sports

*Article*

# Muscle Asymmetries in the Lower Limbs of Male Soccer Players: Preliminary Findings on the Association between Countermovement Jump and Tensiomyography

**Alex Buoite Stella [1,2,*], Annalisa Galimi [1], Miriam Martini [1], Luca Di Lenarda [3], Luigi Murena [1,3] and Manuela Deodato [1,4]**

[1] School of Physiotherapy, Department of Medicine, Surgery and Health Sciences, University of Trieste, Via Pascoli 31, 34100 Trieste, Italy
[2] Clinical, Integrative and Translational Physiology, Department of Medicine, Surgery and Health Sciences, University of Trieste, Strada di Fiume 447, 34149 Trieste, Italy
[3] Orthopaedics and Traumatology Unit, Cattinara Hospital-ASUGI, Department of Medicine, Surgery and Health Sciences, University of Trieste, Strada di Fiume 447, 34149 Trieste, Italy
[4] Ph.D. Program in Neural and Cognitive Sciences, Department of Life Sciences, University of Trieste, Via Weiss 2, 34100 Trieste, Italy
* Correspondence: abuoitestella@units.it

**Abstract:** Strength and power asymmetries have been observed in different sports, including soccer. Such asymmetries, as well as the bilateral deficit (BLD), can be assessed during different tasks, static or dynamic, and with different methods and devices, in order to detect the possible different aspects, as well as the association with physical performance and injuries. The aim of this study was to investigate the association between muscle asymmetries and BLD during a countermovement jump (CMJ), and tensiomyography (TMG) parameters and asymmetries, in the lower limbs of male soccer players. A total of 23 male soccer players (18 ± 4 years) were recruited. Bilateral and unilateral CMJs were performed, and peak power (W) and height (cm) were obtained. TMG was performed on different muscles of the lower limbs, and lateral and functional symmetries were obtained. Playing position and history of injuries were collected. CMJ inter-limb symmetry was found to significantly correlate with biceps femoris ($r = 0.574$, $p = 0.004$) and soleus ($r = 0.437$, $p = 0.037$) lateral symmetry. Players in central roles presented significantly worse functional symmetry scores of the knee than defense players (−17.5%, 95% CI −31.2–−3.9; $p = 0.10$). Participants reporting a history of injury at the ankle were characterized by significantly lower functional symmetry in both the dominant (43%, 39.5–48.0 vs. 74.5%, 46.5–89.3, $p = 0.019$) and non-dominant (45%, 42.5–46.0 vs. 81.0%, 45.8–90.3, $p = 0.024$) ankle. Findings from this preliminary study suggest an association between lower-limb muscle asymmetries during a dynamic task, such as jumping, and muscle contractile properties evaluated with TMG; moreover, functional asymmetries may be present after ankle injuries. Future studies in larger samples should evaluate the presence of such asymmetries as predictors or characteristics of different muscular and joint injuries.

**Keywords:** symmetry; power; soccer; football; skeletal muscles; injury

check for updates

**Citation:** Buoite Stella, A.; Galimi, A.; Martini, M.; Di Lenarda, L.; Murena, L.; Deodato, M. Muscle Asymmetries in the Lower Limbs of Male Soccer Players: Preliminary Findings on the Association between Countermovement Jump and Tensiomyography. *Sports* **2022**, *10*, 177. https://doi.org/10.3390/sports10110177

Academic Editors: Scott Talpey, Emma Siesmaa and Dara Twomey

Received: 20 October 2022
Accepted: 11 November 2022
Published: 14 November 2022

## 1. Introduction

Sport performance involves motor tasks that can be performed with both limbs and a single limb at a time, showing differences in force and power output. Inter-limb (or lateral) and functional asymmetries in strength, power, balance, flexibility, and electromyographic muscle activity have been considered as possible factors associated with both performance and injury risk in sports [1]. Vertical jump performance, as the countermovement jump (CMJ), can provide useful information about the elastic and explosive capacity of the lower limbs [2]. The term bilateral deficit (BLD) refers to the greater expression of force or power obtained when the right and left limb unilateral performances are added together, compared with the force or power measured during the bilateral performance [3,4]. BLD has been reported in different motor tasks, such as isokinetic [5], isometric [6], and dynamic contraction types [7], and in specific sport-related motor tasks; in particular, vertical jumps have often been considered to evaluate inter-limb asymmetries and BLD in relation to different sports-specific performances [7–12]. The mechanisms that have been hypothesized to underlie the BLD include neural mechanisms such as interhemispheric inhibition [4], and mechanics, since during bilateral jumps the muscles shorten at a higher speed, resulting in a lower force output and less joint work per leg [13]. As such, due to the diversity of the contractile elements and mechanisms that seem to be involved, BLD should be considered a multifactorial phenomenon rather than dependent on a single factor [7].

Tensiomyography (TMG) is a well-validated technique developed to assess skeletal muscle contractile properties in humans non-invasively by obtaining a displacement–time curve through a sensor with a certain pre-tension on the muscle belly [14–17]. TMG assessment is independent of motivation or volitional effort, therefore representing an objective evaluation of muscle contractile properties [17]. Through the displacement–time parameters, TMG has been suggested to estimate predominant skeletal muscle fibers non-invasively [18], monitor muscle fatigue [19,20], suggest training and rehabilitation-induced adaptations [21–26], and to assess neuromuscular risk factors of ACL injury [27,28]. Previous studies have not found significant asymmetries in TMG-derived parameters in the lower limbs of non-previously injured male [26,29,30] and female soccer players [17], although TMG has been shown to be a valuable tool for assessing neuromuscular risk factors in ACL injuries [27]. As such, TMG assessments have been recommended to be performed with other measures of neuromuscular function [17].

Lateral symmetry could be assessed through jump performance and TMG, and each method could provide information about different aspects of muscle performance [30]. Since CMJ and TMG could represent different aspects of muscle contractile characteristics [31], considering both assessments could provide a better insight into muscle properties in different sports, such as soccer. Previous investigations have aimed to show associations between jump performance and TMG, but parameters have not shown significant associations with jump performance [30,31]. Nevertheless, despite the evaluation of muscle asymmetries having been proposed in different sports and with different techniques [32,33], there is not a consensus regarding the associations between BLD and jump asymmetries [34], and TMG asymmetries.

Given the above-mentioned neuromuscular characteristics of the inter-limb asymmetry and BLD, the primary aim of this study was to assess the potential associations between bilateral and unilateral jumping performance and TMG parameters. Secondly, such parameters were compared across different playing positions. Lastly, inter-limb asymmetry, BLD, and TMG asymmetries were tested as risk factors associated with players' reported injury history.

## 2. Materials and Methods

A cross-sectional observational study was performed to assess neuromuscular responses in male soccer players. Participants were recruited among local sub-elite male soccer teams during the preseason period. Inclusion criteria were age between 16 and 40 y, a soccer training history of not less than 5 y, and a training frequency of not less than 3 times per week. Exclusion criteria included the presence of current lower-limb injuries, and frequent (more than one time per week) training in sports other than soccer. All participants were recruited and tested before the start of the 2022–2023 season of competitions. One week before data collection players were informed about the measurement procedures and detailed study protocol, and they were asked to sign the informed consent. In the case of minors, the approval of the parents or legal representative was requested. Participants were advised not to have a strenuous workout for at least 48 h before the assessment. All players were physically healthy, without acute pain, and free from serious lower-limb injury for at least one year. This study was approved by the Ethical Committee of the University of Trieste.

### 2.1. Anamnestic Questionnaire and Anthropometrics

All the participants were asked to complete a questionnaire to report demographic characteristics (body mass, body height, and ethnicity), training history and characteristics (frequency, times/week; training duration, min; and training volume, min/week), playing position (goalkeeper, defense, center, or forward), and whether they normally performed training sessions dedicated to strength and conditioning. Leg dominance was determined from the self-reported preferred kicking leg [35]. The reported history of previous injuries was revised by an expert physiotherapist with specific experience in sports injuries and rehabilitation. Muscle or joint injuries in the last 5 years were grouped into the following categories according to the involved muscles and joints: quadriceps, hamstring, knee, leg, and ankle.

### 2.2. Jump Performance, Inter-Limb Asymmetry, and BLD Assessment

After a 5-min warm-up, jumps were performed on an integrated force platform—video analysis system (D-Wall, Tecnobody, Dalmine – Bergamo, Italy), and parameters such as peak power and jump height were extracted by the software. The sampling rate of the force platform was 100 Hz, 150 g resolution, while the 3D camera collected the video at 30 fps. The video analysis supported the standardization of the positioning of the subjects before and during the jump, while the force platform collected the jump parameters. Data were then reported for each jump showing peak values that could be double-checked by comparing the force platform data with the video analysis. Time was given to familiarize the participants with procedures and jump performances. Vertical countermovement jumps (CMJs) were performed bilaterally and unilaterally on both single legs in a randomized order, with the hands on the hips. All jumps were performed three times and the higher value was considered for the final analysis, according to previous literature [7,30]. Between each jump, a 1-min rest was allowed to minimize the effect of fatigue on performance [12]. Inter-limb asymmetry was calculated as the difference between the two lower limbs' unilateral jumps, over the limb with the higher values in the unilateral jump. BLD was obtained by the following formula for both power and jump height [36]:

$$\mathrm{BLD}(\%) = \left[100 \times \frac{\mathrm{bilateral}}{(\mathrm{rightunilateral} + \mathrm{leftunilateral})}\right] - 100$$

### 2.3. Tensiomyography

TMG measurements were performed during electrically evoked maximal isometric contractions on selected skeletal muscles of the lower limbs, bilaterally, according to previously described procedures [17]. Assessed muscles were: adductor longus (m.AL), biceps femoris (m.BF), gastrocnemius lateralis (m.GL), gastrocnemius medialis (m.GM), gluteus major (m.GT), rectus femoris (m.RF), soleus (m.SO), tibialis anterior (m.TA), vastus lateralis (m.VL), and vastus medialis (m.VM). A single, 1 ms maximal monophasic electrical impulse was used to elicit a twitch contraction that caused the muscle belly to oscillate. These oscillations were recorded using a sensitive digital displacement sensor (TMG-BMC Ltd., Ljubljana, Slovenia) placed on the skin's surface at the measuring site of the muscle of interest. Initially, the stimulation amplitude was set just above the threshold and then gradually increased until the amplitude of the radial twitch Dm (in millimeters) increased no further. Electrical pulses ranged between 85 and 110 mA at constant 30 V. An inter-stimulation time interval of 10–15 s was used. From two maximal responses, all contractile parameters were estimated and average values were taken for further consideration. The TMG parameters were: Dm [the maximal displacement (mm)], Td [delay time; the time from electrical pulse to 10% of Dm (ms)], Tc [contraction time; the time between 10%

and 90% of Dm (ms)], Ts [sustain time; the time when the response was above 50% of Dm (ms)], and Tr [half-relaxation time; the time from 90% to 50% of Dm during muscle relaxation (ms)], and were extracted by TMG software (Version 3.6.16) and used for offline analysis [18,33]. Dm is the absolute spatial transverse deformation of the muscle and reduced Dm is interpreted as an increase in muscle stiffness, whereas larger Dm implies lower muscle stiffness; Td provides a measure of muscle responsiveness; Tc reflects the speed of twitch force generation, and may reflect muscle fiber type or tendon stiffness; Ts provides a theoretical assessment of muscle fiber fatigue status; and Tr is considered the least reliable parameter across studies and should be further investigated [37].

In addition, the TMG software applied an algorithm to calculate the lateral (i.e., interlimb symmetry for a specific muscle) and functional symmetries (i.e., symmetry between the muscles that surround a joint) [15,17].

Lateral symmetry (LS) was defined as follows:

$$\mathrm{LS}(\%) = 0.1 \times \left(\frac{MIN\ (TdR;TdL)}{MAX\ (TdR;TdL)}\right) + 0.6 \times \left(\frac{MIN\ (TcR;TcL)}{MAX\ (TcR;TcL)}\right) + 0.1 \times \left(\frac{MIN\ (TsR;TsL)}{MAX\ (TsR;TsL)}\right) + 0.2 \times \left(\frac{MIN\ (DmR;DmL)}{MAX\ (DmR;DmL)}\right) \times 100$$

where, *MIN*—the minimum, *MAX*—the maximum, *R*—right leg parameters and *L*—left leg parameters.

For functional symmetry (FS), different algorithms are used according to the investigated site (Achilles tendon: GL/GM; ligament patellae: $VM/VL$; knee: $RF$, $VL\&VM/BF$; ankle: $TA$/GL&GM; leg: $VL\&VM$/GL&GM); for the knee:

$$\begin{aligned}\mathrm{FS}(\%) = {} & 0.1 \times \left(\frac{MIN\ (AVERAGE(TdRF;TdVL;TdVM);TdBF)}{MAX\ (AVERAGE(TdRF;TdVL;TdVM);TdBF)}\right) + 0.8 \times \left(\frac{MIN\ (AVERAGE(TcRF;TcVL;TcVM);TcBF)}{MAX\ (AVERAGE(TcRF;TcVL;TcVM);TcBF)}\right) + 0.1 \\ & \times \left(\frac{MIN\ (AVERAGE(TrRF;TrVL;TrVM);TrBF)}{MAX\ (AVERAGE(TrRF;TrVL;TrVM);TrBF)}\right) \times 100\end{aligned}$$

where, *MIN*—the minimum, *MAX*—the maximum, *RF*—rectus femoris, *VM*—vastus medialis, *VL*—vastus lateralis, and *BF*—biceps femoris.

As such, LS and FS were also analyzed in this study, considering an 80% and 65% cut-off value, respectively [17].

### *2.4. Statistical Analyses*

All statistical analyses were performed with SPSS v.23 (IBM Inc., Armonk, NY, USA). The Shapiro–Wilk test for normality of distribution was performed. Data are reported as mean ± standard deviation (sd) or counts and proportions (%), as appropriate. Within-subject variation (CV) was performed as a measure of reliability of the bilateral and unilateral jump performance, and TMG parameters [38–40]. For CMJ, CV ranged from 2.5% for bilateral height to 3.4% for non-dominant limb power. For TMG parameters, CV ranged from 2.1% for m.RF Tc in the dominant limb to 8.7% for m.AL Tr in the dominant limb. Correlations between CMJ and TMG parameters were performed and Pearson's coefficient was reported. To test differences between playing roles, a one-way analysis of variance (ANOVA) with Bonferroni test corrections was used to identify differences in CMJ performance, symmetry, and TMG lateral symmetries; furthermore, a mixed-factors ANOVA with limb (dominant vs. non-dominant) as a within-subject factor, and playing position (defense vs. center vs. forward) as a between-subject factor, was used. Since only one goalkeeper was included in the study, they were not included in such analyses. When significant effects were found for limb or playing position (two-way interactions were excluded from the analysis), post hoc pairwise comparisons were performed for each variable independently. Partial Eta squared (pη2) effect size was reported for identified main and interaction effects. The criteria for effect size were small (pη2 = 0.01), medium (pη2 = 0.06), and large (pη2 = 0.14) [41]. Lastly, due to the limited frequency of reported injuries, a Mann–Whitney U-test was used to test differences in CMJ and TMG parameters between those reporting previous injuries in the lower limbs. Significance was set at $p < 0.05$.

## 3. Results

From twenty-five male soccer players who volunteered for the study, two participants were excluded due to the presence of ongoing injuries and were not able to participate in the assessments; as such, 23 participants (18 ± 4 years, range 16–27 years) were included in the final analysis. Demographics and sport-related characteristics of the participants are reported in Table 1. The most prevalent reported injuries were in the right hamstrings (*n* = 4, 17.4%) and in both ankles (*n* = 5, 21.7%). TMG analysis showed that low lateral symmetry scores were mainly present in m.AL (*n* = 16, 69.6%), m.BF (*n* = 6, 26.1%), and m.TA (*n* = 9, 39.1%), while low functional symmetry scores were mainly present in the knees (right *n* = 8, 34.8%; left = 6, 26.1%) and ankles (right *n* = 12, 52.2%; left = 9, 39.1%).

**Table 1.** Demographics, training characteristics, health and injuries of the included participants. Medians (25th–75th percentile) and proportions, as appropriate.

| | **Participants (*n* = 23)** |
|---|---|
| **Demographics** | |
| Age, y | 18 ± 4 |
| Body mass, kg | 70.3 ± 5.4 |
| Body height, m | 1.80 ± 4.9 |
| BMI, kg/m$^2$ | 21.69 ± 1.44 |
| **Training history and characteristics** | |
| Years of training in soccer, years | 13 ± 5 |
| Training frequency, training/week | 3 ± 0.3 |
| Training volume, min/week | 318 ± 57 |
| Strength & Conditioning, *n* (%) | 20 (87.0) |
| Playing position, *n* (%) | |
| Goalkeeper | 1 (4.3) |
| Defense | 7 (30.4) |
| Center | 8 (34.8) |
| Forward | 7 (30.4) |
| **Health and injuries** | |
| Quadriceps, *n* (%) | |
| Right | 1 (4.3) |
| Left | 1 (4.3) |
| Hamstrings, *n* (%) | |
| Right | 4 (17.4) |
| Left | 1 (4.3) |
| Knee, *n* (%) | |
| Right | 1 (4.3) |
| Left | 2 (8.7) |
| Leg, *n* (%) | |
| Right | 1 (4.3) |
| Left | 2 (8.7) |
| Ankle, *n* (%) | |
| Right | 5 (21.7) |
| Left | 5 (21.7) |

Notes: BMI: body mass index.

### 3.1. CMJ Asymmetry, Bilateral Deficit, and TMG

Bilateral CMJ performance parameters (peak power and height) were found to significantly correlate with BLD (r = 0.682, $p$ < 0.001), CMJ inter-limb symmetry (r = 0.488, $p$ = 0.018), and m.GL (r = 0.486, $p$ = 0.019) and m.VL (r = 0.418, $p$ = 0.047) lateral symmetries. During CMJ, BLD was found to significantly correlate with CMJ inter-limb symmetry (r = 0.665, $p$ < 0.001) (Figure 1), but none of the TMG asymmetries. Finally, CMJ inter-limb symmetry was found to significantly correlate with m.BF (r = 0.574, $p$ = 0.004) and m.SO (r = 0.437, $p$ = 0.037) lateral symmetries (Figure 2). Unilateral CMJ performance of the dominant limb showed significant correlations with m.AL Tc (r = −0.428, $p$ = 0.042), m.GL Tc (r = −0.556, $p$ = 0.006), and m.RF Tc (r = −0.532, $p$ = 0.009), whereas on the non-dominant limb significant correlations were found between CMJ performance and m.GL Tc (r = −0.432, $p$ = 0.039) and knee functional symmetries (r = 0.445, $p$ = 0.033). CMJ and TMG outcomes are reported in Table 2.

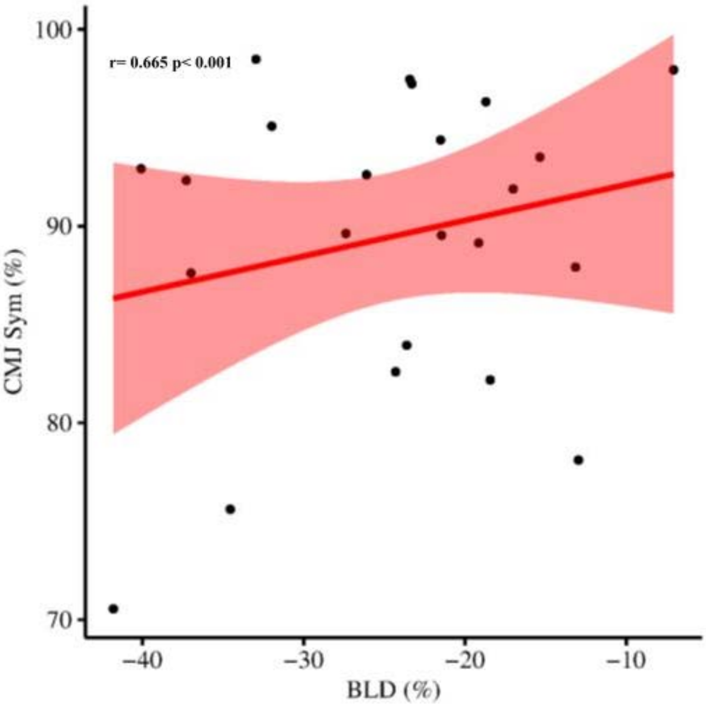

**Figure 1.** Correlation analysis between bilateral deficit (BLD, %) and countermovement jump (CMJ) inter-limb symmetry (CMJ Sym, %) in twenty-three male soccer players. Dots representing the individual data, fit line in red. Pearson's coefficient r = 0.665, $p < 0.001$.

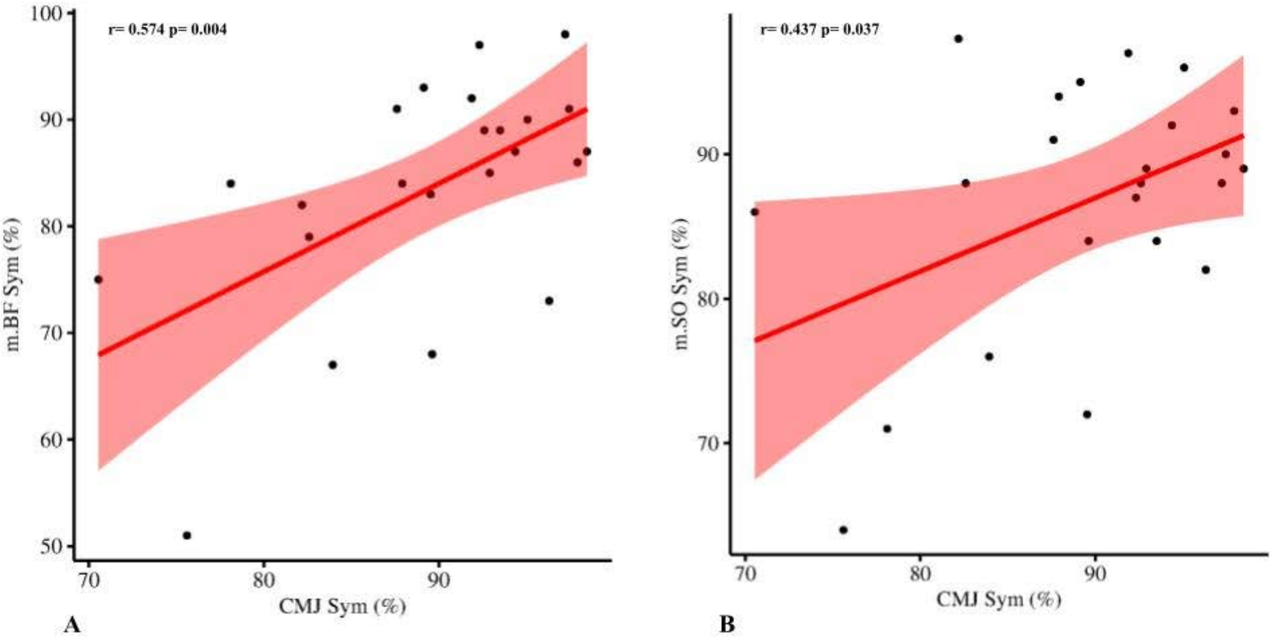

**Figure 2.** Correlation analysis between countermovement jump (CMJ) inter-limb symmetry (CMJ Sym, %) and (**A**) biceps femoris lateral symmetry (m.BF, %) Pearson's coefficient r = 0.574, $p$ = 0.004, and (**B**) biceps femoris lateral symmetry (m.BF, %) Pearson's coefficient r = 0.437, $p < 0.037$ in twenty-three male soccer players. Dots representing the individual data, fit line in red.

**Table 2.** CMJ performance and TMG parameters.

| | **Participants** (***n* = 23)** |
|---|---|
| **CMJ** | |
| Peak Power, W | |
| Bilateral | 3870.7 ± 661.3 |
| DL | 2576.1 ± 485.4 |
| N-DL | 2602.3 ± 487.2 |
| Inter-limb symmetry, % | 89.4 ± 7.5 |
| BLD, % | 24.7 ± 9.4 |
| Peak Height, cm | |
| Bilateral | 45.4 ± 8.2 |
| DL | 34.0 ± 4.8 |
| N-DL | 35.1 ± 5.6 |
| Inter-limb symmetry, % | 91.9 ± 8.2 |
| BLD, % | 34.0 ± 10.6 |
| **TMG** | |
| Lateral symmetry | |
| m.AL, % | 67.3 ± 18.9 |
| m.BF, % | 83.5 ± 10.8 |
| m.GL, % | 87.4 ± 9.6 |
| m.GM, % | 89.0 ± 5.9 |
| m.GT, % | 85.6 ± 11.2 |
| m.RF, % | 87.0 ± 6.7 |
| m.SO, % | 86.7 ± 8.8 |
| m.TA, % | 77.1 ± 19.4 |
| m.VL, % | 88.7 ± 6.4 |
| m.VM, % | 88.3 ± 6.6 |
| Functional symmetry | |
| Achilles tendon, % | |
| DL | 87.4 ± 1.0 |
| N-DL | 85.1 ± 9.0 |
| Ligament patellae, % | |
| DL | 84.3 ± 6.7 |
| N-DL | 84.2 ± 8.5 |
| Knee, % | |
| DL | 74.7 ± 15.7 |
| N-DL | 77.9 ± 13.6 |
| Ankle, % | |
| DL | 63.3 ± 20.9 |
| N-DL | 66.5 ± 21.3 |
| Leg, % | |
| DL | 86.7 ± 7.1 |
| N-DL | 87.1 ± 7.5 |

Notes: countermovement jump (CMJ); dominant limb (DL); non-dominant limb (N-DL); bilateral deficit (BLD); tensiomyography (TMG); bilateral deficit (BLD). Muscles: adductor longus (m.AL), biceps femoris (m.BF), gastrocnemius lateralis (m.GL), gastrocnemius medialis (m.GM), gluteus major (m.GT), rectus femoris (m.RF), soleus (m.SO) tibialis anterior (m.TA), vastus lateralis (m.VL), vastus medialis (m.VM).

### *3.2. Playing Position*

None of the jump performance and symmetry parameters or TMG lateral symmetries were found to be significantly different between playing roles. Regarding TMG functional asymmetries, no side or side x position effects were found, whereas a significant playing position effect was found in the knee ($F_{2,19} = 5.683$, $p = 0.012$, $p\eta 2 = 0.374$), with players in central roles presenting significantly worse symmetry scores than defense players (−17.5%, 95% CI −31.2–−3.9; $p = 0.10$), especially in the non-dominant limb (Figure 3). CMJ and TMG outcomes are reported in Table 3.

**Table 3.** CMJ performance and TMG parameters according to playing position.

| | **Defense** (*n* = 7) | **Central** (*n* = 8) | **Forward** (*n* = 7) |
|---|---|---|---|
| **CMJ** | | | |
| Peak Power, W | | | |
| Bilateral | 3902.3 ± 436.6 | 3631.5 ± 800.4 | 4043.0 ± 717.1 |
| DL | 2786.9 ± 556.1 | 2276.5 ± 431.8 | 2719.9 ± 374.5 |
| N-DL | 3033.1 ± 399.5 | 2377.4 ± 466.8 | 2421.3 ± 365.7 |
| Inter-limb symmetry, % | 87.5 ± 9.9 | 90.8 ± 5.5 | 89.2 ± 8.1 |
| BLD, % | 32.0 ± 9.8 | 22.4 ± 7.1 | 21.5 ± 8.4 |
| Peak Height, cm | | | |
| Bilateral | 44.9 ± 8.4 | 42.5 ± 7.3 | 50.3 ± 8.1 |
| DL | 36.6 ± 5.5 | 31.3 ± 4.6 | 35.1 ± 2.8 |
| N-DL | 38.6 ± 6.5 | 33.0 ± 4.5 | 35.0 ± 5.0 |
| Inter-limb symmetry, % | 89.5 ± 11.5 | 93.4 ± 7.8 | 92.3 ± 5.8 |
| BLD, % | 39.5 ± 13.4 | 33.8 ± 7.3 | 28.3 ± 9.4 |
| **TMG** | | | |
| Lateral symmetry | | | |
| m.AL, % | 64.3 ± 18.9 | 72.9 ± 14.6 | 62.7 ± 20.8 |
| m.BF, % | 82.9 ± 8.4 | 84.6 ± 11.1 | 82.1 ± 14.3 |
| m.GL, % | 89.1 ± 5.7 | 84.7 ± 15.4 | 88.6 ± 3.3 |
| m.GM, % | 86.1 ± 7.3 | 90.6 ± 5.4 | 90.0 ± 4.9 |
| m.GT, % | 90.2 ± 4.8 | 86.5 ± 7.8 | 80.3 ± 17.8 |
| m.RF, % | 86.1 ± 6.6 | 84.3 ± 7.1 | 90.7 ± 5.8 |
| m.SO, % | 86.6 ± 7.8 | 88.0 ± 6.7 | 85.7 ± 12.7 |
| m.TA, % | 72.1 ± 24.7 | 77.9 ± 20.0 | 81.3 ± 15.4 |
| m.VL, % | 89.1 ± 6.5 | 86.9 ± 4.5 | 92.3 ± 6.0 |
| m.VM, % | 90.6 ± 6.3 | 86.6 ± 6.1 | 86.6 ± 7.2 |
| Functional symmetry | | | |
| Achilles tendon, % | | | |
| DL | 86.6 ± 5.0 | 84.4 ± 15.0 | 91.1 ± 6.8 |
| N-DL | 78.5 ± 8.6 | 89.5 ± 9.5 | 86.4 ± 6.0 |
| Ligament patellae, % | | | |
| DL | 84.1 ± 6.5 | 84.4 ± 6.7 | 85.6 ± 7.5 |
| N-DL | 86.7 ± 5.1 | 83.1 ± 12.9 | 81.9 ± 4.7 |
| Knee, % | | | |
| DL | 86.7 ± 5.1 | 70.9 ± 16.0 | 70.4 ± 16.0 |
| N-DL | 86.7 ± 6.7 | 67.8 ± 16.4 | 82.7 ± 5.5 |
| Ankle, % | | | |
| DL | 59.0 ± 23.7 | 70.9 ± 21.3 | 55.0 ± 14.3 |
| N-DL | 73.4 ± 21.6 | 69.9 ± 22.8 | 53.7 ± 17.2 |
| Leg, % | | | |
| DL | 85.4 ± 8.0 | 86.8 ± 9.6 | 87.3 ± 3.0 |
| N-DL | 83.3 ± 11.6 | 89.1 ± 5.6 | 88.1 ± 2.8 |

Notes: countermovement jump (CMJ); dominant limb (DL); non-dominant limb (N-DL); bilateral deficit (BLD); tensiomyography (TMG); bilateral deficit (BLD). Muscles: adductor longus (m.AL), biceps femoris (m.BF), gastrocnemius lateralis (m.GL), gastrocnemius medialis (m.GM), gluteus major (m.GT), rectus femoris (m.RF), soleus (m.SO) tibialis anterior (m.TA), vastus lateralis (m.VL), vastus medialis (m.VM).

### *3.3. History of Injuries*

Due to the limited prevalence of injuries among the included participants, TMG lateral and functional asymmetries were compared between those who reported a previous history of injuries at the ankles, finding significantly lower functional symmetry values in both the dominant (43%, 39.5–48.0 vs. 74.5%, 46.5–89.3, $p = 0.019$) and non-dominant (45%, 42.5–46.0 vs. 81.0%, 45.8–90.3, $p = 0.024$) limb (Figure 4). When a 65% cut-off value was used for ankle functional asymmetry, associations with previous ankle injuries were also found ($p = 0.037$ and $p = 0.056$, respectively).

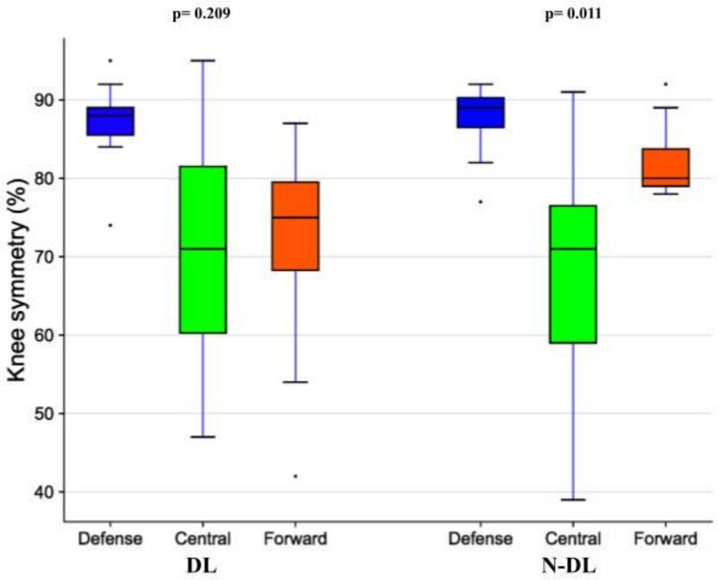

**Figure 3.** Boxplots representing the difference in the knee functional symmetry (%) of the dominant (DL) and non-dominant limb (N-DL) in 7 defense players, 8 central players, and 7 forward players. One-way analysis of variance (ANOVA).

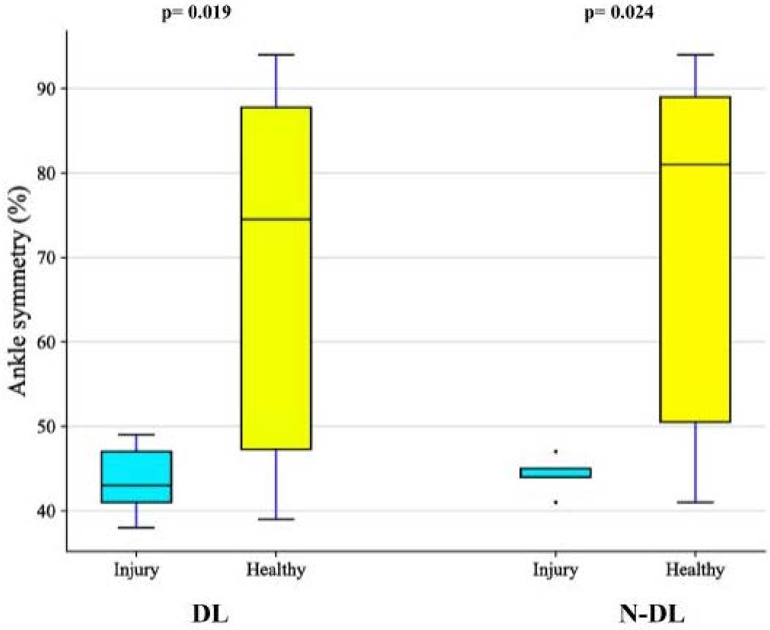

**Figure 4.** Boxplots representing the difference in the ankle functional symmetry (%) of the dominant (DL) and non-dominant limb (N-DL) in 5 players with a reported history of ankle injuries and 18 healthy players. Mann–Whitney U test.

## 4. Discussion

Prior studies have observed the presence of muscle asymmetries as possible factors associated with both performance and injury risk in sports. Our study has investigated the association between muscle asymmetries and bilateral deficit (BLD) during a countermovement jump (CMJ), and tensiomyography (TMG) parameters and asymmetries, in the lower limbs of male soccer players. The main findings from this study suggest that TMG evaluation of lower-limb muscle asymmetries may find some associations with CMJ power and height asymmetries, providing preliminary evidence of a muscular contractile component on a dynamic task such as a vertical jump.

Assessment of vertical jump performance is common in soccer, as it is an expression of lower-limb explosive strength and it is associated with competitive success [2]. In addition, it can provide an opportunity to assess and monitor mechanical inter-limb differences (i.e., asymmetries) [9], as well as bilateral deficits [12]. Vertical jump assessments, including CMJ, provide a physiological and biomechanical evaluation of a dynamic task, which can be influenced by several factors (including elastic properties, multi-joint movement, inter-and intramuscular coordination, and neuromuscular activation, etc.) [42]. TMG, in contrast, evaluates the contractile properties of skeletal muscles in a controlled condition, and only some muscles (those more superficial) can be assessed [43]. Despite such differences, results from this study provide preliminary evidence of potential associations between CMJ performance and TMG parameters, in particular as measures of lower-limb muscle asymmetry. CMJ inter-limb asymmetry was found to be correlated with lateral asymmetry of biceps femoris and soleus; such muscles could be implicated in vertical jump performance. In particular, these muscles may influence jump performance as a) early activation of the biceps femoris has been found to negatively influence the joint power transfer [44], reducing the effect of the stretch-shortening cycle, which is a key factor for performance in vertical jumps [45], and b) the soleus contributes to the center of mass (COM) acceleration during CMJ [46]. CMJ performance, in terms of bilateral or unilateral power and height, showed some association with gastrocnemius lateralis and vastus lateralis inter-limb asymmetry, and with adductor longus, gastrocnemius lateralis, and rectus femoris time to contraction (Tc). Since gastrocnemii and vasti muscles can influence COM acceleration, as previously discussed [46], it may therefore be speculated that asymmetries in such muscles may lead to unbalanced power production, and lower Tc values indicate an overall reduced explosive capacity of the muscle and lower expression of fast-contraction muscle fibers [47]. If rectus femoris and gastrocnemius lateralis contribution to vertical jump is expectable, adductor longus has a minimal contribution to force production in the sagittal plane, in which the countermovement jumps are performed [45]. However, this correlation is significant only during the unilateral CMJ, which in turn requires greater stabilization in which the adductor longus may participate, therefore suggesting a possible role for balance maintenance. The bilateral deficit was found to correlate only with CMJ inter-limb asymmetry, whereas none of the TMG showed any association. BLD has been suggested to be influenced by several factors, including population [36], task [48], joint angle [34], and contraction velocity [49], and it is an expression of altered muscle coordination [50]. Based on these assumptions, the absence of correlations between BLD and TMG might depend on the different characteristics of lower-limb muscle activation, i.e., a dynamic task during CMJ in contrast to a single muscle contraction during TMG.

Inconsistent results were present when the location of injuries and injuries rate were compared between playing positions; excluding goalkeepers, who usually present a lower risk of injuries, it seemed that no differences were present between forward, central, and defense players [51]. According to the present study, CMJ variables did not show significant differences between playing positions; previous research has suggested conflicting results, with some studies reporting forwards being faster and more explosive. Due to the limited sample size from this study, it is not possible to confirm the hypothesis that no differences are present in CMJ parameters in semi-professional young soccer players, although our findings are in line with some previous literature [52]. TMG was found to detect differences in muscle contractile properties between playing positions [32]. In the present results, players in the central roles were characterized by higher knee functional asymmetry compared with defense players. Despite the fact that such findings should be carefully considered due to the small sample size of the study, some hypotheses could be proposed considering previous findings suggesting different load and muscular responses between defense players and those playing in central or forward roles [53–55]), with midfielders sustaining the highest unavailability rates from a match and training injuries [56].

The identification of simple and easily accessible methods to detect risk factors for sport-related injuries can be of particular importance in promoting the implementation of strategies for the successful integration of evidence-based injury prevention programs into real-world soccer settings [57,58]. Muscle injuries can be among the major health issues faced by soccer players and are reported to represent up to 37% of all time-loss injuries at men's professional level and up to 23% at men's amateur level. Most injuries affect the lower extremities: the hamstring, adductor, quadriceps, and calf muscles are the most common injury locations. Almost all muscle injuries (>90%) occur in noncontact situations [59,60]; as such, the implementation of muscle-prevention exercises could help to reduce such injuries. For example, eccentric exercises (such as the "Nordic hamstring exercise") [61], the FIFA 11+ protocol, balance training, and core stability exercises are all effective preventive interventions for hamstring strain injuries in soccer players [62].

There have been various studies in the literature that have tried to analyze the risk factors for muscle injuries. A history of groin injuries was found to led to a four-fold increase in future injuries in the same muscle [39]. The same evidence was found for calf strains [63] and for the four most commonly injured muscles in the lower extremity. In addition to this, previous injuries to other muscle groups were found to be a risk factor for other injuries in the lower extremities [60]. Age was also found to be a risk factor for muscle strain [60] because structural tissue changes are linked with progressive loss of important neuromuscular attributes such as power outputs or rate-of-force development and disruptions to motor unit discharge rates [63]. In addition, playing on natural grass [60], poor flexibility, lower levels of isometric adductor strength, and higher between-limb strength asymmetry [39] were determining factors for muscle injuries in the lower extremities. As such, the present results, combined with evidence from the previous literature, suggest that screening for muscle strength and asymmetry with easily accessible methods, such as vertical jump performance and TMG, could be of particular importance for the prevention of muscle injuries in men's soccer. Based on these results and outcomes, specific muscle-strengthening exercises could be adopted in order to reduce lower extremities injuries.

Taken together, the findings from the present study, although preliminary and on a small sample, encourage the use of different evaluation techniques to detect muscle asymmetries in sports. Unfortunately, present results cannot confirm an association between BLD or jump performance asymmetries and previous injuries, whereas function asymmetry evaluated with TMG proposes some preliminary associations; nevertheless, longitudinal studies could better describe the role of muscle asymmetries as risk factors for future injuries, and the advantage of monitoring such asymmetries with jumping-based performance assessment that can be easily and quickly performed and interpreted, could be implemented in the field.

### *Limitations and Future Perspectives*

This study included a sample of twenty-three young male soccer players, and, due to the interindividual differences, results should be cautiously interpreted and further studies on larger samples (with more athletes representative of the different playing positions) should be encouraged to confirm the observed associations. In addition, the integrated system to analyze CMJ outcomes only reported a limited set of outcomes and additional information might be useful, including eccentric and concentric forces. Only a few participants reported a previous history of lower-limb injuries, and TMG differences should be considered in light of such limitations. In addition, injuries were self-reported and more clinical information might help to describe the association between the injury and TMG asymmetries better. However, the presence of preliminary associations between ankle injuries and functional asymmetries involving the muscles acting on that specific joint encourage the use of TMG as a non-invasive tool that may help to detect agonist–antagonist unbalances, and therefore provide trainers and physiotherapists with some suggestions about the muscle groups that may benefit from dedicated strengthening or stretching protocols. Future studies should evaluate the presence of TMG-detected muscle asymmetries as predictors of ex novo or recurrence of injuries.

## 5. Conclusions

Results from the present study provide preliminary evidence of the association between countermovement jump and tensiomyography parameters, and, in particular, those outcomes evaluating inter-limb asymmetries. Inter-limb asymmetries of the lower limbs could be potential risk factors for sports-related injuries and should be monitored and properly evaluated to propose and implement prevention and training strategies. The combination of vertical jump and tensiomyography assessment could provide further useful information by describing different components (i.e., dynamic and "controlled" muscle contraction properties), which might participate in sport-specific tasks.

**Author Contributions:** Conceptualization, A.B.S., A.G. and M.D.; methodology, A.B.S., M.M. and M.D.; software, A.B.S.; validation, A.B.S., L.M. and M.D.; formal analysis, A.B.S. and M.M.; investigation, A.B.S. and A.G.; resources, L.M. and M.D.; data curation, A.B.S., M.M. and L.D.L.; writing—original draft preparation, A.B.S., A.G., M.M. and L.D.L.; writing—review and editing, A.B.S., L.M. and M.D.; visualization, A.B.S. and M.M.; supervision, L.M. 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 Ethics Committee of the University of Trieste (protocol code 122/2022, 23.05.2022).

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

**Data Availability Statement:** Anonymized data are available upon reasonable request to the corresponding author according to the standard institutional procedure.

**Acknowledgments:** The authors want to thank all the participants and those who helped during data acquisition. The authors want also to thank the PT V. Guido for his support during data acquisition.

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

## References

1. Bishop, C.; Turner, A.; Read, P. Effects of Inter-Limb Asymmetries on Physical and Sports Performance: A Systematic Review. *J. Sports Sci.* **2018**, *36*, 1135–1144. [CrossRef] [PubMed]
2. Castagna, C.; Castellini, E. Vertical Jump Performance in Italian Male and Female National Team Soccer Players. *J. Strength Cond. Res.* **2013**, *27*, 1156–1161. [CrossRef]
3. Jakobi, J.M.; Chilibeck, P.D. Bilateral and Unilateral Contractions: Possible Differences in Maximal Voluntary Force. *Can. J. Appl. Physiol.* **2001**, *26*, 12–33. [CrossRef] [PubMed]
4. Škarabot, J.; Cronin, N.; Strojnik, V.; Avela, J. Bilateral Deficit in Maximal Force Production. *Eur. J. Appl. Physiol.* **2016**, *116*, 2057–2084. [CrossRef]
5. Dickin, D.C.; Too, D. Effects of Movement Velocity and Maximal Concentric and Eccentric Actions on the Bilateral Deficit. *Res. Q. Exerc. Sport* **2006**, *77*, 296–303. [CrossRef] [PubMed]
6. Botton, C.E.; Radaelli, R.; Wilhelm, E.N.; Rech, A.; Brown, L.E.; Pinto, R.S. Neuromuscular Adaptations to Unilateral vs. Bilateral Strength Training in Women. *J. Strength Cond. Res.* **2016**, *30*, 1924–1932. [CrossRef]
7. Ascenzi, G.; Ruscello, B.; Filetti, C.; Bonanno, D.; Di Salvo, V.; Nuñez, F.J.; Mendez-Villanueva, A.; Suarez-Arrones, L. Bilateral Deficit and Bilateral Performance: Relationship with Sprinting and Change of Direction in Elite Youth Soccer Players. *Sports* **2020**, *8*, 82. [CrossRef]
8. Bishop, C.; Berney, J.; Lake, J.; Loturco, I.; Blagrove, R.; Turner, A.; Read, P. Bilateral Deficit during Jumping Tasks: Relationship with Speed and Change of Direction Speed Performance. *J. Strength Cond. Res.* **2021**, *35*, 1833–1840. [CrossRef]
9. Heishman, A.; Daub, B.; Miller, R.; Brown, B.; Freitas, E.; Bemben, M. Countermovement Jump Inter-Limb Asymmetries in Collegiate Basketball Players. *Sports* **2019**, *7*, 103. [CrossRef]
10. Pain, M.T.G. Considerations for Single and Double Leg Drop Jumps: Bilateral Deficit, Standardizing Drop Height, and Equalizing Training Load. *J. Appl. Biomech.* **2014**, *30*, 722–727. [CrossRef]
11. Pérez-Castilla, A.; García-Ramos, A.; Janicijevic, D.; Delgado-García, G.; de la Cruz, J.C.; Rojas, F.J.; Cepero, M. Between-Session Reliability of Performance and Asymmetry Variables Obtained during Unilateral and Bilateral Countermovement Jumps in Basketball Players. *PLoS ONE* **2021**, *16*, e0255458. [CrossRef] [PubMed]
12. Pleša, J.; Kozinc, Ž.; Šarabon, N. Bilateral Deficit in Countermovement Jump and Its Influence on Linear Sprinting, Jumping, and Change of Direction Ability in Volleyball Players. *Front. Physiol.* **2022**, *13*, 768906. [CrossRef]

13. Bobbert, M.F.; De Graaf, W.W.; Jonk, J.N.; Casius, L.J.R. Explanation of the Bilateral Deficit in Human Vertical Squat Jumping. *J. Appl. Physiol.* **2006**, *100*, 493–499. [CrossRef]
14. Burger, H.; Valenčič, V.; Marinček, Č.; Kogovšek, N. Properties of Musculus Gluteus Maximus in Above-Knee Amputees. *Clin. Biomech.* **1996**, *11*, 35–38. [CrossRef]
15. García-García, O.; Cuba-Dorado, A.; Álvarez-Yates, T.; Carballo-López, J.; Iglesias-Caamaño, M. Clinical Utility of Tensiomyography for Muscle Function Analysis in Athletes. *Open Access J. Sport. Med.* **2019**, *10*, 49–69. [CrossRef] [PubMed]
16. Valenčič, V.; Knez, N. Measuring of Skeletal Muscles' Dynamic Properties. *Artif. Organs* **1997**, *21*, 240–242. [CrossRef]
17. Paravlic, A.H.; Milanović, Z.; Abazović, E.; Vučković, G.; Spudić, D.; Majcen Rošker, Z.; Pajek, M.; Vodičar, J. The Muscle Contractile Properties in Female Soccer Players: Inter-Limb Comparison Using Tensiomyography. *J. Musculoskelet. Neuronal Interact.* **2022**, *22*, 179–192.
18. Simunič, B.; Degens, H.; Rittweger, J.; Narici, M.; Mekjavić, I.B.; Pišot, R. Noninvasive Estimation of Myosin Heavy Chain Composition in Human Skeletal Muscle. *Med. Sci. Sports Exerc.* **2011**, *43*, 1619–1625. [CrossRef] [PubMed]
19. García-Manso, J.M.; Rodríguez-Ruiz, D.; Rodríguez-Matoso, D.; de Yves, S.; Sarmiento, S.; Quiroga, M. Assessment of Muscle Fatigue after an Ultra-Endurance Triathlon Using Tensiomyography (TMG). *J. Sports Sci.* **2011**, *29*, 619–625. [CrossRef]
20. Hunter, A.M.; Galloway, S.D.R.; Smith, I.J.; Tallent, J.; Ditroilo, M.; Fairweather, M.M.; Howatson, G. Assessment of Eccentric Exercise-Induced Muscle Damage of the Elbow Flexors by Tensiomyography. *J. Electromyogr. Kinesiol.* **2012**, *22*, 334–341. [CrossRef]
21. Zubac, D.; Paravlić, A.; Koren, K.; Felicita, U.; Šimunič, B. Plyometric Exercise Improves Jumping Performance and Skeletal Muscle Contractile Properties in Seniors. *J. Musculoskelet. Neuronal Interact.* **2019**, *19*, 38–49. [PubMed]
22. Paravlic, A.H.; Pisot, R.; Simunic, B. Muscle-Specific Changes of Lower Extremities in the Early Period after Total Knee Arthroplasty: Insight from Tensiomyography. *J. Musculoskelet. Neuronal Interact.* **2020**, *20*, 390–397. [PubMed]
23. Zubac, D.; Šimunič, B. Skeletal Muscle Contraction Time and Tone Decrease after 8 Weeks of Plyometric Training. *J. Strength Cond. Res.* **2017**, *31*, 1610–1619. [CrossRef] [PubMed]
24. Seijas, R.; Marín, M.; Rivera, E.; Alentorn-Geli, E.; Barastegui, D.; Álvarez-Díaz, P.; Cugat, R. Gluteus Maximus Contraction Velocity Assessed by Tensiomyography Improves Following Arthroscopic Treatment of Femoroacetabular Impingement. *Knee Surg. Sport. Traumatol. Arthrosc.* **2018**, *26*, 976–982. [CrossRef] [PubMed]
25. Alvarez-Diaz, P.; Alentorn-Geli, E.; Ramon, S.; Marin, M.; Steinbacher, G.; Rius, M.; Seijas, R.; Ballester, J.; Cugat, R. Comparison of Tensiomyographic Neuromuscular Characteristics between Muscles of the Dominant and Non-Dominant Lower Extremity in Male Soccer Players. *Knee Surg. Sport. Traumatol. Arthrosc.* **2016**, *24*, 2259–2263. [CrossRef]
26. Alvarez-Diaz, P.; Alentorn-Geli, E.; Ramon, S.; Marin, M.; Steinbacher, G.; Boffa, J.J.; Cuscó, X.; Ares, O.; Ballester, J.; Cugat, R. Effects of Anterior Cruciate Ligament Injury on Neuromuscular Tensiomyographic Characteristics of the Lower Extremity in Competitive Male Soccer Players. *Knee Surg. Sport. Traumatol. Arthrosc.* **2016**, *24*, 2264–2270. [CrossRef]
27. Alentorn-Geli, E.; Alvarez-Diaz, P.; Ramon, S.; Marin, M.; Steinbacher, G.; Rius, M.; Seijas, R.; Ares, O.; Cugat, R. Assessment of Gastrocnemius Tensiomyographic Neuromuscular Characteristics as Risk Factors for Anterior Cruciate Ligament Injury in Male Soccer Players. *Knee Surg. Sport. Traumatol. Arthrosc.* **2015**, *23*, 2502–2507. [CrossRef]
28. Alentorn-Geli, E.; Alvarez-Diaz, P.; Ramon, S.; Marin, M.; Steinbacher, G.; Boffa, J.J.; Cuscó, X.; Ballester, J.; Cugat, R. Assessment of Neuromuscular Risk Factors for Anterior Cruciate Ligament Injury through Tensiomyography in Male Soccer Players. *Knee Surg. Sport. Traumatol. Arthrosc.* **2015**, *23*, 2508–2513. [CrossRef]
29. Loturco, I.; Pereira, L.A.; Kobal, R.; Abad, C.C.C.; Komatsu, W.; Cunha, R.; Arliani, G.; Ejnisman, B.; Pochini, A.D.C.; Nakamura, F.Y.; et al. Functional Screening Tests: Interrelationships and Ability to Predict Vertical Jump Performance. *Int. J. Sports Med.* **2018**, *39*, 189–197. [CrossRef]
30. Gil, S.; Loturco, I.; Tricoli, V.; Ugrinowitsch, C.; Kobal, R.; Cal Abad, C.C.; Roschel, H. Tensiomyography Parameters and Jumping and Sprinting Performance in Brazilian Elite Soccer Players. *Sport. Biomech.* **2015**, *14*, 340–350. [CrossRef]
31. Lewis, M.D.; Young, W.B.; Knapstein, L.; Lavender, A.; Talpey, S.W. Countermovement Jump Variables Not Tensiomyography Can Distinguish between Sprint and Endurance Focused Track Cyclists. *Biol. Sport* **2022**, *39*, 67–72. [CrossRef]
32. García-García, O.; Serrano-Gómez, V.; Hernández-Mendo, A.; Morales-Sánchez, V. Baseline Mechanical and Neuromuscular Profile of Knee Extensor and Flexor Muscles in Professional Soccer Players at the Start of the Pre-Season. *J. Hum. Kinet.* **2017**, *58*, 23–34. [CrossRef]
33. López-Fernández, J.; García-Unanue, J.; Sánchez-Sánchez, J.; Colino, E.; Hernando, E.; Gallardo, L. Bilateral Asymmetries Assessment in Elite and Sub-Elite Male Futsal Players. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3169. [CrossRef]
34. Kuruganti, U.; Murphy, T.; Pardy, T. Bilateral Deficit Phenomenon and the Role of Antagonist Muscle Activity during Maximal Isometric Knee Extensions in Young, Athletic Men. *Eur. J. Appl. Physiol.* **2011**, *111*, 1533–1539. [CrossRef]
35. Rouissi, M.; Chtara, M.; Owen, A.; Chaalali, A.; Chaouachi, A.; Gabbett, T.; Chamari, K. Effect of Leg Dominance on Change of Direction Ability amongst Young Elite Soccer Players. *J. Sports Sci.* **2016**, *34*, 542–548. [CrossRef]
36. Howard, J.D.; Enoka, R.M. Maximum Bilateral Contractions Are Modified by Neurally Mediated Interlimb Effects. *J. Appl. Physiol.* **1991**, *70*, 306–316. [CrossRef]
37. Macgregor, L.J.; Hunter, A.M.; Orizio, C.; Fairweather, M.M.; Ditroilo, M. Assessment of Skeletal Muscle Contractile Properties by Radial Displacement: The Case for Tensiomyography. *Sport. Med.* **2018**, *48*, 1607–1620. [CrossRef]
38. Hopkins, W.G. Measures of Reliability in Sports Medicine and Science. *Sport. Med.* **2000**, *30*, 375–378. [CrossRef]

39. Markovic, G.; Šarabon, N.; Pausic, J.; Hadžić, V. Adductor Muscles Strength and Strength Asymmetry as Risk Factors for Groin Injuries among Professional Soccer Players: A Prospective Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 4946. [CrossRef]
40. Lohr, C.; Braumann, K.M.; Reer, R.; Schroeder, J.; Schmidt, T. Reliability of Tensiomyography and Myotonometry in Detecting Mechanical and Contractile Characteristics of the Lumbar Erector Spinae in Healthy Volunteers. *Eur. J. Appl. Physiol.* **2018**, *118*, 1349–1359. [CrossRef]
41. Cohen, J. *Statistical Power Analysis for the Behavioural Sciences*, 2nd ed.; Lawrence Erlbaum Associates: Hillside, NJ, USA, 1988.
42. Nuzzo, J.L.; Mcbride, J.M.; Cormie, P.; Mccaulley, G.O. Relationship between Countermovement Jump Performance and Multijoint Isometric and Dynamic Tests of Strength. *J. Strength Cond. Res.* **2008**, *22*, 699–707. [CrossRef] [PubMed]
43. Wilson, M.T.; Ryan, A.M.F.; Vallance, S.R.; Dias-Dougan, A.; Dugdale, J.H.; Hunter, A.M.; Hamilton, D.L.; Macgregor, L.J. Tensiomyography Derived Parameters Reflect Skeletal Muscle Architectural Adaptations Following 6-Weeks of Lower Body Resistance Training. *Front. Physiol.* **2019**, *10*, 1493. [CrossRef] [PubMed]
44. Fukashiro, S.; Besier, T.F.; Barrett, R.; Cochrane, J.; Nagano, A.; Lloyd, D.G. Direction Control in Standing Horizontal and Vertical Jumps. *Int. J. Sport Health Sci.* **2005**, *3*, 272–279. [CrossRef]
45. Falch, H.N.; Rædergård, H.G.; Van Den Tillaar, R. Relationship of Performance Measures and Muscle Activity between a 180° Change of Direction Task and Different Countermovement Jumps. *Sports* **2020**, *8*, 47. [CrossRef]
46. Kipp, K.; Kim, H. Relative Contributions and Capacities of Lower Extremity Muscles to Accelerate the Body's Center of Mass during Countermovement Jumps. *Comput. Methods Biomech. Biomed. Engin.* **2020**, *23*, 914–921. [CrossRef]
47. Šimunič, B.; Koren, K.; Rittweger, J.; Lazzer, S.; Reggiani, C.; Rejc, E.; Pišot, R.; Narici, M.; Degens, H. Tensiomyography Detects Early Hallmarks of Bed-Rest-Induced Atrophy before Changes in Muscle Architecture. *J. Appl. Physiol.* **2019**, *126*, 815–822. [CrossRef]
48. Magnus, C.R.A.; Farthing, J.P. Greater Bilateral Deficit in Leg Press than in Handgrip Exercise Might Be Linked to Differences in Postural Stability Requirements. *Appl. Physiol. Nutr. Metab.* **2008**, *33*, 1132–1139. [CrossRef]
49. Vandervoort, A.A.; Sale, D.G.; Moroz, J. Comparison of Motor Unit Activation during Unilateral and Bilateral Leg Extension. *J. Appl. Physiol. Respir. Environ. Exerc. Physiol.* **1984**, *56*, 46–51. [CrossRef]
50. Rejc, E.; Lazzer, S.; Antonutto, G.; Isola, M.; Di Prampero, P.E. Bilateral Deficit and EMG Activity during Explosive Lower Limb Contractions against Different Overloads. *Eur. J. Appl. Physiol.* **2010**, *108*, 157. [CrossRef]
51. Della Villa, F.; Mandelbaum, B.R.; Lemak, L.J. The Effect of Playing Position on Injury Risk in Male Soccer Players: Systematic Review of the Literature and Risk Considerations for Each Playing Position. *Am. J. Orthop.* **2018**, *47*. [CrossRef]
52. Haugen, T.A.; Tønnessen, E.; Seiler, S. Anaerobic Performance Testing of Professional Soccer Players 1995–2010. *Int. J. Sports Physiol. Perform.* **2013**, *8*, 148–156. [CrossRef]
53. Bona, C.C.; Filho, H.T.; Izquierdo, M.; Ferraz, R.M.P.; Marques, M.C. Peak Torque and Muscle Balance in the Knees of Young U-15 and U-17 Soccer Athletes Playing Various Tactical Positions. *J. Sports Med. Phys. Fitness* **2017**, *57*, 923–929. [CrossRef]
54. Romero-Moraleda, B.; Nedergaard, N.J.; Morencos, E.; Casamichana, D.; Ramirez-Campillo, R.; Vanrenterghem, J. External and Internal Loads during the Competitive Season in Professional Female Soccer Players According to Their Playing Position: Differences between Training and Competition. *Res. Sport. Med.* **2021**, *29*, 449–461. [CrossRef] [PubMed]
55. Granero-Gil, P.; Gómez-Carmona, C.D.; Bastida-Castillo, A.; Rojas-Valverde, D.; De La Cruz, E.; Pino-Ortega, J. Influence of Playing Position and Laterality in Centripetal Force and Changes of Direction in Elite Soccer Players. *PLoS ONE* **2020**, *15*, e0232123. [CrossRef] [PubMed]
56. Leventer, L.; Eek, F.; Hofstetter, S.; Lames, M. Injury Patterns among Elite Football Players: A Media-Based Analysis over 6 Seasons with Emphasis on Playing Position. *Int. J. Sports Med.* **2016**, *37*, 898–908. [CrossRef] [PubMed]
57. McCall, A.; Carling, C.; Davison, M.; Nedelec, M.; Le Gall, F.; Berthoin, S.; Dupont, G. Injury Risk Factors, Screening Tests and Preventative Strategies: A Systematic Review of the Evidence That Underpins the Perceptions and Practices of 44 Football (Soccer) Teams from Various Premier Leagues. *Br. J. Sports Med.* **2015**, *49*, 583–589. [CrossRef]
58. Owoeye, O.B.A.; VanderWey, M.J.; Pike, I. Reducing Injuries in Soccer (Football): An Umbrella Review of Best Evidence across the Epidemiological Framework for Prevention. *Sports Med.-Open* **2020**, *6*, 46. [CrossRef]
59. Ekstrand, J.; Hägglund, M.; Waldén, M. Epidemiology of Muscle Injuries in Professional Football (Soccer). *Am. J. Sports Med.* **2011**, *39*, 1226–1232. [CrossRef]
60. Hägglund, M.; Waldén, M.; Ekstrand, J. Risk Factors for Lower Extremity Muscle Injury in Professional Soccer: The UEFA Injury Study. *Am. J. Sports Med.* **2013**, *41*, 327–335. [CrossRef]
61. Petersen, J.; Thorborg, K.; Nielsen, M.B.; Budtz-Jørgensen, E.; Hölmich, P. Preventive Effect of Eccentric Training on Acute Hamstring Injuries in Men's Soccer: A Cluster-Randomized Controlled Trial. *Am. J. Sports Med.* **2011**, *39*, 2296–2303. [CrossRef]
62. Biz, C.; Nicoletti, P.; Baldin, G.; Bragazzi, N.L.; Crimì, A.; Ruggieri, P. Hamstring Strain Injury (Hsi) Prevention in Professional and Semi-Professional Football Teams: A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8272. [CrossRef] [PubMed]
63. Green, B.; Pizzari, T. Calf Muscle Strain Injuries in Sport: A Systematic Review of Risk Factors for Injury. *Br. J. Sports Med.* **2017**, *51*, 1189–1194. [CrossRef] [PubMed]