standard pre-competition warm-up lasting 25 min; as other authors [14,36], they justified the positive effects in proprioception by changes in muscle circulatory supply, improvements in nerve conduction and/or increases in muscle spindle sensitivity. Additionally, Romero-Franco and Jiménez-Reyes [16] or Baker et al. [17] also observed an increase in joint position sense after warm-up exercises.

Concerning balance, previous studies also reported positive effects of warm-up exercise on static and dynamic balance [18,33,37]. Nonetheless, Kim et al. [38] did not observe any acute effect on the dynamic balance after plyometric exercises, stretching exercises, or walking, in a group of 22 individuals; similar results were observed in other studies, for instance, Pancar et al. [39] did not observe changes in balance after a warm-up session in 30 young boys. The potential explanations to our results may be related to the increase in the viscoelastic properties and the elasticity index of muscle fibers, increase in body temperature and O_2 availability at cellular level, resulting in an increased sensitivity of mechanoreceptor and a more effective motor control response [40]. Proske [41] hypothesized that in addition to signals arising from the body periphery, copies of motor commands (efference copy) are able to be transmitted to sensory areas in the brain to generate conscious sensations.

The exercise performed on an unstable surface could induce a higher stimulation and recruitment of mechanoreceptors at the tendon, ligament, and articular level, which may increase the proprioceptive feedback to the central nervous system [42,43]. The dynamic balancing process (more emphasized in the specific exercise group) requires constant adjustments of joint positioning and therefore leads to an increase in the proprioceptive feedback and, ultimately, neuromuscular control. This could explain why the proprioceptive exercise session increased the joint position sense to a larger extend in comparison to the non-specific exercise session when considering only the responders.

This study has some limitations that should be mentioned. Concerning the evaluation instruments, they may be not transmitting all the changes induced by the exercise session, especially since YBT and BESS are functional tests that reflect a whole set of movements that require synergies between systems. It should also be noted that BESS and joint position sense have no visual input, unlike YBT; when the visual system is present, it prevails over the vestibular and proprioceptive system. The outcome evaluators were not blinded to the exercise session, an issue that should be taken into consideration in future studies. Some learning effects could not be excluded from our results. Nevertheless, when comparing the baseline data from the first and second sessions (irrespective of the exercise type that followed) we did not find significant differences. Finally, it should be noted that the experimental protocol was performed after one day of work (semi-professional athletes) without control of the physical and mental effort developed during the day.

Although the benefits of proprioceptive exercise and non-specific exercise in proprioception and postural balance are known, it is not yet known which one is the most efficient in an acute way to potentiate these variables during a rehabilitation session or training or competition, to reduce the risk of injury. We found that most studies tested the effects of a proprioceptive exercise program and very few studies the influence of a single session. Future studies can help answer the question of whether by associating the two types of exercise in the same session we could increase the benefits and whether the results would be different if performed in individuals recovering from a joint injury of the lower limb. This study enrolled only men, future studies may also document whether the responses to proprioceptive exercise are different between men and women.

5. Conclusions

In conclusion, a single session of either proprioceptive or non-specific exercise seems to improve the proprioception and balance of young athletes. The proprioceptive exercise seems to be more effective in improving joint position sense when considering only athletes who respond to the intervention.

Author Contributions: Conceptualization, P.H.-L. and F.R.; methodology, P.H.-L., J.T., M.S. and J.S.; data curation, P.H.-L. and F.R.; writing—original draft preparation, P.H.-L. and F.R.; writing—review and editing, P.H.-L., F.R., M.P. and J.A.F.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Jean Piaget Higher School of Health of Vila Nova de Gaia.

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

Data Availability Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments: We would like to thank the clubs and athletes for providing the facilities and taking the time to participate in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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