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Agreement between Inter-Limb Asymmetries in Single and Triple Unilateral Hops, and Associations with Bilateral Jumping and Sprint Performance in U17 and U19 Soccer Players

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Abstract: The purpose of this study was to investigate the agreement regarding the direction of interlimb asymmetry (ILA) between different horizontal jumping tests, to examine the differences in ILA between different age categories and to assess the relationship between ILA and sprint and jump performance. The sample included 38 elite youth male soccer players from two distinct age categories (U17 and U19). The testing procedure consisted of a 10 m sprint test, unilateral and bilateral broad jumps, and unilateral and bilateral triple hops. The results showed moderate correlation and fair agreement in the direction of ILA between single broad jumps and single-leg triple hops ($\kappa = 0.42$; $p = 0.014$). The magnitude of ILAs tended to be larger in the unilateral triple hop ($5.41 \pm 5.25\%$) compared to the unilateral single hop ($3.54 \pm 2.67\%$). Furthermore, the older group had smaller ILA magnitudes in both jumping tests, with significant differences between age groups being observed only in single hops ($p = 0.46$; d = 0.78). Additionally, significant associations were found only between the ILA unilateral triple hop with bilateral single jump ($r = -0.39$) and sprint performance ($r = 0.40$), while ILA in the broad jump showed no significant associations with performance metrics. Based these results, the unilateral triple hop could be recommended as the preferred horizontal jump variation for screening soccer players. Furthermore, in line with the literature, mean ILA in horizontal jumps were far below the commonly used threshold of >10–15% (mean ILA 3.5–6.5%), which suggests that the ILA threshold for horizontal jumps should be reconsidered.

Keywords: football; asymmetry; horizontal jumps; sprint; soccer performance

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1. Introduction

Soccer is a complex and high-intensity contact sport, involving a multitude of ballistic actions, which are underpinned by rapid and powerful movements of the lower-limb muscles [1]. Soccer players are required to perform a combination of movements, such as quick accelerations, decelerations, changes of direction (CoD) and kicking. In these activities, the strength and power of the lower limbs serve as critical predisposing factors for effective performance [2,3].

Soccer predominantly involves unilateral movements, as indicated by numerous studies [2,4–6]. Additionally, soccer players often exhibit a preference for a particular limb when executing certain tasks [7] and face distinct demands based on their playing positions. These sport-specific unilateral demands are linked to mechanical adaptations, potentially leading to an imbalance in lower limb strength. This imbalance may result in the development of inter-limb asymmetry (ILA) [8]. ILA is quantified as the percentage difference between limbs in performance or function during a given task [4,9]. In other words, ILA reflects the difference in the performance or function of one limb with respect to another [10]. ILAs, specifically in strength, have been identified as significant risk factors for injury [11,12]. For instance, soccer players with notable asymmetries are at an increased risk of sustaining hamstring injuries [12]. Additionally, limb dominance has been implicated as an etiological factor in the occurrence of anterior cruciate ligament (ACL) injuries in soccer players [13]. Consequently, ILA assessment is a routine aspect of injury rehabilitation, with a commonly accepted threshold for asymmetries in the return-to-sport context typically being less than 10% [9]. The literature suggests that the return-to-sport protocol following an ACL injury includes the assessment of ILA through various jump tests and metrics [14,15], with a primary rehabilitation goal being the achievement of an ILA of less than 10% [16].

In recent years, a multitude of studies have explored the association between ILA and its effects on athletic performance in soccer players [2,6,7,17–20]. Specifically, the literature indicates a correlation between a larger asymmetry in quadricep and hamstring strength and an inferior change of direction (CoD), sprinting, and jumping performance in soccer players [7,18]. However, the literature presents conflicting results regarding the impact of jumping asymmetries on CoD, sprint, and jump performance in soccer players. While most studies suggest that ILAs in vertical jumps (such as countermovement jumps (CMJ) and drop jumps (DJ)) adversely affect sprint and CoD performance [19,20], ILAs in lateral and horizontal jumps have not been shown to correlate with sprint and CoD performance in team-sport athletes [21,22]. Furthermore, Isin et al. [17] and Pardos-Mainer et al. [6] found no significant correlation between jump asymmetries and performance in male and female soccer players, respectively, while Bishop et al. [2] observed negative impacts of jumping asymmetries on performance in female players. Additionally, a study on adolescent female soccer players reported that asymmetries in jumping and CoD asymmetries did not interfere with physical performance [6], with similar results reported also in young female handball players [23]. The study reported that in U14 and U16 categories, jumping asymmetries did not correlate with jumping performance, while some moderate correlations were found in U18 players. On the other hand, Bishop [2], Fort-Vanmeerhaeghe [11] and Madruga Parera [24] reported a negative effect of jumping asymmetries on sprint speed in young team-sport athletes. These contrasting findings suggest varied effects of asymmetries on soccer performance, depending on the tasks and investigated population.

While it has been traditionally believed that ILAs exceeding 10–15% are associated with an increased risk of injury and negative impacts on performance, recent studies have highlighted that the extent of ILA significantly depends on the specific task being performed. This suggests that various tests may necessitate different thresholds for ILA [21,25,26]. Furthermore, recent research has also investigated the direction of asymmetry, revealing that the more “capable” or “proficient” limb can vary depending on the test administered [6,25,27]. This divergence in findings suggests that ILA could be both task-specific and individual-specific [2,5,6,11]. Consequently, it is advisable for practitioners to utilize multiple testing protocols to comprehensively assess ILA in soccer players, as a single test may not entirely reveal an individual’s ILA profile.

Bishop et al. [19] reported a variability in asymmetries among soccer players throughout a season, indicating that asymmetries may quickly adapt to the specific load demands of the sport. While it is established that asymmetries depend on the task and metric, the question of whether the magnitude of asymmetry varies with age remains unresolved. Load demands are different between different age categories and compared to senior teams, thus data asymmetry scores among young categories may be different compare to those reported in senior teams [19]. Kalata et al. [28] showed that 28–68% of the players have asymmetries of higher than 10% in the knee extensors and flexors. Moreover, regrading lower limb asymmetry in young soccer players, some studies show that asymmetry is reducing with training age [29], while others show that there is no exact order in asymmetry magnitude between different age categories [28,30]. Furthermore, although the magnitude and direction of asymmetry are known to be test-dependent, there is a need for a comprehensive study to evaluate the magnitude, agreement, and relationships among ILA in various jumping tasks and their correlation with sprint performance in soccer players. In light of the unilateral demands of soccer and the importance of assessing ILA, this study was designed with three primary objectives: (a) to evaluate the agreement in the direction of ILA between different horizontal jumping tests; (b) to investigate differences in ILA across various age categories; and (c) to examine the relationship between jumping asymmetries and both sprint and jump performance in elite youth male soccer players.

2. Materials and Methods

2.1. Participants

For this study, we recruited 38 youth professional soccer players from two distinct age categories (U17 and U19). The participants had an average age of 16.4 years (±1.0), an average body height of 173.83 cm (±23.9), and an average body mass of 75.9 kg (±28.5). All players were professional, actively involved in regular soccer training and matches on regional or national levels, and participating at least five times per week (~10 h), and engaged in resistance training a minimum of twice per week at the youth academy of a professional football club. The inclusion criteria for participants required the absence of any musculoskeletal injuries or pain syndromes within the last year, as well as the absence of any medical conditions that could potentially be exacerbated by the measurement procedures. Prior to the commencement of measurements, participants were thoroughly informed about the details of the protocol and were required to sign an informed consent form. For underage participants, their parents or legal guardians signed the consent form on their behalf. The protocol for this study was conducted in accordance with the latest revision of the Declaration of Helsinki. The experimental procedures of this study were reviewed and received approval from the Republic of Slovenia's National Medical Ethics Committee (reference number: 0120-690/2017/8).

2.2. Study Design

This was a cross-sectional study conducted in a single visit (total time: ~60 min). The participants had been routinely performing the testing procedures that are regularly implemented in the physical preparation part of the training process; therefore, no familiarization session was conducted. The participants performed a warm-up, consisting of 10 min of light running, 5 min of dynamic stretching and 5 min of dynamic exercises simulating the testing drills (lunges, and jumps in different directions and accelerations). After the warm-up protocol, participants first completed the sprint test, followed by unilateral and bilateral broad jumps, and unilateral and bilateral triple hops, with the order of jumping tests being randomized.

2.3. Testing Procedures

The assessments were performed on a soccer field in soccer boots. Participants were instructed to perform a single jump (broad jump) or three consecutive jumps (triple hop) for distance. The participants started with their toes aligned to the starting line. They were instructed to jump a best distance. The distance for all jumps was recorded from the starting point (participants were instructed to align their toes with the starting line) to the point where the heel landed upon the competition of the jump (last jump in the case of the triple hop). Broad jumps were performed in unilateral and bilateral circumstances, with 3 correct repetitions performed for each jump [31]. The unilateral triple hop was performed with three consecutive jumps on the same leg for distance [25]. In the bilateral triple hop, the first jump was performed bilaterally, followed by consecutive unilateral jumps on each leg in alternating order. Subjects were free to choose the order of one-legged jumps during the bilateral triple hop, with the same order being kept constant across repetitions [32].

Sprint was assessed using two pairs of single-beam laser timing gates (Brower Timing Systems, Draper, UT, USA), which were positioned at the hip level and recorded the times to the nearest 0.001 s. Sprints were performed across a distance of 10 m. The test started 30 cm behind the start line, to prevent early triggering. Participants started in standing position, with their preferred front leg. The instruction was to sprint from the start line through all sets of timing gates as fast as possible. Participants did three trials with 2 min breaks between repetitions.

2.4. Assymetry Calculation

Asymmetries were calculated for single-leg hop and unilateral triple hop, using the following formula: asymmetry (%) = ((max (left or right) − min (left or right))/(max (left or right)) × 100 [9].

2.5. Statistical Analysis

The data are presented as means ± standard deviations. The normality of the data distributions for all variables was verified with the Shapiro–Wilk test (all $p \geq 0.195$). The reliability across repetitions was evaluated with intra-class correlation coefficient (ICC; single measures, absolute agreement). We considered ICC values <0.5 to be indicative of poor reliability, values between 0.5 and 0.75 to indicate moderate reliability, values between 0.75 and 0.9 to indicate good reliability, and values greater than 0.90 to indicate excellent reliability [33]. Additionally, absolute reliability was assessed by calculating the coefficient of variation (CV) and was interpreted as poor (CV > 10%), moderate (CV = 5–10%) and good (CV < 5%) [34]. Pearson's correlation coefficients were used to examine the correlations between variables and was interpreted as follows: 0.0–0.1 (no association), 0.1–0.4 (weak), 0.4–0.6 (moderate), 0.6–0.8 (strong) and >0.8 (very strong) [35]. Kappa coefficients were calculated to determine the levels of agreement for the direction of ILAs between the tests. The agreement was interpreted as follows 0.01–0.20 = slight; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = substantial; 0.81–0.99 = nearly perfect. Differences between U19 and U17 groups were assessed with independent-sample t-tests, and the differences between the tests were assessed with pair-wise t-tests. Cohen's d effect sizes were calculated as trivial (<0.2), small (0.2–0.5), medium (0.5–0.8), large (0.8–1.2), very large (1.2–2.0), and huge (>2.0) [36]. The threshold for statistical significance was set at $\alpha < 0.05$. To control for the type 1 error, we applied Holm–Bonferroni sequential correction of p-values [37]. All analyses were carried out using SPSS statistical software (version 25.0, IBM: Armonk, NY, USA).

3. Results

The relative and absolute reliabilities were good for all tests: unilateral single hop on the left (ICC = 0.87, CV = 2.20) and right leg (ICC = 0.83, CV = 2.17), the unilateral triple hop on the left (ICC = 0.84, CV = 2.15) and right leg (ICC = 0.88, CV = 2.53), the bilateral single jump (ICC = 0.88; CV = 1.99), and the triple hop (ICC = 0.81, CV = 2.85). The exception was the 10 m sprint, which showed only moderate reliability (ICC = 0.69, CV = 2.70).

3.1. Descriptive Statistics and Differences between the Age Categories

The descriptive statistics, stratified by age category, are shown in Table 1. The U19 group had a smaller ILA magnitude in the unilateral single hop ($p = 0.46$; d = 0.78) compared to the U17 group, while the ILA in the unilateral triple hop was not statistically significantly different between the groups ($p = 0.187$). The U19 group also showed superior performance in the unilateral triple hop ($p = 0.025$–0.041; d = 0.78–0.86), the bilateral single jump ($p = 0.012$; d = 1.05), the triple hop ($p = 0.021$; d = 0.88) and the 10 m sprint ($p = 0.011$; d = 0.93) compared to the U17 group. They also tended to have better unilateral single-hop results (d = 0.57–0.74), but the differences did not reach statistical significance ($p = 0.056$–0.141).

Table 1. Descriptive statistics with between-group differences.

Outcome	U19		U17		Difference	
	Mean	SD	Mean	SD	Sig. (*p*)	ES (d)
Unilateral Single Hop—Left (cm)	228.6	16.3	216.5	16.6	0.056	0.74
Unilateral Single Hop—Right (cm)	225.2	15.4	217.4	13.3	0.141	0.54
Unilateral Single Hop—ILA (%)	2.50	2.03	4.41	2.89	**0.046**	0.78
Unilateral Triple Hop—Left (cm)	706.4	44.0	666.9	48.3	**0.025**	0.86
Unilateral Triple Hop—Right (cm)	683.4	44.5	645.7	52.2	**0.041**	0.78
Unilateral Triple Hop—ILA (%)	4.02	3.02	6.54	6.42	0.187	0.54
Bilateral single jump (cm)	251.6	13.1	236.4	16.0	**0.012**	1.05
Triple Hop (cm)	732.2	54.6	686.8	48.7	**0.021**	0.88
10 m Sprint (s)	1.70	0.08	1.77	0.06	**0.011**	0.93

SD—standard deviation; sig.—significance; ES—effect size, cm—centimeter, s—seconds; ILA—interlimb asymmetry; U19—under 19; U17—under 17.

3.2. Agreement between ILAs in Single and Triple Unilateral Hops

We observed a fair agreement regarding the direction of ILAs between the two tests (κ = 0.42; p = 0.014). The magnitude of ILAs tended to be larger in the unilateral triple hop (5.41 $\pm$ 5.25%) compared to the unilateral single hop (3.54 $\pm$ 2.67%), but the difference was not statistically significant (p = 0.056). The ILA magnitudes between the single and triple unilateral hop were also in moderate correlation (r = 0.50; p = 0.004). Figure 1 shows the participant-by-participant data for ILAs in both tests.

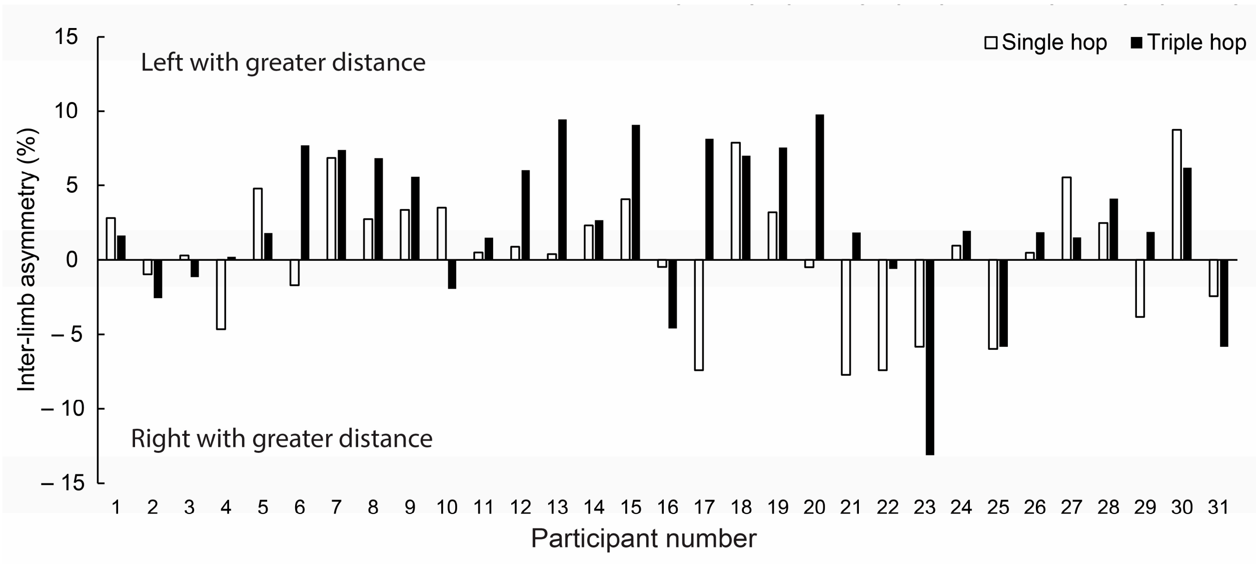

Figure 1. Inter-limb asymmetry magnitudes for individual participants.

3.3. Correlations with Bilateral Jump

The bilateral single-jump distance was moderately associated with the unilateral single-hop distance (r = 0.59–0.67; p < 0.001), but not with the ILA magnitude in the unilateral single hop (p = 0.634). In addition, the bilateral single-jump distance was moderately associated with single–triple-hop distances (r = 0.62–0.64; p < 0.001) and was also in small inverse correlation with ILA magnitudes in single–triple hop (r = $-$0.39; p = 0.038).

3.4. Correlations with Triple-Hop Distances

Triple-hop distance was in moderate to high association with unilateral single-hop distances (r = 0.55–0.68; p < 0.001) and unilateral triple-hop distances (r = 0.76–0.77; p < 0.001), but not with the ILA magnitude in any of the unilateral tests (r = 0.16–0.33; p = 0.066–0.385).

3.5. Correlations with Sprint Performance

Sprint performance was moderately associated with unilateral single-hop distances on the right (r = −0.41; p = 0.009) but not the left leg (r = −0.31; p = 0.081), nor with the ILA magnitude in the unilateral single-hop (r = 0.12; p = 0.489). In addition, sprint performance was associated with unilateral triple-hop distance for the left (r = –0.40; p = 0.029) and the right leg (r = –0.67; p < 0.001), as well as with the magnitude of the ILA in unilateral triple-hop (r = 0.40; p = 0.030

4. Discussion

The aims of the present study were (a) to assess the agreement in the direction of ILAs between different horizontal jumping tests; (b) to examine the differences in ILAs between the U17 and U19 categories; and (c) to assess the relationship between jumping asymmetries and sprint and jump performance in elite youth male soccer players. The older group (U19) demonstrated smaller ILA magnitudes in both jumping tests. However, statistical significance was reached only in the single hop, not in the triple hop. Furthermore, ILAs in the two jumping tests showed moderate correlation and fair agreement in the direction of the asymmetries. Regarding the associations between ILA and performance tests, no correlations were found between triple-hop distances and ILA in any of the tests. In contrast, ILA in the unilateral triple hop was in a small negative correlation with the bilateral single jump. Additionally, sprint performance was positively correlated with the magnitude of the ILA in unilateral triple-hop distances.

The older group (U19) demonstrated superior performance with smaller Inter-limb asymmetry (ILA) in all tests, compared to the younger group (U17). These results were expected, as the disparity in physical performance is likely attributed to differences in physical maturity between the groups. This hypothesis is supported by previous research, such as the study by Gissis et al. [38], which found that elite soccer players exhibited superior performance in key indicators like 10 m sprint speed compared to younger players. The age difference between the groups in our study was approximately two years, positioning the age groups around or just after peak height velocity (PHV). PHV is indicative of the process of physical maturation, suggesting that the U17 team was either at or just past their PHV, while the U19 team had progressed further beyond PHV (i.e., they had reached physical maturity) [39,40]. Furthermore, Fousekis, Tsepis and Vagenas [29] reported that asymmetry reduces with training age in professional soccer players. Additionally, Kalata et al. [28] reported that the incidence of significant ILA (ILA of >10%) in knee extensors and flexors is higher in younger categories (U13 and U15) compared to older (U17) categories. Similar was found for CoD asymmetries, where U15 and U16 had the higher ILA score than U17 and U18 soccer players [30]. In agreement with previous results, in our study we showed that the U17 category exhibited higher ILA scores than the U19 category, indicating that ILA decreases with age in soccer players as a result of the maturation process and/or training age. Therefore, practitioners must be aware of higher baseline asymmetry magnitudes in younger age categories and may consider implementing training strategies to ensure that side-to-side differences do not increase any further [20]. Nevertheless, although the literature suggests that asymmetry in magnitudes of >10–15% presents a higher injury risk, it should be pointed out that the asymmetry threshold of 10–15% may not be suitable for horizontal jumping tasks, as studies are showing mean asymmetry magnitude to range from 3.5 to 6.3% in team-sport athletes [2,11,21,22,25]. The present study indicates that a 5% ILA is significant in tasks involving horizontal force production, indicating that asymmetries in such tasks may appear on a smaller scale. This suggests that the asymmetry threshold for horizontal jumps might be set at a lower magnitude than the commonly used 10–15%.

Regardless of age group, correlations with sprint performance were positive, indicating that larger asymmetries were associated with slower sprint speeds. Additionally, correlations with bilateral and unilateral hops were negative, suggesting that larger asymmetries correlated with reduced jump performance. While several studies have shown that ILAs in strength negatively influence the athletic performance of team-sport athletes [7,18,41], the literature presents conflicting results regarding the influence of ILA in jump tests on sprint and jump performance. Some studies report a negative influence of ILA [2,19,20,24], while others did not report a statistically significant relationship with physical performance in soccer players [6,17,21]. Furthermore, Kozinc and Šarabon [25] reported no significant correlations with jumping and CoD performance in volleyball players, while Bishop et al. [2] reported significant moderate negative correlations with horizontal jumping (r = −0.47 to −0.58), but not with CoD and sprint performance. In line with these results, Isin et al. [17] and Dos'Santos et al. [22] reported no significant correlations between triple-hop ILA and sprint performance in soccer players and team-sports athletes, respectively. Similarly, research indicates that while ILA in single horizontal jumps adversely affects jump performance, it does not significantly impact sprint performance [6,7,11,21]. Moreover, all performance variables included in this study (10 m sprint, triple jump, and bilateral single-jump) were moderately associated with the unilateral single-hop and unilateral triple-leg hop distance. These results are in line with the study from Lockie and his colleagues [21], reporting that longer jumps in single-leg horizontal hops indicate better sprint and CoD performance (r = −0.31 to −0.70), while no significant correlations were reported between ILA and performance metrics [21]. In summary, the literature indicates that larger between-limb differences tended towards negative influences on athletic performance in soccer players (with no significant correlations or correlations towards reduced performance), showing the importance of screening soccer players for ILA.

Jumping tests used in this study are commonly used in sport practice as part of return-to-sport testing after the injury and as a pre-season screening protocol to evaluate athletes' physical function. When using these tests, practitioners must be aware of potential pitfalls during result interpretation. In similar unilateral tasks, asymmetry index usually draws a lot of attention, with the traditional threshold being set at >10–15%, which may not be suitable for horizontal tasks. Instead, a lower benchmark of 5% could be proposed for young soccer players. Although the literature associates ILA with injury occurrence [12], the magnitude can be underestimated due to the poor performance of the uninjured side when returning to sport after an injury [14,16]. Moreover, as seen also in our study, jumping asymmetries have detrimental effects on physical performance [41]; thus, fixing jumping asymmetries may potentially improve athletes' physical performance. Additionally, practitioners are also encouraged to take into account pure physical performance, as a recent study showed that longer jumps were (i.e., better performances) in soccer players who went on to sustain a primary or secondary ACL injury compared to those who did not over a two-year follow-up period [42]. Although the relationship between better jump performance and injury risk is unclear and performance is likely not a predictor per se, it is recommended that practitioners consider both metrics, pure performance, and asymmetry index, to navigate future training programs for soccer athletes. Even though hop tests are usually not used in isolation to evaluate athletes' physical readiness, their interpretation needs the consideration of both performance and asymmetry score in the decision making when planning training processes for soccer players.

Some limitations of this study, along with implications for future research, should be acknowledged. The sample was restricted to male youth soccer players, which limits the generalizability of the findings to other sports. Additionally, the maturation status of participants was not monitored, potentially affecting the results; outcomes might differ if early developers were excluded from the younger group and late developers were from the older group. Next to that, all measurements were taken in a single day, which may have impacted players' performances and thus influenced the results of this study. Furthermore, the study's variables encompassed only a limited aspect of performance and were measured at a single time point. For example, we did not include unilateral jump distance as a performance measure, while it may still be useful performance measure because of its relationship with other unilateral movement tasks such as CoD ability. Future research should aim to monitor ILAs longitudinally, assessing the relationship between changes in asymmetry and changes in performance measures, alongside the longitudinal monitoring of injury occurrence. Additionally, future studies should aim to establish more precise thresholds for ILA magnitude in horizontal jumping, as the current reliance on a 5–15% guideline lacks individualization for specific tasks. Moreover, future research is encouraged to report asymmetry data together with leg/hand dominance to obtain a more comprehensive view of the asymmetry behavior in different movement tasks in specific populations.

5. Conclusions

In summery, fair agreement in the direction of ILA in both unilateral single hops and triple hops was found, with a higher ILA magnitude observed in the unilateral triple hop. The U19 group exhibited a smaller ILA magnitude in both jumping tests compared to the U17 group, indicating that practitioners should be cautious of a higher baseline asymmetry magnitude in younger age categories. Moreover, the unilateral triple jump (both distance and ILA magnitude) showed higher correlations with performance metrics compared to unilateral single-hop variables. Given the findings of this study, the unilateral triple hop might be preferable to horizontal jump variations for coaches to use for screening soccer players. Furthermore, it could be suggested that the commonly used asymmetry threshold of >10–15% is not suitable for horizontal jumps. Instead, a lower threshold, with a 5% benchmark, is proposed to be more appropriate for asymmetry recognition in these tasks.

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