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Long Jump Performance Is Not Related to Inter-Limb Asymmetry in Force Application in Isometric and Vertical Jump Tests

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Abstract: The aim of the study was to examine the inter-limb asymmetry in force application in a 1-s maximum isometric leg press test (ISOM) and vertical jump tests without an arm swing (VJ)of male long jumpers. Nine experienced jumpers (age: 18–30 y, LJ personal best: 6.50–8.05 m) were examined. Participants performed: (a) bilateral VJs from the squatting position (SQJ) and with a countermovement (CMJ), (b) unilateral CMJ from the take-off (TOL) and swing (SWL) leg used in the LJ take-off, and c) bilateral 1-s ISOM tests. Data were collected for each lower limb with separate force dynamometers (sampling frequency: VJs = 1 kHz, ISOM = 500 Hz). The inter-limb asymmetry of the peak applied force was evaluated using the symmetry angle. The paired samples T-test revealed non-significant ($p > 0.05$) inter-limb differences for the force output in the bilateral jump tests, in the unilateral jump tests, and in the ISOM. In conclusion, despite the fact that a powerful unilateral take-off is required for the optimization of long jump performance, no asymmetry was found in the examined tests, suggesting that the dominant/take-off leg was not stronger than the contralateral leg. This is possibly due to the intensive execution of other bilateral tasks involved, like the approach run.

Keywords: track and field; sport performance; squat jump test; countermovement jump test; maximum voluntary isometric strength test; inter-limb asymmetry; laterality; specificity; rate of force development; stretch-shortening cycle

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1. Introduction

The long jump and the triple jump comprise the horizontal jumps in track and field. Advanced levels of strength and conditioning are required to optimize performance in these athletic events. It is suggested that, within a specified test battery, reaction time, explosive force, and flexibility were significantly correlated with long jump (LJ) performance [1–3]. From a biomechanical point of view, LJ performance is mainly determined by approach velocity, the lowering of the body center of mass (BCM) during the penultimate step of the approach, and the take-off angle [4]. As approach velocity is the single most important factor for success in LJ [5–7], practitioners aim to accomplish their technique targets with increased speed. However, increased speed results in higher vertical ground reaction forces (vGRF) when planting the foot at the take-off board, leading coaches to search for the optimization of the result of the negatively interrelated performance factors such as speed, force, and coordination [8].

Added to the increased vGRFs due to increased speed during the approach, a considerable loading to the take-off leg (TOL) is evident during the LJ take-off phase, as vGRF about 10 times the body mass have been recorded [9]. This loading is transferred through the ankle joint to other segments of the body [10]. Due to the unilateral nature of the LJ take-off technique, this loading is suggested to be handled with specific strength exercises [8] to improve performance and prevent injury. In addition to sprint training [11], core strength training [12], strength resistance training [13], and velocity-based resistance training in particular [14,15] also led to the improvement of sprinting and jumping performance [12]. In addition, plyometric training was found to improve performance in track and field jumpers [16]. Furthermore, it is suggested that long jumpers should develop their explosiveness using a variety of squat weight-bearing exercises similar to the specific kinetic and kinematic patterns that correspond to their technique [17]. Thus, bilateral plyometric exercises are suggested to be included in the LJ strength and conditional program, especially for the maintenance and/or improvement of strength and power during the off-season training [18].

The evaluation of the specific strength and power of track and field jumpers using common laboratory tests provide information about their fitness level, their performance capacity, and the inter-limb asymmetry in these factors. These tests are the squat jump (SQJ) and the countermovement jump (CMJ) with and without an arm swing, executed bipedal or unilaterally [19–21]. Despite the fact that the isometric muscle contraction is different than the function of the acting muscles during sport movements, isometric [22] and isokinetic [23] tests have been suggested as well. From the above-mentioned tests, those who evaluate the effectiveness of the stretch-shortening cycle with regard to the force-length relationship of the muscular actions in the LJ are suggested to be related to LJ performance [24]. Furthermore, unilateral vertical jump tests are suggested to monitor the specific strength parameters [20], as well as to evaluate the inter-limb asymmetry in force application and its effect on the jumping ability [21]. Due to the higher observed reliability in the assessment of inter-limb asymmetry, the force application recorded in the unilateral CMJ is suggested to be the parameter of interest [25].

Asymmetries are possibly the result of limb dominance, and it is suggested to be enlarged due to the long-term systematic participation in sports training and competition [11]. The inter-limb asymmetry in force application of about 10% results in decreased vertical jump performance [26] and sport performance in general [27], while an asymmetry of above 10–15% is suggested to be one of the main indicators for musculoskeletal injury [28–30]. This latter is suggested to be the case in track and field athletes [31] and long jumpers in specific [32]. For example, larger inter-limb asymmetry in the unilateral vertical jump was detected in track and field jumpers rather than in weight lifters [33]. However, in a similar study, no significant differences were observed in the inter-limb comparison of force output between the TOL and the swing leg (SWL) in collegiate-level jumpers [34]. The findings of this study show that even if the TOL is subjected to higher, long-term loading, no significant differences between the TOL and the SWL were detected in force application and jumping capability, as well as in balance parameters [34]. Despite this, it is stressed that the asymmetric nature of the LJ generates additional loading to the body [35] and could provoke limited joint mobility, skeletal injuries, and injuries in the lower back [36]. Finally, about the LJ event itself, no significant asymmetry in the approach step parameters was observed in seven out of ten male jumpers [37].

There is an obvious bias in the literature about the existence of possible inter-limb asymmetry between TOL and SWL regarding the force application capability in laboratory tests and its relation with LJ performance. The purpose of the study was to examine the possible inter-limb asymmetry in the force output in an isometric leg press test, as well as in bilateral and unilateral vertical jump tests. It was hypothesized that inter-limb asymmetry between TOL and SWL in force output would be observed in all tests.

2. Materials and Methods

2.1. Participants

A convenient sample comprised of nine male long jumpers ($n = 9$, age: 22.9 ± 3.8 years, height: 1.80 ± 0.06 m, body mass: 72.4 ± 4.3 kg) was examined. Their personal bests in LJ ranged from 6.50 m to 8.05 m. All had more than five years of experience in national-level competitions, with four of them being members of the national team and having competed in international events. The participants had records of systematical involvement in their training program (6–8 training sessions per week; 12–18 h/wk). The inclusion criteria were the absence of injury in the previous three months that did not allow them to participate in practice for over three days, their systematic participation in their training program, and their participation in an LJ competition within the past 10 days. The official distance in this competition was registered as LJ performance. The testing sessions were conducted during the early summer competitive season. All participants volunteered to participate in the study and provided signed informed consent. The study was conducted following the guidelines of the Declaration of Helsinki and was approved by the Institutional Reviewing Board (117/2022-01.06.2022).

2.2. Experimental Procedure

The anthropometric parameters of the participants were measured with a digital weight scale (Delmac PS400L, Delmac Instruments S.A., Athens, Greece). A wall-mounted stadiometer (Seca 220, Seca Deutschland, Hamburg, Germany) was used to measure the barefoot standing height. The TOL and SWL lower limbs were defined based on the preferred side to execute the LJ take-off in competition.

As warm-up, the participants cycled for 8 min on an 817E Monark Exercise Cycle (Monark-Crescent AB, Varberg, Sweden). Warm-up also included dynamic stretches with a progressively increased range of motion and pairs of SQJ and CMJ, both with and without an arm swing, as well as with a unilateral and bilateral impulse. The intensity of the jumping tasks progressed from sub-maximal to maximal.

2.2.1. Vertical Jump Tests

After the warm-up, participants executed, in random order, the isometric and vertical jump tests. The bilateral vertical jump tests (BIL) were the SQJ and the CMJ, and the unilateral vertical jump tests were the CMJ on the TOL (CMJ-TOL) and SWL (CMJ-SWL). In all the vertical jump tests, the participants were barefooted and did not use an arm swing (arms were kept akimbo). The instruction given was to "jump as high as you can with the shortest push-off time". In the SQJ-BIL, a full feet contact was obligatory, and at the "set" command, the knees were flexed at an approximate 90 deg angle. This posture was kept for about 2 s to check the validity of the jump as described elsewhere [38]. No specific command, i.e., no restrictions were imposed regarding the depth of the countermovement in the CMJs. For the CMJ-TOL and CMJ-SWL, the respective limb was in full contact with the ground, while the free limb was flexed at an angle of 90 deg approximately and hung freely aside the testing lower limb [39]. Again, a 2-s period was given between the "set" and "go" signals to verify the correctness of the initial posture for the jump test.

Before the execution of the testing trials, a pair of jumps of each type was provided for familiarization with the testing procedure. Three maximum vertical jumps in each jumping test were performed. An intra-test rest of 60 s was allowed, while the inter-test interval was 3 min.

2.2.2. Isometric Test

A bilateral maximum voluntary isometric contraction of 1 s (ISOM) against a leg press dynamometer (LegPress, ©: Biomechanics Lab AUTh, Thessaloniki, Greece) was conducted to record the isometric force output. The LegPress dynamometer has the ability to record the applied force from each leg separately. The participants sat on the dynamometer's chair, with the waist and the upper thigh stabilized using velcro straps to secure any movement that could interfere with the measurement quality. The chair was slid and fixed at the appropriate distance from the dynamometers so that the knees were flexed at a 120 deg position (180 deg = full extension) and the ankle joint was at a neutral position. The upper arms were kept crossed on the chest, while the forefoot of the feet was placed vertically to the dynamometer.

For familiarization, pairs of 3-s and 1-s submaximal trials, followed by a 1-s ISOM, were allowed. The instruction was to react as fast as possible to the "go" signal and to apply force as fast as possible. Three ISOMs were performed, with an interval of 60 s between trials.

2.3. Data Acquisition and Analysis

2.3.1. Vertical Jump Tests

The vertical jump tests were executed on a one-dimensional double force plate (3-Dynami, ©: Biomechanics Lab AUTh, Thessaloniki, Greece) that recorded the vGRFs with a sampling frequency of 1 kHz. Data acquisition and analysis were conducted using the K-Dynami 2018 (©: Iraklis A. Kollias, Biomechanics Laboratory, Aristotle University of Thessaloniki, Thessaloniki, Greece) software according to the methods described earlier [38,40]. Only the best trial in each test, as defined by the jump height (h_{JUMP}), was selected for further analysis. The examined parameters were the following:

1. Kinetic parameters: vGRF at the initiation of the jump (FzSTART), maximum vGRF (FzMAX); peak net vertical force (FzNET); peak rate of force development (RFD_{MAX}); peak power output (P_{MAX}).
2. Spatial/kinematic parameters: h_{JUMP}; vertical BCM take-off velocity (Uz_{TOFF}), maximum downward ($Sz_{BCM\text{-}BR}$), and upward vertical BCM displacement ($Sz_{BCM\text{-}PR}$).
3. Temporal parameters: total impulse time (t_{IMP}); time to achieve maximum vGRF (tFz_{MAX}); the duration of the downward phase (t_{BR}); time to achieve peak power (tP_{MAX}).

2.3.2. Isometric Test

The kinetic and temporal parameters of the ISOM test were extracted from the recorded force–time curve using the respective modules of the LegPress 2018 software (©: Iraklis A. Kollias, Biomechanics Laboratory, Aristotle University of Thessaloniki, Thessaloniki, Greece). Only the trial with the largest recorded total force was selected for further analysis. The ISOM parameters included in the analysis were as follows:

4. Temporal parameters: time for the initiation of force application (tF_{START}); time to achieve maximum isometric force output (tF_{MAX}); time to achieve RFD_{MAX} ($tRFD_{MAX}$).
5. Kinetic parameters: peak isometric force (F_{MAX}), peak net isometric force (F_{MAXnet}), RFD_{MAX}.

2.3.3. Asymmetry

The inter-limb asymmetry was evaluated using the symmetry angle (Θ_{SYM}) [41] as (1):

$$\Theta_{SYM} = \frac{\left(45^\circ - \arctan\left(\frac{TOL}{SWL}\right)\right)}{90^\circ} \times 100\% \tag{1}$$

but in the case of (2):

$$\left(45^\circ - \arctan\left(\frac{TOL}{SWL}\right)\right) > 90^\circ \tag{2}$$

Equation (1) was replaced by (3):

$$\Theta_{SYM} = \frac{\left(45^\circ - \arctan\left(\frac{TOL}{SWL}\right) - 180^\circ\right)}{90^\circ} \times 100\% \tag{3}$$

where positive Θ_{SYM} values indicated the direction of asymmetry towards TOL, while negative Θ_{SYM} values indicated the direction of asymmetry towards SWL.

2.4. Statistical Analysis

The intra-test reliability of the h_{JUMP} in the examined vertical jump tests and of the F_{MAX} for the ISOM test was checked with the Interclass Correlation coefficient (ICC). Values lower than 0.5, between 0.5 and 0.75, between 0.75 and 0.9, and above 0.9 are considered as poor, moderate, good, and excellent reliability, respectively [42]. The Shapiro–Wilk test

($p > 0.05$) was run to establish the normal distribution of the data. Based on its result, the differences regarding the biomechanical parameters between the SQJ-BIL and CMJ-BIL, the respective differences between CMJ-TOL and CMJ, as well as the inter-limb differences in the biomechanical parameters of ISOM were checked using paired samples *T*-tests. The effect size was calculated using Cohen's *d* (values of <0.2, <0.5, <0.8, and ≥0.8 represented trivial, small, moderate, and large effect sizes, respectively) [43]. The level of significance was set at $a = 0.05$. The IBM SPSS Statistics v.27.0.1.0 software (IBM Corp., Armonk, NY, USA) was used for all statistical analyses.

3. Results

3.1. Intra-Test Reliability Measures

Excellent intra-test reliability of the h_{JUMP} was revealed for the bilateral (SQJ-BIL: ICC = 0.951, CMJ-BIL: ICC = 0.977) and unilateral (CMJ-TOL: ICC = 0.978, CMJ-SWL: ICC = 0.986) vertical jump tests. The reliability of the F_{MAX} was moderate (ICC = 0.521).

3.2. Bilateral Vertical Jump Tests

The biomechanical parameters of the bilateral vertical jump tests are presented in Table 1. Significant ($p < 0.05$) differences were observed in all parameters except $Sz_{BCM\text{-}PR}$, RFD_{MAX}, and P_{MAX}.

Table 1. Results (Mean ± Standard Deviation) of the biomechanical parameters in the examined bilateral vertical jump tests ($n = 9$).

Parameter	SQJ-BIL	CMJ-BIL	*t*	*p*	*d*
h_{JUMP} (m)	0.404 ± 0.082	0.453 ± 0.084	3.570	0.007 *	1.19
Uz_{TOFF} (m/s)	2.80 ± 0.29	2.97 ± 0.27	4.464	0.001 *	1.14
$Sz_{BCM\text{-}BR}$ (m)	-	−0.29 ± 0.05	-	-	-
$Sz_{BCM\text{-}PR}$ (m)	0.38 ± 0.06	0.41 ± 0.07	1.074	0.314	0.36
FzNET (kN)	1.27 ± 0.13	1.51 ± 0.16	3.169	0.013 *	1.06
RFD_{MAX} (kN/s)	16.80 ± 3.08	22.3 ± 8.42	1.857	0.100	0.62
P_{MAX} (kW)	2.78 ± 0.43	2.87 ± 0.48	1.197	0.266	0.40
t_{IMP} (ms)	392.89 ± 99.00	614.22 ± 242.13	3.289	0.011 *	1.10
t_{BR} (ms)	-	474.78 ± 62.7	-	-	-
tFz_{MAX} (ms)	289.78 ± 90.91	506.22 ± 75.67	10.573	<0.001 *	3.52
tP_{MAX} (ms)	329.56 ± 100.16	620.22 ± 83.44	9.680	<0.001 *	3.23

h_{JUMP}: jump height; Uz_{TOFF}: vertical body center of mass (BCM) take-off velocity; $Sz_{BCM\text{-}BR}$: maximum downward vertical BCM displacement; $Sz_{BCM\text{-}PR}$: maximum upward vertical BCM displacement; FzNET: net vertical ground reaction force; RFD_{MAX}: peak rate of force development; P_{MAX}: peak power output; t_{IMP}: total impulse time; t_{BR}: the duration of the downward phase; tFz_{MAX}: time to achieve maximum vertical ground reaction force; tP_{MAX}: time to achieve peak power output; d: effect size (Cohen's *d*); *: $p < 0.05$ vs. SQJ-BIL.

The results of the force output at selected instances of the SQJ-BIL and CMJ-BIL are presented in Table 2. No significant ($p > 0.05$) inter-limb differences were observed.

Table 2. Results (Mean ± Standard Deviation) of the force output in the examined bilateral vertical jump tests ($n = 9$).

Parameter	TOL	SWL	*t*	*p*	*d*	Θ_{SYM}
			SQJ-BIL			
FzSTART (N)	348.6 ± 36.7	360.3 ± 14.3	0.955	0.368	0.32	−1.18
FzMAX (N)	988.8 ± 82.2	988.7 ± 69.7	0.001	0.999	0.00	0.02
FzNET (N)	640.2 ± 83.4	628.4 ± 63.2	0.513	0.662	0.17	0.50
FzNET (N/kg)	0.91 ± 0.15	0.89 ± 0.12	0.543	0.602	0.18	0.50
			CMJ-BIL			
FzSTART (N)	351.3 ± 33.7	356.3 ± 26.1	0.355	0.732	0.12	−0.49
FzMAX (N)	1103.0 ± 122.9	1116.8 ± 61.5	0.372	0.719	0.12	−0.52
FzNET (N)	751.7 ± 129.4	760.6 ± 60.6	0.212	0.837	0.07	−0.68
FzNET (N/kg)	1.06 ± 0.18	1.08 ± 0.13	0.283	0.785	0.09	−0.68

FzSTART: vertical ground reaction force at the initiation of the jump; FzMAX: maximum vertical ground reaction force; FzNET: peak net vertical force; *d*: effect size (Cohen's d); Θ_{SYM}: symmetry angle (%).

3.3. Unilateral Vertical Jump Tests

The biomechanical parameters of the unilateral vertical jump tests are presented in Table 3. The only significant ($p < 0.05$) difference was observed in $Sz_{BCM\text{-}BR}$ (trivial effect size).

Table 3. Results (Mean ± Standard Deviation) of the biomechanical parameters in the examined unilateral vertical jump tests (n = 9).

Parameter	CMJ-TOL	CMJ-SWL	t	p	d	Θ_{SYM}
h_{JUMP} (m)	0.221 ± 0.032	0.224 ± 0.037	0.123	0.910	0.09	−0.49
Uz_{TOFF} (m/s)	2.08 ± 0.15	2.09 ± 0.17	0.117	0.921	0.06	−0.25
$Sz_{BCM\text{-}BR}$ (m)	−0.189 ± 0.050	−0.204 ± 0.118	3.622	0.036 *	0.17	−2.43
$Sz_{BCM\text{-}PR}$ (m)	0.354 ± 0.022	0.368 ± 0.060	0.431	0.695	0.31	−0.99
FzSTART (N)	705.54 ± 41.74	705.74 ± 44.98	0.122	0.911	0.01	0.00
FzMAX (N)	1610.79 ± 210.33	1571.74 ± 157.25	0.550	0.621	0.21	0.69
FzNET (N)	905.25 ± 170.52	866.00 ± 139.19	0.542	0.626	0.25	1.25
RFD_{MAX} (kN/s)	12.01 ± 2.56	12.36 ± 2.50	0.108	0.921	0.14	−0.75
P_{MAX} (kW)	1.43 ± 0.29	1.29 ± 0.25	1.127	0.342	0.52	3.10
t_{IMP} (ms)	726.00 ± 39.27	730.50 ± 133.38	0.061	0.955	0.05	−0.14
t_{BR} (ms)	470.25 ± 47.25	466.75 ± 98.60	0.056	0.959	0.05	0.59
tFz_{MAX} (ms)	574.00 ± 55.91	515.00 ± 92.21	0.908	0.431	0.77	3.61
tP_{MAX} (ms)	630.75 ± 35.28	636.25 ± 126.98	0.078	0.943	0.06	−0.13

h_{JUMP}: jump height; Uz_{TOFF}: vertical body center of mass (BCM) take-off velocity; $Sz_{BCM\text{-}BR}$: maximum downward vertical BCM displacement; $Sz_{BCM\text{-}PR}$: maximum upward vertical BCM displacement; FzSTART: vertical ground reaction force at the initiation of the jump; FzMAX: maximum vertical ground reaction force; FzNET: net vertical ground reaction force; RFD_{MAX}: peak rate of force development; P_{MAX}: peak power output; t_{IMP}: total impulse time; t_{BR}: the duration of the downward phase; tFz_{MAX}: time to achieve maximum vertical ground reaction force; tP_{MAX}: time to achieve peak power output; d: effect size (Cohen's d); Θ_{SYM}: symmetry angle (%); *: $p < 0.05$ vs. CMJ-TOL.

3.4. Isometric Tests

The biomechanical parameters of the ISOM test are presented in Table 4. No significant ($p > 0.05$) inter-limb differences were found.

Table 4. Results (Mean ± Standard Deviation) of the biomechanical parameters in the examined isometric tests (n = 9).

Parameter	TOL	SWL	t	p	d	Θ_{SYM}
F_{MAXnet} (kN)	1.67 ± 0.42	1.57 ± 0.53	0.949	0.381	0.39	2.24
F_{MAX} (N/kg)	2.29 ± 0.60	2.19 ± 0.78	0.891	0.407	0.34	2.24
RFD_{MAX} (kN/s)	11.18 ± 1.80	10.95 ± 3.24	0.220	0.833	0.83	1.28
tF_{START} (ms)	165.86 ± 51.26	167.63 ± 47.64	0.462	0.660	0.18	−0.67
tF_{MAX} (ms)	782.43 ± 155.88	716.29 ± 121.09	1.461	0.194	0.55	2.64
$tRFD_{MAX}$ (ms)	237.14 ± 46.54	240.29 ± 44.88	1.252	0.257	0.47	−0.50

F_{MAXnet}: peak net isometric force; F_{MAX}: peak isometric force; RFD_{MAX}: peak rate of isometric force development; tF_{START}: time for the initiation of isometric force application; tF_{MAX}: time to achieve maximum isometric force output; $tRFD_{MAX}$: time to achieve RFD_{MAX}; d: effect size (Cohen's d); Θ_{SYM}: symmetry angle (%).

4. Discussion

The results of the present study revealed that force output was not different between TOL and SWL in bilateral and unilateral vertical jump tests, as well as in a maximum voluntary isometric leg press test. In addition, the direction of the inter-limb differences was mainly towards the TOL for the force output and towards the SWL for the temporal parameters.

The reliability of the measurements was excellent for the vertical jump tests and moderate for the isometric test. The reliability scores in the vertical jump tests' performance confirm previous observations [44–47]. In contrast, the moderate reliability for the isometric strength assessment test does not confirm the results of previous research reporting excellent reliability for this test [48]. This result may be due to the fact that, in the present study, the isometric leg press was used, while the isometric knee extension torque was used in the past research. Also, it has been found that the reliability in an isometric strength assessment test is excellent at knee joint angular positions of 60 deg and 90 deg [49], while, in the present study, the angular position of the knee joint was 120 deg. Another possible reason may be the fact that the isometric evaluation is not a specialized laboratory evaluation test for track and field athletes. This is because isometric dynamometry is a commonly used method of assessing muscle function, but the mode of contraction used in this test is different from the plyometric muscle function encountered in the majority of sports techniques [22].

Previous studies have shown no inter-limb asymmetry in force application during vertical jump tests [50]. The same was observed in the present study. In general, the assessment of the mechanical performance and, in particular, the examination of maximal force is effective for the study of inter-limb asymmetries due to its high reliability [21,25]. In addition, the results showed that the h_{JUMP} did not differ between the unilateral vertical jump tests. This finding is also in agreement with the literature [45,51–55]. Like the bilateral vertical jumps, there was no significant difference in the applied force in the single-leg vertical jump tests. This verifies earlier observations [45,51]. On the contrary, there are studies showing ambiguous results [56]. However, it has been argued that bilateral and unilateral force application tests provide reliable results concerning absolute, net, and relative force [57].

As in a previous study [23], no significant difference was found between the TOL and SWL in the examined tests. In relation to previous studies [45,51,55,58], the asymmetry values observed in the present research are smaller. This finding was based on the symmetry angle since this index has the ability to express the magnitude and the direction of the asymmetry, thus overcoming the limitations associated with the selection of a reference limb [59]. Furthermore, the participants in the present study were adults, and thus, an earlier report on the existence of isokinetic torque asymmetries in Greek jumpers of developmental ages [32] is not confirmed. Additionally, in the majority of adult Greek long jumpers, no significant asymmetry was observed in their step parameters during the approach for a jump [37]. Earlier findings suggest that isokinetic torque is correlated with LJ performance [60]. However, it is not clear if the isometric and/or the isotonic muscle strength is, to some extent, an important determining performance factor in the long jump [61].

It has been argued that the type of sport, combined with the length of time an athlete has been involved in the sport, influences the magnitude of the asymmetry [62]. Asymmetries are an adaptive consequence that is magnified with long-term sports participation [33], where the differences in asymmetry in force application are affected by physical activity since repetitive unilateral loadings of the neuromuscular system cause adaptations, both to optimize performance as well as to ensure isomerism [11,58]. Increased loading is evident during the take-off phase of the long jump [9,63]. In the horizontal jumps, the conversion of horizontal speed to vertical to achieve the desired take-off angle with the minimum loss of speed is based on the application of maximum force in the shortest push-off time [64]. This appears to cause asymmetric adaptations in the gastrocnemius muscle force application capacity and Achilles tendon stiffness between the push and swing leg [65]. Nevertheless, it seems that there is a protective mechanism with the existence of uniformity in the myotendinous complex [65]. In addition, the possible absence of asymmetry in the tested jumpers can be attributed to the fact that the performance of the steps during the approach run can be considered as repeated symmetrical plyometric functions of the lower limb muscles and constitute an isomeric training stimulus [66]. Another possible explanation is that subjects undergoing systematic strength training were found to show little asymmetry in isometric force application [67]. Finally, it is suggested that inter-limb asymmetries do not impose a negative impact on vertical jump performance, unlike sprinting and change of direction actions [68].

This study is not free from limitations. One is that there was no arm movement, despite the fact that an arm swing is used in the long jump take-off technique, and it is not restricted when jumping exercises are included in the training. However, arm movement generates work that is transferred to the legs, and that enhances vertical jump ability [69–71]. Thus, to ensure the validity of the examined vertical jump tests, the arms were kept akimbo. Another limitation is that the profiling of the examined jumpers, i.e., if they present asymmetry in the step parameters of the approach [37] or the applied technique to the generated mechanical work at the take-off [72], could add context to the examination of their asymmetry in the vertical jump tests. Another limiting factor is the duration of the force application in the examined tests, which is much longer than the duration of the push-off phase in the long jump, being, on average, 0.125 s [4].

To conclude, vertical jump tests are unable to indicate which muscle or muscle groups are responsible for the asymmetry [73]. It has also been observed that asymmetry values are not constant across a set of tests but can shift the direction of asymmetry from one limb to the other depending on the assessment test [39], as the preference and dominance of a limb are determined by the skill to be performed [74]. For this reason, in addition to the appropriate selection of the assessment test, it has been suggested that future research should quantify the reliability of asymmetry in the measurements that evaluate the lower extremity function [75], as well as a longitudinal assessment of the asymmetry and its interpretation depending over a training period [76]. In this case, asymmetry should also be examined in relation to the type of training (single- or double-legged plyometric and strengthening exercises), as there is a different effect on the symmetry indexes [77,78]. Finally, future research should examine vertical jump asymmetry along with the reliance and asymmetry in the step parameters in athletes competing in the track and field horizontal jumps.

5. Conclusions

The long jump is characterized by the powerful execution of a unilateral take-off. Despite the fact that the long jump also includes the intensive execution of the bilateral tasks of the approach run, it is widely considered reasonable that the dominant/take-off leg is stronger than the contra-lateral leg. Consequently, this inter-limb asymmetry in force application is considered to be a factor responsible for causing injuries in athletes competing in the track and field horizontal jumps. According to the findings of the present study, no significant asymmetries in the kinetic and temporal parameters of commonly conditioning monitoring tests were observed in the examined jumpers. This can be interpreted as a predisposition for improved jumping ability in practice and a reduced injury occurrence possibility. Therefore, coaches are encouraged to include unilateral and bilateral jumping tests to retrieve useful information concerning inter-limb asymmetry in the pursuit of augmented performance and injury-free training programs.

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