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TMG Symmetry and Kinematic Analysis of the Impact of Different Plyometric Programs on Female Athletes' Lower-Body Muscles

Nikola Prvulović [1,*], Milena Žuža Praštalo [1,2], Ana Lilić [3], Saša Pantelić [3], Borko Katanić [4], Milan Čoh [5] and Vesna Vučić [1,2]

[1] Group for Nutritional Biochemistry and Dietology, Institute for Medical Research, National Institute of Republic of Serbia, University of Belgrade, 11000 Beograd, Serbia; milena.zuza@imi.bg.ac.rs (M.Ž.P.); vesna.vucic@imi.bg.ac.rs (V.V.)
[2] Center of Research Excellence in Nutrition and Metabolism, Institute for Medical Research, National Institute of Republic of Serbia, University of Belgrade, 11000 Beograd, Serbia
[3] Faculty of Sport and Physical Education, University of Niš, 18000 Niš, Serbia; analilic93@gmail.com (A.L.); spantelic2002@yahoo.com (S.P.)
[4] Montenegrin Sports Academy (MSA), 81000 Podgorica, Montenegro; borkokatanic@gmail.com
[5] Faculty of Sport, University of Ljubljana, 1000 Ljubljana, Slovenia; milan.coh@fsp.uni-lj.si
* Correspondence: nikola.prvulovic@imi.bg.ac.rs; Tel.: +381-69770001

Abstract: Asymmetries in sports are common and can lead to various issues; however, different training programs can facilitate change. This study aimed to assess the effects of opposing plyometric programs on tensiomyography lateral symmetry (TMG LS)/inter-limb asymmetry in female athletes' lower-body muscles, alongside kinematic and body composition parameters. Twenty female subjects from basketball, volleyball, and track and field (sprinting disciplines) were divided into two experimental groups (n = 10 each). Two six-week plyometric programs (two sessions/week) were implemented: the first program (E1) focused on eccentric exercises, depth landings, while the second (E2) emphasized concentric exercises, squat jumps. TMG assessed LS in six muscles: vastus lateralis, vastus medialis, biceps femoris, semitendinosus, gastrocnemius lateralis, and gastrocnemius medialis. A kinematic analysis of the countermovement jump (CMJ) and body composition was conducted using "Kinovea; Version 0.9.4" software and InBody 770, respectively. The results showed significant increases in LS percentages (E1—VL 9.9%, BF 18.0%, GM 10.6% and E2—BF 22.5%, $p < 0.05$), and a significant large effect in E1 for VL, and in E2 for BF, $p < 0.01$). They also showed that E1 had a significant effect on VL, and that E2 had a significant large effect on BF ($p < 0.01$). E1 also led to increased lean muscle mass in both legs (left: 1.88%, right: 2.74%) and decreased BMIs (-0.4, $p < 0.05$). Both programs improved LS, with E1 enhancing muscle mass and lower-body positioning in CMJ. We recommend future studies use varied jump tests, incorporate 3D kinematic analysis, include male subjects, and examine more muscles to enhance TMG LS analysis.

Keywords: TMG symmetry; inter-limb asymmetry; kinematic; CMJ; body composition

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1. Introduction

For symmetry analysis in sports, the term sports asymmetry is more commonly used and describes bilateral differences in parameters, such as power output or jump height [1]. Asymmetries in sport are a function of limb dominance and are increased by long-standing participation in a sport [2]. Thus, sporting asymmetries are both common and expected, with their extent varying based on the evaluation method and the body part being analyzed. While some degree of asymmetry is natural in sports, excessive imbalance in limbs can increase the risk of injury [2]. Inter-limb asymmetries have caught the attention of researchers and have been analyzed in recent years to offer a better understanding of the effects on sports performances and motorical abilities [3–6]. Inter-limb asymmetry refers to an imbalance or deficit between limbs (e.g., dominant vs. non-dominant, left vs. right, or healthy vs. injured) [3], and it can be calculated through the formula: average symmetry index (ASI) = [1 − dominant leg/non-dominant leg] × 100 [7].

The negative aspects of inter-limb asymmetry in physical qualities, such as strength, power, reactive strength, and speed, lead to reduced physical and sports performance [8,9], although there have been conflicting study results [5,6,10]. Also, inter-limb asymmetry or imbalance is a very important factor for consideration in predicting and preventing injury [2,11]. Limit values of inter-limb asymmetry below or above 15 percent are evident in injured and uninjured athletes [7]. According to the motor control theory [2], the presence of asymmetry can act as a constraint, limiting an athlete's movement strategies. Consequently, athletes may adopt motor behaviors that elevate the risk of injury. These potential injury mechanisms could involve athletes performing inefficient or dysfunctional movements, leading to the accumulation of fatigue or micro-trauma. Moreover, physical constraints might force athletes into postures during their performance that compromise muscle or joint health, further increasing the likelihood of injury [2,12]; the most common injury in the lower extremities is to the anterior cruciate ligament (ACL) [13]. For non-contact ACL, the injury rate has been reported to be 3.5-fold greater for female athletes than for male athletes [14].

Although the symmetry of the lower limbs is measured using various bilateral and unilateral tests, it is challenging to obtain accurate results because asymmetry measured from one test should not be expected to be the same in another test [15]. One of the most used tests is the countermovement jump (CMJ) test with force plates, which, in addition to strength and kinetic parameters, shows inter-limb asymmetry [16]. In addition, kinematic 2D analyses from the frontal plane are used to determine the dynamic knee valgus [17], which has been indicated as a possible biomechanical factor for predicting future ACL injuries [18]. Therefore, a relatively new analysis, using the tensiomyography (TMG) symmetry parameters, could give a more accurate and detailed picture [19,20]. Non-invasive TMG detects the mechanical response (lateral thickening in millimeters) of the skeletal muscle belly to single-twitch stimulation. This mechanical response reflects both the bulk movement of the muscle belly (a shift in the muscle mass) and the lateral oscillations and thickening of muscle fibers [21]. Therefore, TMG shows four time-related and one metric parameter, as well as functional and lateral symmetry (LS) results, which gives us a better understanding of neuromuscular changes. By combining different types of contractions through jumping movements, the eccentric and concentric phases of a jump play key roles in understanding neuromuscular adaptations in athletes performing various jump tasks [22]. Inter-limb asymmetry, which may or may not be present in athletes, can be hypothesized and linked to different training programs. Additionally, TMG analysis, which provides LS results from neuromuscular parameters, can offer deeper insights into the topic that we explored and questioned in this study.

There have been studies that have examined different programs' effects on inter-limb asymmetry, with a focus on bilateral and unilateral strength exercises, plyometrics, balance, and core training in a variety of different sports, with mixed findings [4,23,24]. The meta-analysis results of various training programs' effects on inter-limb asymmetry have shown small-to-moderate effects on the reduction in asymmetry, and a large effect when compared with the control groups for different symmetry tests [6]. Although there have been few studies that have examined different training programs in a small number of subjects, the results have to be viewed cautiously. Plyometric programs of a moderate or high intensity enable the best progress in developing strength and speed for both genders, regardless of the sport [22,25]. The positive effects of plyometric training, which involve rapid movements, are associated with the stretch-shortening cycle [22]. Most double-leg jumps and exercises using this method generate significant forces and strains on the muscles [22]. Therefore, when there are imbalances in strength between limbs, the equal use of both legs can help to balance deficits and inter-limb asymmetries. Some plyometric exercises are used to develop stability, such as depth landings [22], but the effects on inter-limb asymmetry have still not been well investigated [7,26,27].

Therefore, the aim of this study was to determine the effects of different plyometric programs with opposite-based exercises on TMG LS/inter-limb asymmetry in female athletes' lower-body muscles, using TMG, kinematic, and body composition parameters.

2. Materials and Methods

2.1. Experimental Design

An experimental longitudinal controlled study was conducted with female athletes participating in three distinct sports: volleyball, basketball, and track and field (sprinting disciplines), all competing at the national league level, divided into experimental groups, E1 (eccentric plyometric program) and E2 (concentric plyometric program). This study analyzed the effects after 6-week interventions in the CMJ kinematic parameters from two points of view, sagittal and frontal, TMG LS, on 6 muscles of the lower extremities and body composition parameters (LBM—lean body mass, SSM—skeletal muscle mass, FFM—fat-free mass, BMI—body mass index, left leg lean muscle mass, right leg lean muscle mass, and InBody total score).

2.2. Participants

At the beginning, there were 24 female athletes aged 16 to 18 years old who volunteered to participate in this study. The same number of participants, eight, were from each of the following sports: volleyball, basketball, field (sprinting) disciplines. All participants were active in their sport for at least 3 years and injury free at least one year before this study. After the study protocol received approval from the Ethics Committee of the Faculty of Sport and Physical Education, University of Nis (number: 04-227/2), and prior to familiarization and data collection sessions, the parents and coaches of minor participants (participants that 16 or 17 years old) were fully informed about the goals, course, participation and possible side effects of the research and signed informative written consent before the start of this study. Adult participants were also fully informed verbally and signed informative written consent before this study. The study protocol was conducted according to the Declaration of Helsinki [28]. The participants were randomly divided into two groups of 12 to exercise following two different plyometric programs. The equality of the groups was determined based on the results of the mean values of their morphological characteristics (BH—body height, BM—body mass). The first plyometric program was based on exercises with eccentric contraction (E1), and the second on concentric contraction (E2) (see Table 1). Four participants were excluded for not attending 85% of their training programs, so the final sample included 20 subjects (E1, n = 10, age: 17.0 ± 0.94 years, height: 174.9 ± 4.75 cm, mass: 65.5 ± 6.68 kg; E2, n = 10, age: 16.9 ± 1.1 years, height: 171.9 ± 8.36 cm, mass: 65.8 ± 9.6 kg, Table 2) who successfully completed the experimental protocol.

Table 1. Characteristics of the plyometric programs.

Characteristics of the Program	Eccentric Plyometric Program, E1	Concentric Plyometric Program, E2
Duration	6 weeks	6 weeks
Frequency	2/week	2/week
Duration	45–60 min	45–60 min
Intensity	High	High
Structure	3-part	3-part
BJump	1–5 s	1–5 s
BSets	60–120 s	60–120 s
BExc	120–240 s	120–240 s
RAllJump-DLandSJ	30–40% to 70–60%	30–40% to 70–60%
Number of exercises	12 (4 warm up)	12 (4 warm up)

Table 1. *Cont.*

Characteristics of the Program	Eccentric Plyometric Program, E1	Concentric Plyometric Program, E2
Type of exercise	HLJ/S3J/HV2JBox (30 cm)/ DJ (30 cm)-2/Sp10–20 m	HLJ/S3J/HV2JBox (30 cm)/ DJ (30 cm)-2/Sp10–20 m
DiffPr	DL (heights 60–100 cm)	SJ (jump on height boxes 30–60 cm)

Legends: s—seconds; BJump—breaks between jumps; BSets—breaks between sets; BExc—breaks between exercises; RAllJump-DLandSJ—ratio between all jumps, and depth landings or squat jump; HLJ—horizontal standing long jump; S3J—standing triple jump; HV2JBox (30 cm)—horizontal vertical double jump from a standing position from box (30 cm); DJ (30 cm)-2—drop jump (30 cm) with double rebound; Sp10–20 m—sprint (10 m and 20 m); DL—depth landings; SJ—squat jump; DiffPr—differences between plyometric programs. Note: The structure of the training sessions was based on previous research and guidelines, intensity was based on the length of breaks between jumps, exercises and sets in study [29], and the type of exercise [22]. The total number of jumps in a set as well as the number of sets decreased as landing height or SJ increased during the program [22,29].

Table 2. Initial and final results, and differences between initial and final measurements for both groups on the CMJ sagittal and frontal plane kinematics and body composition.

Tests		Variables	G	Pre-Test (M + Sd)	Post-Test (M + Sd)	Diff (%) Pre-Post	ηp^2
Anthropometric		Age	E1 E2	17.0 ± 0.94 16.9 ± 1.1	N/A	N/A	N/A
		Height (cm)	E1 E2	174.9 ± 4.75 171.9 ± 8.36			
		Mass (kg)	E1 E2	65.5 ± 6.68 65.8 ± 9.6			
Body composition		Lean Body Mass (kg)	E1 E2	48.55 ± 4.11 47.92 ± 6.33	47.97 ± 3.99 48.20 ± 6.45	0.58 (1.19) −0.28 (−0.58)	0.20 0.06
		SMM (kg)	E1 E2	28.76 ± 2.69 28.29 ± 3.92	28.36 ± 2.57 28.55 ± 3.95	0.4 (1.39) −0.26 (−0.92)	0.22 0.12
		FFM (kg)	E1 E2	51.63 ± 4.43 50.99 ± 6.76	51.03 ± 4.29 51.31 ± 6.92	0.6 (1.16) −0.32 (−0.63)	0.19 0.07
		Left Leg Lean Mass (%)	E1 E2	115.98 ± 4.50 113.05 ± 7.18	114.10 ± 4.26 111.67 ± 7.91	1.88 (1.62) * 1.38 (1.22)	**0.52** 0.13
		Right Leg Lean Mass (%)	E1 E2	116.93 ± 4.71 113.38 ± 7.76	114.19 ± 4.37 112.88 ± 8.32	2.74 (2.34) * 0.5 (0.44)	**0.54** 0.01
		BMI	E1 E2	21.4 ± 2.38 22.2 ± 2.35	21.8 ± 2.33 22.4 ± 2.25	−0.4 (−1.87) * −0.2 (−0.90)	**0.60** 0.20
		InBodyScore	E1 E2	77.8 ± 5.83 79.2 ± 4.16	77.7 ± 3.47 79.6 ± 4.84	0.1 (0.13) −0.4 (−0.51)	0.00 0.03
CMJ	Sagittal	Hip (°)	E1 E2	39.92 ± 10.46 46.01 ± 11.74	36.70 ± 9.46 45.20 ± 8.43 #	−3.22 (8.06) −0.81 (1.76)	0.12 0.01
		Knee (°)	E1 E2	82.85 ± 9.82 86.67 ± 3.51	83.56 ± 7.97 88.64 ± 6.70	0.71 (0.86) 1.97 (2.27)	0.01 0.10
	Frontal	Left Knee (°)	E1 E2	182.30 ± 22.01 179.83 ± 6.74	186.09 ± 15.55 182.82 ± 13.83	3.79 (2.08) 2.99 (1.66)	0.05 0.06
		Hip (°)	E1 E2	170.23 ± 20.41 177.14 ± 17.49	173.19 ± 11.23 175.40 ± 15.93	2.96 (1.74) −1.74 (0.98)	0.04 0.02

Legends: G—group; N/A—not applicable; M—mean; Sd—standard deviation; pre-test; initial measurement; Post-test—final measurement; Diff—difference between the initial and final measurements; ηp^2—partial eta square (results in **bold** represent significant results for column ηp^2); SSM—skeletal muscle mass; FFM—fat-free mass; BMI—body mass index; #—statistically significant result at the post-test, $p < 0.05$; *—statistically significant result between the pre- and post-tests, $p < 0.05$.

2.3. Procedure

The participants were told to refrain from physical activity for 2 days before the start of the initial measurement. All participants were measured at the same time immediately before and two days after the applied programs, at the initial and final measurements. All measurements, were conducted 10 min after warm-up using the same measuring devices and by the same researchers. A 20 min warm-up with neuromuscular activation exercises and lower-body dynamic stretches to prepare for the upcoming tests was performed before the measurement [30].

2.4. Anthropometric Measurements

According to international standards for anthropometric assessment [31], all anthropometric measurements were performed before any exercise program. Due to the need for precise testing, the participants were asked to be barefoot and wear light clothing. Anthropometric measurements were obtained using a mobile stadiometer (SECA 217, Hamburg, Germany) and an electronic scale (SECA 803, Hamburg, Germany). Body height was measured with the accuracy of (±0.1) cm, and body mass with the accuracy of (±0.1 kg).

2.5. Body Composition Measurements

These measurements were conducted using a professional body composition analyzer, the InBody770 (Body Composition Analyzer—InBody770, InBody Co., Ltd., Seoul, Republic of Korea), which has been verified for its reliability with 95% accuracy [32]. Participants were instructed to stand on the platform of the device barefoot with the soles of their feet on the electrodes. Participants then grasped the handles of the unit with their thumb and fingers to maintain direct contact with the electrodes. They stand still for ~1 min while maintaining their elbows fully extended and their shoulder joint abducted to approximately a 30-degree angle. Body mass index (BMI) was calculated using the standard procedure, dividing body weight in kilograms by the square of body height in meters (BMI = BW (kg)/BH (m^2)). Other parameters were LBM (kg), SMM (kg), FFM (kg), Left Leg Lean Mass (%), Right Leg Lean Mass (%) and InBodyScore. The result of the measurement for the values of body composition and body mass was measured with a precision of 0.1 kg [33].

2.6. Countermovement Jump (CMJ) and Kinematic Measurements

The CMJ without an arm swing was used to assess lower-body muscular power and can be used for assessment inter-limb asymmetry [34]. The participant stood upright with their knees fully extended at a 180° angle, hands placed on their hips. They then performed a countermovement until the knee angle reached approximately 90°, followed immediately by a maximal vertical jump, landing with their knees extended back to a 180° angle. The participants were instructed to jump as high as possible and to land in a similar position to that of take-off from the force plate on a force plate Kistler model 9286A (Kistler Group, Winterthur, Switzerland) with a sampling rate of 1000 Hz. The participants practiced the CMJ task 2 times, followed by a 2 min rest period before 3 maximal jumps (with a break at their discretion between the jumps, no more the 30 s) that were recorded and used for analysis.

Kinematic parameters were performed using reflective markers that were placed according to the description in the study [35] (hip joint, knee and ankle joint), with video recording and 2D analysis using two Nikon high-resolution cameras, with a frequency of 200 Hz and a resolution of 1024 × 768 pixels. The camera position recorded jumps from the sagittal and frontal planes. Kinovea; Version 0.9.4 software was used to process the kinematic parameters. From the sagittal plane, the parameters were measured at two moments, the first when the velocity of movement of the body's center of gravity is equal to zero at the moment of transition from the eccentric to the concentric phase (T1), and the second moment when the body moves into the flight phase and the feet are no longer in contact with the ground (T2). The investigated parameters are: knee, and hip angle.

From the frontal plane, the parameters were measured at the T1. The examined parameters are the angles of the left and right knee joints. Although 3D analysis is used for more detailed data, according to current knowledge, 2D analysis is recommended, which records less errors when analyzing the angle of the knee and hip joints during vertical jumps [36].

2.7. Tensiomyography Measurement

TMG was used to assess skeletal muscle contractile properties in the vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), semitendinosus (SM), gastrocnemius lateralis (GL), and gastrocnemius medialis (GM) of both legs. All measurements were performed isometrically in relaxed predefined positions: for VL and VM, in a supine position with the knee angle set at a 30-degree flexion (where 0 degree represents the extended joint); for BF and SM, in a prone position with the knee angle set at a 5-degree flexion; for GL and GM muscles, in supine and prone positions, respectively, with the ankle in a neutral position [37]. Foam pads were used to support the joints. When necessary, the measuring point and electrode positions were adjusted to obtain the maximal Dm of the muscle belly. An electrical stimulator (TMG-S2, TMG-BMC, Ljubljana, Slovenia) and a digital high-precision displacement sensor (digital–optical comparator, TMG-BMC Ltd., Ljubljana, Slovenia) were used, pressed by a spring (0.2 N/cm^2) on the muscle belly during the measurement, to assure a high signal-to-noise ratio and high reliability [38]. The sensor was positioned perpendicular to the tangential plane on the skin above the muscle belly. A 1 ms rectangular (twitch) impulse started at 20 mA and was applied through stimulation electrodes (5/5 cm Compex Medical AS, Ecublens, Switzerland) that were positioned 5 cm distally (cathode) from and 5 cm proximally (anode) to the measuring point and positioned on the muscle surface, following the arrangement of the fibers [39]. Initially, the electrical current amplitude was set just above the threshold and was then gradually increased until the Dm readings stabilized. From two maximal twitch responses, the muscle contractile properties were calculated and an average was used for further analysis [20,37]. To avoid fatigue or potentiation effects, a 15 s resting period was allowed between electrical stimuli [37]. Both TMG (pre- and post-) tests were conducted in the morning and by the same experienced specialist. Measured TMG parameters were: delay time (Td), sustain time (Ts), relaxation time (Tr), contraction time (Tc), and maximal displacement (Dm) [39].

Moreover, the TMG defined the algorithm for calculating the LS, which was implemented in the current investigation (Equation (1)).

$$\mathrm{LS} = 0.1 \times \left(\frac{MIN(TdR:TdL)}{MAX(TdR;TdL)}\right) + 0.6 \times \left(\frac{MIN(TcR:TcL)}{MAX(TcR;TcL)}\right) + 0.1 \times \left(\frac{MIN(TsR:TsL)}{MAX(TsR;TsL)}\right) + 0.2 \times \left(\frac{MIN(DmR:DmL)}{MAX(DmR;DmL)}\right) \times 100 \quad (1)$$

where LS—lateral symmetry, MIN—the minimum, MAX—the maximum, R—right leg parameters and L—left leg parameters. As such, the LS has cut-off value of 80%, respectively [20].

2.8. Experimental Training Interventions

One week was spent providing detailed explanations of the course (a deeper understanding of the training program) and the aims of the experiment (possible effects of the programs), as well as familiarizing participants with the measuring instruments and testing rooms before the start of the experimental plyometric programs. This was followed by the beginning of the initial measurement of all the assigned tests and the implementation of the planned plyometric programs (see Table 1).

2.9. Statistical Analysis

All statistical analyses were performed using the IBM SPSS Statistics for Windows software (Version 28.1; IBM Corp., Armonk, NY, USA). All obtained data are represented by descriptive statistics parameters central and dispersive parameters: the arithmetic mean (mean) and standard deviation (std. deviation). Normality was tested using the

Kolmogorov–Smirnov test. The homogeneity of variances was confirmed using Leven's test. Student's independent *t*-test was used to determine differences between groups at the initial measurements, and two-way repeated-measures (ANOVA) was used to determine the effects of different plyometric programs over time (pre- and post-tests). The degree of the effect was determined for dependent variables by using partial-eta squared (ηp^2). Partial-eta squared readings of 0.01, 0.06, and 0.14 were rated as small, moderate and high differences, respectively [40]. One-way analysis of covariance (ANCOVA), using baseline values as covariates, was calculated to determine the effects, i.e., differences between the plyometric programs [41]. Statistical significance was accepted at $p < 0.05$.

3. Results

3.1. Anthropometric, Body Composition and CMJ Kinematics

In Table 2, the results show no significant differences between groups at the initial measurement for anthropometric parameters, in any of the body composition parameters, nor in any of the CMJ kinematic parameters from the sagittal or frontal points of view ($p > 0.05$).

Also, differences between groups at the final measurement were only seen for the CMJ kinematic parameter from the sagittal point of view for the hip angle (E1—36.70 ± 9.46° to E2—45.20 ± 8.43°, $p > 0.05$).

Table 2 also displays the differences between the initial and final measurements, and a large significant effect of the body composition parameters only in the E1 group for three measured parameters—the left and right leg lean muscle mass increase, 1.88% (1.62) and 2.74% (2.34), and the BMI decreases, −0.4 (−1.87) at $p < 0.05$, respectively.

3.2. TMG Symmetry

In Table 3, the results show no significant differences between groups at the initial measurement for TMG LS parameters for all six muscles ($p > 0.05$). Significant differences between groups at the final measurement were only seen in muscle GM (from E1—91.60 ± 4.17% to E2—84.80 ± 8.84%, $p > 0.05$), respectively.

Table 3. Initial and final results, and differences between initial and final measurements for both groups on the TMG lateral symmetry of six muscles.

Tests	Variables	G	Pre-Test (M + Sd)	Post-Test (M + Sd)	Diff (%) Pre-Post	ηp^2
Lateral Symmetry	m.Vastus medialis (%)	E1	88.60 ± 5.36	88.70 ± 5.80	0.1 (0.11)	0.00
		E2	85.40 ± 12.47	90.00 ± 4.19	4.6 (5.38)	0.16
	m.Vastus lateralis (%)	E1	78.70 ± 11.27	88.60 ± 6.00	9.9 (12.57) *	**0.50**
		E2	84.20 ± 6.96	89.80 ± 5.87	5.7 (6.77)	0.22
	m.Biceps femoris (%)	E1	68.10 ± 18.18	86.10 ± 10.69	18.0 (26.43) *	**0.39**
		E2	61.50 ± 16.53	84.00 ± 11.18	22.5 (36.58) **	**0.58**
	m.Semitendinosus (%)	E1	89.80 ± 6.03	86.00 ± 10.10	−3.8 (4.23)	0.15
		E2	80.90 ± 15.09	83.60 ± 8.17	2.7 (3.34)	0.02
	m.Gastrocnemius medialis (%)	E1	81.00 ± 9.24	91.60 ± 4.17	10.6 (13.08) *	**0.52**
		E2	81.00 ± 7.83	84.80 ± 8.84 #	3.8 (4.69)	0.24
	m.Gastrocnemius lateralis (%)	E1	77.90 ± 15.82	84.40 ± 10.15	6.5 (8.34)	0.09
		E2	76.50 ± 13.43	83.50 ± 10.19	7.0 (9.15)	0.14

Legends: G—group; M—mean; Sd—standard deviation; pre-test; initial measurement; post-test—final measurement; Diff—difference between the initial and final measurements; ηp^2—partial eta square; E1—experimental eccentric group; E2—experimental concentric group; #—statistically significant result at the post-test, $p < 0.05$; *—statistically significant result between the pre- and post-tests, $p < 0.05$; **—statistically significant result between the pre- and post-tests, $p < 0.01$.

Table 3 also show the differences between the initial and final measurements, and a large significant effect and increase in symmetry percentages in the E1 group for three measured muscles, VL, BF, and GM (E1—9.9% (12.57), 18.0% (26.43), and 10.6% (13.08)), and in the E2 group, with the largest increase in symmetry percentages for only one muscle, BF (E2—22.5% (36.58)) at $p < 0.05$, respectively.

3.3. Effects Between Programs on TMG Symmetry

Figure 1 displays the effects between plyometric programs for LS, and an increase in percentages in the E1 group in VL, with a large effect ($p < 0.05$), and in the E2 group largest increase in LS for BF, also with a large effect ($p < 0.01$).

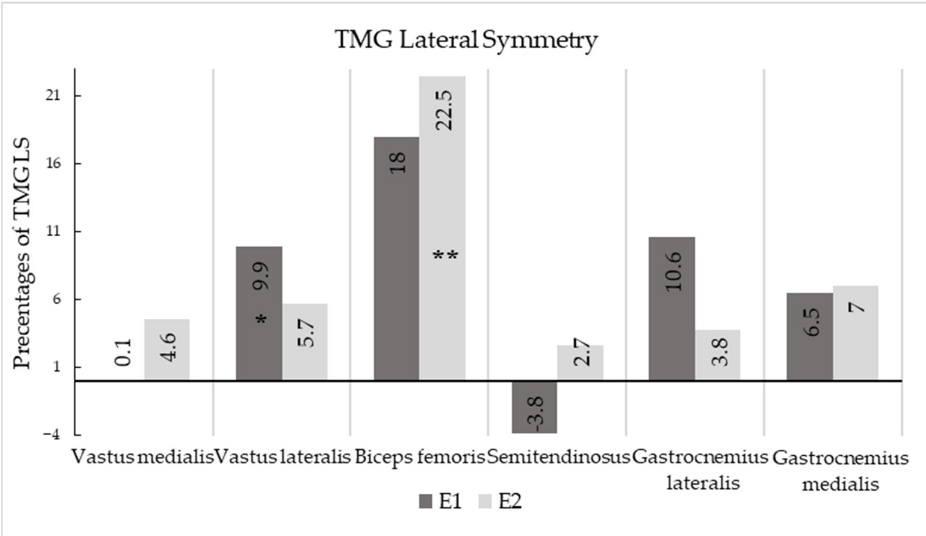

Figure 1. Effects between plyometric programs on TMG lateral symmetry of six lower-body muscles. *—statistically significant result with $p < 0.05$; **—statistically significant result with $p < 0.01$. Note: Ef Diff was calculated by subtracting the mean value for E1 from E2.

3.4. Effects Between Programs on CMJ Kinematics and Body Composition

Figure 2 shows the effects between plyometric programs for CMJ kinematic parameters and only one significant decrease with a large effect in hip angle from the sagittal point of view ($-2.41°$, $p < 0.05$), respectively. There are no significant effects between plyometric programs for any of the body composition measured parameters.

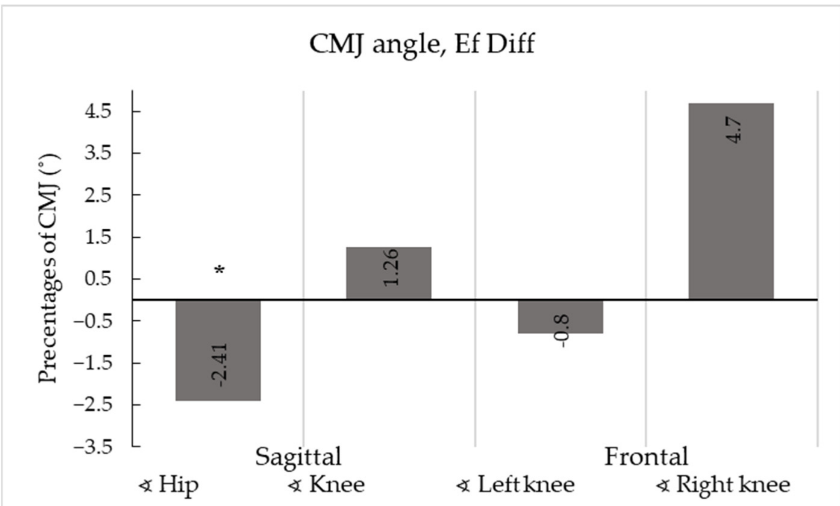

Figure 2. Effects between plyometric programs of CMJ kinematic parameters from sagittal and frontal view. *—statistically significant result with $p < 0.05$. Note: Ef Diff was calculated by subtracting the mean value for E1 from E2.

4. Discussion

This study aimed to determine the effects of two plyometric programs, based on eccentric and concentric exercises, on TMG LS/inter-limb asymmetry of female athletes' lower-body muscles, using TMG, kinematic, and body composition parameters. Our findings show that opposite-based plyometric programs affect inter-limb asymmetry differently (Tables 2 and 3, Figures 1 and 2).

The plyometric training method positively affects the development of strength and speed in various sports across all ages [22]. Few studies [26,27] have examined the effects of plyometric programs on inter-limb asymmetry. A meta-analysis [6] of different interventions on inter-limb asymmetry shows varied results. Furthermore, there are studies examining different interventions on inter-limb asymmetry using different symmetry tests [23,24]. To the best of the authors' knowledge, there are no studies in the literature analyzing the effects of plyometric programs on TMG asymmetry in female athletes.

The results from this study show different exercise-based plyometric program effects on TMG LS on female adolescent athletes. A significant increase in TMG LS percentages was observed in the E1 group, which followed an eccentric-based plyometric exercise program, for three muscles: VL (9.9%), BF (18.0%), and GM (10.6%). In the E2 group, which followed a concentric-based plyometric program, the largest increase in LS was for the BF (22.5%). Only one muscle, the BF, in both the E1 group (18.0%) and the E2 group (22.5%), exceeded the optimal suggested range of LS score > 80% [20]. One of reasons for those results is that the plyometric exercises have positive effects on inter-limb asymmetry due to a large force that occurs when performing two-legged jumps that lead to the same use of the both legs muscles, i.e., the flow of forces [22,27]. The reasons why only the BF showed such results still need to be analyzed.

One study [26] measured the effect of 8 weeks of additional plyometric training, performed three times per week, on jump performance and lower-extremity asymmetry in 26 adolescent fencers, divided into experimental and control groups. They used kinematic parameters from an app tool ("My Jump 2") and a drop jump test from a 40 cm box height to calculate inter-limb asymmetry. Although the results of asymmetry did not show statistical differences, the results should be interpreted with caution, as asymmetry measured from one test varied when measured with another [15]. Factors such as the subjects' young age and sports experience also contributed to the findings. These results are not consistent with the findings of our research. Another study [27] measured the effects of an 8-week, twice-weekly plyometric program on physical fitness and inter-limb asymmetry in 27 prepubertal male soccer players, divided into experimental and control groups. A jump-based asymmetry score was calculated as the difference between single-leg jump tests of the dominant and non-dominant legs. The plyometric group showed a significant reduction in the inter-limb asymmetry score (−45.21%). This study's findings, suggesting that plyometric training can reduce lower-limb asymmetry and potentially decrease the risk of lower limb injuries [27], are consistent with our results, though the percentages differ due to the use of different symmetry test parameters.

We found only one study that examined female athletes of a similar age to those in our research but with a different training program [24]. This study examined the effects of an 8-week, twice-weekly combined strength and power training program on inter-limb asymmetries and physical performance in 37 adolescent female soccer players, divided into experimental and control groups. Asymmetries were analyzed using unilateral tests, which have different values compared to other tests [15]. The researchers did not find significant results, which is inconsistent with our findings. Unilateral tests yield fewer sensitive results compared to other asymmetry tests and TMG analysis. This is one of the reasons for the differences compared to our results, along with the distinct plyometric programs used in our study.

A few studies have analyzed different training programs on inter-limb asymmetry and other parameters in athletes of similar age to those in our study [23,42]. The study by Gonzalo-Skok et al. [23] explored a similar concept by analyzing two different training programs' effects on inter-limb asymmetry and both unilateral and bilateral jumping performance. Forty-five male adolescent soccer players were randomly assigned to three experimental groups with different eccentric overload training programs. Asymmetries were analyzed with unilateral jumping tests, which differ from our study. CMJ asymmetry was reduced (ES = 0.08–0.24, $p < 0.05$) in all groups, and triple hop asymmetry was also significantly decreased (ES = 0.88, $p < 0.05$). Another study [42] compared the effects of an 8-week iso-inertial and eccentric-based training program, using a flywheel device, on motor skill performance and inter-limb asymmetry in thirty-four adolescent male handball players. Inter-limb asymmetries were measured in the dominant and non-dominant limbs with various tests, including the unilateral CMJ, the unilateral lateral jump, and the unilateral broad jump. Reductions in inter-limb asymmetry were found in unilateral CMJ (−0.70 moderate vs. −0.32, small), and a significant main effect of time ($p < 0.001$, moderate) was also observed. Although both resistance training programs improved physical performance and reduced inter-limb asymmetry, greater improvements were seen with the iso-inertial resistance training than with the cable resistance program [42]. When using different unilateral jump tests, various factors, such as the training program, duration, and timing of the experimental program, significantly affect the results [22]. Additionally, jump technique plays a crucial role in determining jump length, which directly affects inter-limb asymmetry effect scores, helping to explain these results.

At the end of the experiment, our results showed a difference in the CMJ hip angle from the sagittal point of view between the two groups (E1—36.70 ± 9.46° vs. E2—45.20 ± 8.43°) at the T1 moment. The effects between the plyometric programs also resulted in a large decrease of −2.41° in the CMJ hip angle (Table 2, Figure 2).

Explaining knee alignment or the most common problem in different sports—dynamic knee valgus—and inter-limb asymmetry via kinematic analysis and parameters is well documented [13,17]. Additionally, the specific issues, such as the risk of injury, particularly ACL injuries [12–14,17,18], are widely recognized. However, monitoring changes in inter-limb asymmetry or knee valgus after training interventions using kinematic analysis has not been thoroughly investigated [6]. Studies using sagittal or frontal viewpoints in the kinematic analysis of CMJ or drop jump biomechanics [43,44] present inconsistent results.

In one study by Arabatzi et al. [43], 36 male athletes were divided into three experimental groups and one control group. Kinematic analysis from only the sagittal viewpoint of the CMJ test revealed differences between the three training programs: plyometric, resistance, and combined. All programs led to different outcomes. The plyometric program caused a significant change in the kinematic parameter from the sagittal plane, specifically the hip joint angle [43]. The differences between initial and final measurements in CMJ are partially in line with our findings. The absence of significant differences in the hip angle [43] aligns with the results of our study, whereas the significant differences in the knee angle are in contrast. The disparity in results may be due to the older male athletes and the use of 3D kinematic analysis in the other study, while our study used 2D analysis. Another study [44], involving a six-week plyometric program on 15 older athletes, showed significant improvement in CMJ height, with notable differences between initial and final measurements for two kinematic parameters from the sagittal plane [44]. However, the results regarding knee and hip angles do not align with our study. The differences in knee and hip angle results could be due to the older male athletes and the different plyometric program design compared to our two experimental plyometric programs.

A study involving similarly aged adolescent female basketball players [45] showed that, after six weeks of a plyometric program, there were significant reductions in knee angle from the frontal plane—by −9.8° in the left leg and −12.3° in the right leg. These results do not align with our findings. The discrepancies could be attributed to their use of the drop jump from height for kinematic analysis, whereas we used CMJ, which involves a smaller body impact (depending on the platform height from which the jump is performed [46]), particularly at the lowest point of the body during the eccentric phase at the T1 moment.

The only differences in body composition parameters between the initial and final measurements were in the E1 group, with increases in lean muscle mass in the left and right legs (E1—1.88% (1.62) and 2.74% (2.34), respectively), and a decrease in BMI (E1—−0.4% (−1.87)) (Table 2).

Body composition is considered one of the primary health-related components of physical fitness. From an athletic perspective, lean body mass is particularly associated with performance in several exercise tests [47]. A meta-analysis of 21 studies analyzing the effects of plyometric training on body composition parameters in male athletes showed increases and small effects in total leg muscle volume (ES = 0.55, $p = 0.009$), thigh muscle volume (ES = 0.38, $p = 0.043$), and large effects for thigh girth (ES = 1.78, $p = 0.011$) and calf girth (ES = 1.89, $p = 0.022$) [47].

Overall, studies tracking the effects of plyometric programs on body composition parameters last 8 weeks or longer [47], which is longer than the duration of our study. However, some shorter-duration studies of 4 weeks, with participants of a similar age, showed no effects on body composition parameters [48], which are not fully consistent with our findings.

A study that observed significant differences between pre- and post-measurement lean muscle mass in the lower body was noted in Dæhlin et al. [49]. Although the plyometric program lasted 8 weeks with 18 male athletes and results were obtained via DEXA, the increase of 2.7% to 3.2% aligns with our findings. The difference is that they did not report body composition results for each leg, and their plyometric program included additional full-body strength training, unlike ours. Even though the plyometric program in the study [50] lasted 10 weeks, longer than ours, leg lean mass differences after plyometric training were not observed. Consequently, their results do not align with our findings.

A limitation of this study is that at the time of writing, we have not found any similar studies analyzing the effects of plyometric programs or any other training interventions especially on inter-limb asymmetry and body composition parameters, particularly lean muscle mass for each leg. Another limitation is the relatively small number of subjects.

5. Conclusions

The findings of the current study indicated that both plyometric programs, incorporating eccentric and concentric-based exercises, led to partial improvements in inter-limb asymmetry in female athletes. The eccentric-based group, E1, showed better improvements in LS of the concentric contraction muscle, VM (agonist), while the concentric-based group, E2, demonstrated better improvements in LS of the eccentric contraction muscle BF (antagonist). The larger forces generated during eccentric exercise in the E1 group led to enhanced neuromuscular adaptations, resulting in a quicker equalization of LS in the lower-extremity muscles compared to concentric exercise in the E2 group. The eccentric-based plyometric program improved lean muscle mass in both legs, even over a relatively short period of six weeks compared to the concentric-based program. The athletes' jump technique and body position during the CMJ shifted to a lower hip position. However, it remains unclear whether this is due to increased strength in the athletes' lower-body muscles or the result of specific adaptations to the plyometric exercises. We recommend that future studies utilize different jump tests to evaluate asymmetry and incorporate 3D kinematic analysis. Additionally, including male subjects and examining a greater number of muscles would enhance the analysis of TMG LS.

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References

1. Maloney, S.J. The relationship between asymmetry and athletic performance: A critical review. *J. Strength Cond. Res.* **2019**, *33*, 2579–2593. [CrossRef] [PubMed]
2. Helme, M.; Tee, J.; Emmonds, S.; Low, C. Does lower-limb asymmetry increase injury risk in sport? A systematic review. *Phys. Ther. Sport* **2021**, *49*, 204–213. [CrossRef] [PubMed]
3. Bishop, C.; Read, P.; Chavda, S.; Turner, A. Asymmetries of the lower limb: The calculation conundrum in strength training and conditioning. *Strength Cond. J.* **2016**, *38*, 27–32. [CrossRef]
4. Bishop, C.; Turner, A.; Read, P. Training methods and considerations for practitioners to reduce inter-limb asymmetries. *Strength Cond. J.* **2017**, *40*, 40–46. [CrossRef]
5. 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]
6. Bettariga, F.; Turner, A.; Maloney, S.; Maestroni, L.; Jarvis, P.; Bishop, C. The effects of training interventions on inter-limb asymmetries: A systematic review with meta-analysis. *Strength Cond. J.* **2022**, *44*, 69–86. [CrossRef]
7. Hewit, J.; Cronin, J.; Hume, P. Multidirectional leg asymmetry assessment in sport. *Strength Cond. J.* **2012**, *34*, 82–86. [CrossRef]
8. Bishop, C.; Turner, A.; Maloney, S.; Lake, J.; Loturco, I.; Bromley, T.; Read, P. Drop jump asymmetry is associated with reduced sprint and change-of-direction speed performance in adult female soccer players. *Sports* **2019**, *7*, 29. [CrossRef]
9. Maloney, S.; Richards, J.; Nixon, D.; Harvey, L.; Fletcher, I. Do stiffness and asymmetries predict change of direction performance? *J. Sports Sci.* **2017**, *35*, 547–556. [CrossRef]
10. Prvulović, N.; Čoh, M.; Čular, D.; Tomljanović, M.; Sporiš, G.; Fišer, S.Ž. Countermovement Jump in Female Sprinters: Kinetic Parameters and Asymmetry. *Symmetry* **2022**, *14*, 1130. [CrossRef]
11. Fort-Vanmeerhaeghe, A.; Mila-Villarroel, R.; Pujol-Marzo, M.; Arboix-Alio, J.; Bishop, C. Higher vertical jumping asymmetries and lower physical performance are indicators of increased injury incidence in youth team-sport athletes. *J. Strength Cond. Res.* **2022**, *36*, 2204–2211. [CrossRef] [PubMed]
12. Murphy, D.F.; Connolly, D.A.J.; Beynnon, B.D. Risk factors for lower extremity injury: A review of the literature. *Br. J. Sports Med.* **2003**, *37*, 13–29. [CrossRef] [PubMed]
13. Prodromos, C.C.; Han, Y.; Rogowski, J.; Joyce, B.; Shi, K. A Meta-analysis of the Incidence of Anterior Cruciate Ligament Tears as a Function of Gender, Sport, and a Knee Injury–Reduction Regimen. *Arthrosc. J. Arthrosc. Relat. Surg.* **2007**, *23*, 1320–1325. [CrossRef] [PubMed]
14. Moses, B.; Orchard, J.; Orchard, J. Systematic review: Annual incidence of ACL injury and surgery in various populations. *Res. Sports Med.* **2012**, *20*, 157–179. [CrossRef]
15. Bishop, C.; Lake, J.; Loturco, I.; Papadopoulos, K.; Turner, A.; Read, P. Interlimb asymmetries: The need for an individual approach to data analysis. *J. Strength Cond. Res.* **2021**, *35*, 695–701. [CrossRef]
16. Maly, T.; Zahalka, F.; Mala, L.; Cech, P. The bilateral strength and power asymmetries in untrained boys. *Open Med.* **2015**, *10*, 224–232. [CrossRef]
17. Powers, C.M. The influence of abnormal hip mechanics on knee injury: A biomechanical perspective. *J. Orthop. Sports Phys. Ther.* **2010**, *40*, 42–51. [CrossRef]
18. Ho, K.Y.; Murata, A. Asymmetries in Dynamic Valgus Index After Anterior Cruciate Ligament Reconstruction: A Proof-of-Concept Study. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7047. [CrossRef]
19. 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. Sports Med.* **2019**, *10*, 49–69. [CrossRef]
20. Paravlic, A.H.; Milanović, Z.; Abazović, E.; Vučković, G.; Spudić, D.; Rošker, Z.M.; 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.
21. 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]

22. Verkhoshansky, Y.; Siff, M.C. *Supertraining*, 6th ed.; Verkhoshansky SSTM: Moscow, Russia, 2009.
23. Gonzalo-Skok, O.; Moreno-Azze, A.; Arjol-Serrano, J.L.; Tous-Fajardo, J.; Bishop, C. A comparison of 3 different unilateral strength training strategies to enhance jumping performance and decrease inter-limb asymmetries in soccer players. *Int. J. Sports Phy. Perf.* **2019**, *14*, 1256–1264.
24. Pardos-Mainer, E.; Casajús, J.A.; Bishop, C.; Gonzalo-Skok, O. Effects of combined strength and power training on physical performance and inter-limb asymmetries in adolescent female soccer players. *Int. J. Sports Phy. Perf.* **2020**, *15*, 1147–1155.
25. Prvulović, N.; Pantelić, S.; Stanković, R.; Bubanj, S. Effects of plyometric programms on biomechanical parameters in track and field, basketball and volleyball: A systematic review. *Facta Univ. Ser. Teach. Learn. Teach. Educ.* **2022**, *6*, 103–117. [CrossRef]
26. Kosova, S.; Beyhan, R.; Kosova, M.K. The effect of 8-week plyometric training on jump height, agility, speed and asymmetry. *Pedagog. Phys. Cult. Sports* **2022**, *26*, 13–18. [CrossRef]
27. Sammoud, S.; Negra, Y.; Bouguezzi, R.; Ramirez-Campillo, R.; Moran, J.; Bishop, C.; Chaabene, H. Effects of plyometric jump training on measures of physical fitness and lower-limb asymmetries in prepubertal male soccer players: A randomized controlled trial. *BMC Sports Sci. Med. Rehabil.* **2024**, *16*, 37. [CrossRef]
28. World Medical Association. World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA* **2013**, *310*, 2191–2194. [CrossRef]
29. Ramirez-Campillo, R.; Andrade, D.C.; Nikolaidis, P.T.; Moran, J.; Clemente, F.M.; Chaabene, H.; Comfort, P. Effects of plyometric jump training on vertical jump height of volleyball players: A systematic review with meta-analysis of randomized-controlled trial. *J. Sports Sci. Med.* **2020**, *19*, 489–499.
30. Frikha, M.; Chaâri, N.; Mezghanni, N.; Souissi, N. Influence of warm-up duration and recovery interval prior to exercise on anaerobic performance. *Biol. Sport* **2016**, *33*, 361–366. [CrossRef]
31. Marfell-Jones, M.; Olds, T.; Stewart, A.; Carter, L. *ISAK Accreditation Handbook*; International Society for the Advancement of Kinanthropometry (ISAK): Potchefstroom, South Africa, 2006.
32. McLester, C.N.; Nickerson, B.S.; Kliszczewicz, B.M.; McLester, J.R. Reliability and agreement of various InBody body composition analyzers as compared to dual-energy X-ray absorptiometry in healthy men and women. *J. Clin. Densitom.* **2020**, *23*, 443–450. [CrossRef]
33. Silva, A.M.; Fields, D.A.; Heymsfield, S.B.; Sardinha, L.B. Body composition and power changes in elite judo athletes. *Int. J. Sports Med.* **2010**, *31*, 737–741. [CrossRef] [PubMed]
34. Fernandez-Santos, J.R.; Ruiz, J.R.; Cohen, D.D.; Gonzalez-Montesinos, J.L.; Castro-Piñero, J. Reliability and validity of tests to assess lower-body muscular power in children. *J. Strength Cond. Res.* **2015**, *29*, 2277–2285. [CrossRef] [PubMed]
35. Holden, S.; Boreham, C.; Doherty, C.; Wang, D.; Delahunt, E. Clinical assessment of countermovement jump landing kinematics in early adolescence: Sex differences and normative values. *Clin. Biomech.* **2015**, *30*, 469–474. [CrossRef] [PubMed]
36. Sorenson, B.; Kernozek, T.W.; Willson, J.D.; Ragan, R.; Hove, J. Two-and three-dimensional relationships between knee and hip kinematic motion analysis: Single-leg drop-jump landings. *J. Sport Rehabil.* **2015**, *24*, 363–372. [CrossRef]
37. Šimunič, B.; Degens, H.; Rittweger, J.; Narici, M.; Mekjavic, I.; Pisot, R. Noninvasive estimation of myosin heavy chain composition in human skeletal muscle. *Med. Sci. Sports Exerc.* **2011**, *43*, 1619–1625. [CrossRef]
38. Dumitru, D.; Amato, A.A.; Zwarts, M.J. (Eds.) Special nerve conduction techniques. In *Electrodiagnostic Medicine*, 2nd ed.; Hanley & Belfus: Philadelphia, PA, USA, 2001; pp. 225–256.
39. 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.
40. Hopkins, W.; Marshall, S.; Batterham, A.; Hanin, J. Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sports Exerc.* **2009**, *41*, 3–12. [CrossRef]
41. Vickers, A.J.; Altman, D.G. Analysing controlled trials with baseline and follow up measurements. *BMJ* **2001**, *323*, 1123–1124. [CrossRef]
42. Madruga-Parera, M.; Bishop, C.; Fort-Vanmeerhaeghe, A.; Beato, M.; Gonzalo-Skok, O.; Romero-Rodríguez, D. Effects of 8 weeks of isoinertial vs. cable-resistance training on motor skills performance and interlimb asymmetries. *J. Strength Cond. Res.* **2022**, *36*, 1200–1208. [CrossRef]
43. Arabatzi, F.; Kellis, E.; De Villarreal, E.S.S. Vertical jump biomechanics after plyometric, weight lifting, and combined (weight lifting + plyometric) training. *J. Strength Cond. Res.* **2010**, *24*, 2440–2448. [CrossRef]
44. Azreh, R.; Oskouei, A.H.; Shirazi, S.A.E. Effects of Short-term Plyometric Training on Countermovement Vertical Jump Height and Kinematics of Take-Off. *Thrita* **2020**, *9*, e108054. [CrossRef]
45. Herrington, L. The effects of 4 weeks of jump training on landing knee valgus and crossover hop performance in female basketball players. *J. Strength Cond. Res.* **2010**, *24*, 3427–3432. [CrossRef] [PubMed]
46. Bosco, C.; Tihanyi, J.; Komi, P.V.; Fekete, G.; Apor, P. Store and recoil of elastic energy in slow and fast types of human skeletal muscles. *Acta Physiol. Scand.* **1982**, *116*, 343–349. [CrossRef] [PubMed]
47. Ramirez-Campillo, R.; García-Pinillos, F.; Nikolaidis, P.T.; Clemente, F.M.; Gentil, P.; García-Hermoso, A. Body composition adaptations to lower-body plyometric training: A systematic review and meta-analysis. *Biol. Sport* **2022**, *39*, 273–287. [CrossRef] [PubMed]

48. Egan-Shuttler, J.D.; Edmonds, R.; Eddy, C.; O'Neill, V.; Ives, S.J. The effect of concurrent plyometric training versus submaximal aerobic cycling on rowing economy, peak power, and performance in male high school rowers. *Sports Med. Open* **2017**, *3*, 7. [CrossRef]
49. Dæhlin, T.E.; Haugen, O.C.; Haugerud, S.; Hollan, I.; Raastad, T.; Rønnestad, B.R. Improvement of ice hockey players' on-ice sprint with combined plyometric and strength training. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 893–900. [CrossRef]
50. Cormie, P.; McGuigan, M.R.; Newton, R.U. Influence of strength on magnitude and mechanisms of adaptation to power training. *Med. Sci. Sports Exerc.* **2010**, *42*, 1566–1581. [CrossRef]