10-17-2022

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10.1007/s42978-022-00188-8
This is an Authors Accepted Manuscript version of an article published by Springer in Journal of Science in Sport and Exercise.
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Bettariga, F., Maestroni, L., Martorelli, L., Jarvis, P., Turner, A., & Bishop, C. (2022). The effects of a unilateral strength and power training intervention on inter-limb asymmetry and physical performance in male amateur soccer players. *Journal of Science in Sport and Exercise, 5,* 328–339. https://doi.org/10.1007/s42978-022-00188-8

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The Effects of a Unilateral Strength and Power Training Intervention on Inter-limb Asymmetry and Physical Performance in Male Amateur Soccer Players

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All authors have reviewed and approved the final version of this manuscript

Abstract

The aims of this study were: a) to investigate the effects of a unilateral training program in reducing inter-limb asymmetry in male soccer players; b) to explore such effects on measures of physical performance and unilateral inter-limb asymmetry. Twenty-four soccer players, randomly assigned to a 6-week unilateral strength and power training (UNI) (*n* = 12) or a control group (CON) (*n* = 12), performed single countermovement jump (SLCMJ), single leg broad jump (SLBJ), and single leg drop jump (SLDJ), and 10-meter sprint and 505 change of direction (COD) speed test. Raw jump scores revealed small to large improvements in SLCMJ, SLBJ, and SLDJ reactive strength index (RSI) (*g* = 0.46 to 1.66) in the UNI group; whereas negligible changes were found in the CON group (*g* = -0.31 to 0.33). Asymmetry indexes showed a moderate significant reduction in the SLDJ (RSI) and in the SLDJ stiffness (K) (*g* = 1.00 to 1.11) in the UNI group. The between-group comparison indicated a significant change in the SLDJ (RSI) and in the SLDJ (K) (*g* = 1.01 to 1.07) in favour of the UNI group. Thus, a unilateral training program seems to be able to reduce between-limb imbalances and foster improvements in jump performance, without any detrimental effects on linear or COD speed times. Given the importance of these physical characteristics for soccer, it is suggested that unilateral strength and power training are incorporated into strength training routines for players of all abilities.

Key Words: training program, between-limb differences, resistance training, plyometrics, football.

INTRODUCTION

Soccer is a high-intensity team sport that requires a range of physical qualities (i.e., strength, power, speed, and agility) to optimize performance (Turner and Stewart, 2014). Specifically, soccer players are required to jump, kick, accelerate, decelerate, sprint, and change direction at different angles, numerous times during both training and matches (e.g., professional players often perform ~11 sprints and ~700 directional changes per match) (Wing et al., 2020, Andrzejewski et al., 2013, Bloomfield et al., 2007). Of particular importance, speed and change of direction (COD) abilities are essential for a high level of athleticism, and many studies have been conducted to improve such qualities in soccer (Emmonds et al., 2019). Owing to the unilateral nature of soccer (e.g., kicking, jumping, sprinting, and changing direction), athletes are likely to develop a preferred limb to complete these athletic movements (Virgile and Bishop, 2020). This results in inter-limb asymmetry, which refers to the difference in performance or function of one limb relative to the other (Virgile and Bishop, 2020). For example, jump testing represents a valid and reliable method to assess a wide range of different athletic qualities unilaterally (e.g., jump height, reactive strength, force and power), which can then be analysed to identify inter-limb asymmetry profiles (Bishop et al., 2017). The association between inter-limb asymmetry and independent measures of physical performance (e.g., sprinting and COD speed), has shown equivocal results regardless of the sporting sample in question (Fort-Vanmeerhaeghe et al., 2020, Bishop et al., 2018b). However, studies reporting correlational data cannot infer any cause and effect, which can only be done via some training intervention studies. Thus, further research using training intervention studies and their effects on inter-limb asymmetry are warranted.

Recently, the impacts of training interventions on between-limb imbalances have been investigated across different sports, reporting unclear results (Bettariga et al., 2022). For example, Dello Iacono et al. (Dello Iacono et al., 2016) found a large reduction in between-limb imbalances (ES = 2.01) in the single leg countermovement jump (SLCMJ) height in male soccer players after a 6-week core stability training program. However, it should be acknowledged that the training intervention was mainly based on strength and sprinting exercises (e.g., Nordics, lunges and sprints), not what many might perceive to be "core exercises". In addition, Pardos-Mainer et al. (Pardos-Mainer et al., 2019) found trivial to moderate reductions in asymmetry indexes in horizontal jumps (ES = 0.26) and COD speed (ES = 0.49) in female soccer players after a 10-week FIFA 11+ protocol, consisting of core exercises (e.g., plank), lower limbs strength exercises (e.g., Nordics, lunges) and plyometrics (e.g., bounding). Similar findings were found in a 8-week strength and power training in female soccer players, when lunges, hip thrusts, box drops, lumbar bridges and plank exercises were programmed and undertaken twice a week (Pardos-Mainer et al., 2020). Results reported trivial reductions in the asymmetry index related to the single leg broad jump (SLBJ) (ES = 0.26) and COD (ES = -0.30). In contrast, in the same studies, negligible or even negative changes were examined in the post-intervention analysis on asymmetry in vertical jump tests (ES = -0.62 to -0.21) (Pardos-Mainer et al., 2019, Pardos-Mainer et al., 2020). Additionally, Rey et al. (Rey et al., 2017) showed a decrease in the asymmetry index in two different eccentric training groups (i.e., Nordic hamstring exercise vs. Russian belt exercise) in young male soccer players using the single leg hamstring bridge (SLHB) performed to failure after a 10-week training program. Results showed between-limb imbalances reduced by 5.28% and 1.92%, respectively from each exercise. However, when performed to failure, the SLHB is an endurance or muscle capacity test, and limited data exists on using such methods as outcome measures to inform practice. In addition, Madruga-Parera et al. (Madruga-Parera et al., 2020) examined the effects of an 8-week isoinertial vs. cable-resistance training intervention, based on unilateral lunges and squats both forward and lateral, vertical and horizontal hops, acceleration and COD sprints in young male handball players. The training intervention also included specific handball skills and match replication movements (i.e., defensive vs. attacking actions). Results showed trivial to small changes in the SLBJ (ES = -0.40 to 0.15) and the unilateral lateral jump (ES = -0.34 to 0.00) asymmetry indexes in both groups; whilst larger decreases were found in the SLCMJ in the isoinertial (ES = -0.70) compared to the cable-resistance group (ES = -0.32). Finally, Gonzalo-Skok et al. (Gonzalo-Skok et al., 2019) also showed mixed results examining the effects of three different eccentric training volumes (i.e., same or double volume) and limb dominance (i.e., starting with the weaker or stronger leg) on inter-limb asymmetry in the SLBJ (ES = -0.58 to 0.06), triple hop (THOP) (ES = -0.07 to 0.88), and SLCMJ (ES = 0.08 to 0.24) tests, in male young soccer players after 10 weeks of training consisting of unilateral squats using a portable conical pulley. Cumulatively, the current literature reports equivocal results pertaining to the effects of training interventions on inter-limb asymmetry in soccer players. Importantly though, the absence of a control group (Gonzalo-Skok et al., 2019, Madruga-Parera et al., 2020), limits any conclusive understanding of the possible effects of these training programs. An additional limitation in asymmetry interventions to date, is that these changes in asymmetry have not been related back to independent measures of athletic performance, which is of utmost importance for practitioners. Simply put, whilst changes in asymmetry may of course be possible from any given training intervention, does a given reduction in asymmetry correspond to athletes improving their athletic performance, very much remains unanswered. Finally, and to the best of our knowledge, no studies have been conducted adopting a solely unilateral training approach, which intuitively, seems like it may be relevant when assessing existing side-to-side differences.

When designing training interventions, strength and power training helps to develop physical qualities such as strength, power, speed, and COD ability, which are essential for heightened performance in soccer (Suchomel et al., 2018, Suchomel et al., 2016). Specifically, Stern et al. (Stern et al., 2020) found that unilateral strength and power training (i.e., rear foot elevated split squat (RFESS) followed by a variety of unilateral jumps) improved 1 repetition maximum (RM) in the RFEES (ES = 1.64), SLCMJ (ES = 0.54 to 0.76), and SLBJ (ES = 0.57 to 0.97) in elite youth soccer players. Moreover, significant improvements were also evident in 10-meter linear sprint (ES = -1.50) and 505 COD speed (ES = -0.78 to -0.57) times. Similarly, Faude et al. (Faude et al., 2013) examined investigated the effects of a combined unilateral strength and power training (i.e., half squat followed by single leg hurdle jumps) compared to a control group in adult male soccer players, finding significant difference for the 1RM half squat (ES = 0.76), countermovement jump height (CMJ) (ES = 0.58), and reactive strength index (RSI) (ES = 0.49) in favour of the intervention group. Therefore, a unilateral training intervention seems like it could be especially relevant for soccer players who require unilateral movement competency (e.g., kicking, sprinting or changing direction) and to improve physical performance (Stern et al., 2020).

Therefore, the main aims of this study were twofold: a) to investigate whether a unilateral strength and plyometric training was effective in reducing inter-limb asymmetry in vertical and horizontal jump tests in amateur male soccer players and, b) to explore the effects of a such training intervention on measures of physical performance and inter-limb asymmetry. Firstly, our hypothesis was that a unilateral strength and plyometric training would have a significant impact in reducing inter-limb asymmetry, due to the unilateral-based nature of soccer. Secondly, it was hypothesized that modifications in inter-limb asymmetry, induced by the training program, elicited improvements in athletic performance.

METHODS

Design

A randomized controlled trial design was used to determine the effects of a unilateral training intervention on inter-limb asymmetry and athletic performance in amateur soccer players. Between-limb imbalance tests (i.e., SLCMJ, SLBJ, single leg drop jump (SLDJ)) and athletic performance tests (i.e., 10-meter linear sprint and 505 COD speed test) were performed at baseline and 6 weeks after the training intervention in both groups. Subjects were randomly allocated to a unilateral (UNI) training intervention or a control (CON) group. The subjects were randomly allocated and equally distributed, using shuffled sealed envelopes, to one of the two groups. The experimental intervention was based on a 6-week training intervention, conducted 2 times per week at the end of the competitive season (i.e., no official matches), even though subjects continued to train. A 48-hour rest period was provided between the final test and the start of the intervention or the final training session and post-intervention testing.

Subjects

Twenty-four amateur male adult soccer players from three amateur soccer clubs (Italian league – fourth division) volunteered to participate in this study (subject characteristics are reported in Table 1). A minimum of 18 subjects was established from a priori power analysis using G*Power (Version 3.1, University of Dusseldorf, Germany) implementing statistical power of 0.8 and a type 1 alpha level of 0.05, which has been used in comparable literature (Dos'Santos et al., 2017a). Subjects were included if they fulfilled the following inclusion criteria: 1) older than 18 years of age, 2) a minimum of a 3-years' competitive soccer experience in the first team, 3) a minimum of a 1-year of resistance training experience, 4) no muscle injuries occurred in the last 6 months (i.e., no absence from competitions > 28 days) (Ekstrand et al., 2020) and, 5) no surgery in the last 12 months (e.g., anterior cruciate ligament reconstruction). All subjects were informed about the purpose of the study and the informed consent was given before the start of the experimental study according to the Declaration of Helsinki 2013. Ethical approval was granted by the London Sports Institute Research and Ethics Committee at Middlesex University.

Methodology

A standardized dynamic warm up was performed before the testing protocols, consisting of 2 sets of 10 repetitions of overhead squats, forward lunges, crab walks, glute bridges, and pogo jumps. Subsequently, 5 trials of CMJs, broad jump (BJ)s, and drop jump (DJ)s, with a 60-second rest period, were performed in order to familiarize players with the jumps required. Following this, 3 practice trials of incremental 10-meter linear sprint and 180° COD speed tests at 60, 80 and 100% of their maximal effort perceived (measured via RPE scale) were completed with a 120-second rest period between attempts (Alsamir Tibana et al., 2019). Jump testing was conducted in the gym with trainers, whilst 10-meter linear sprint and 505 COD speed test were completed on the grass soccer ~~football~~ pitch wearing soccer boots. Three minutes of rest was given between the last practice trial and the beginning of the assessments. Tests were executed starting with the jump tests followed by the 10-meter sprint and COD speed test, in an attempt to minimize fatigue impacting certain tests. Assessments were conducted on the same time of the day (i.e., 10 AM, 23° degrees, 42% humidity, sunny and no wind in the soccer pitch and 23° degrees and 40% humidity in the gym) to minimize confounding variables. Moreover, throughout the experimental study the subjects were asked to maintain their habitual lifestyle (e.g., diet, sleep and leisure activities).

For the jump tests, soccer players performed 3 trials on each leg, with the average value used for subsequent analysis, in the following order: SLCMJ, SLBJ, SLDJ. A sixty-second rest period was provided between trials during the same jump test, and 3-minute rest period between different jump tests. All subjects were required to start the unilateral jump tests with the right leg first. Subsequently, subjects performed 3 trials of a 10-meter linear sprint. A 3-minute rest period was provided between trials during each sprint test, and 3-minute rest period between linear sprint test and the COD speed test. For the 10-meter linear sprint test, the starting leg was arbitrarily chosen by the subjects. Then, subjects performed 2 trials of 505 COD speed test, with both the right and the left leg. Three-minute rest period was provided between trials during COD speed tests. The average values were also taken for both sprint and COD speed tests.

Single Leg Countermovement Jump. Subjects were instructed to jump on one leg and place their hands on their hips for the duration of the test. The jump was performed executing a countermovement immediately followed by an explosive vertical jump, with an aggressive extension at the ankle, knee, and hip. Subjects were instructed to jump whenever they wanted after the signal "go". Examiners' verbal instruction was to "jump as high as possible". The tested limb had to remain completely extended during the flight phase before landing on the floor, whilst the opposite leg was slightly flexed with the medial malleolus at mid-shin level for the entire duration of each trial. No additional swinging of the non-jumping leg was allowed (Bishop et al., 2020b). Subjects were required to maintain the position described after the landing for 3 seconds. Jump height in centimetres was recorded using the "My Jump 2" smartphone app, which reports strong agreement (ICC = 0.997) and correlation ($r = 0.995$; $p < 0.05$) with force platform (Balsalobre-Fernández et al., 2015).

Single Leg Broad Jump. Subjects were instructed to stand behind the starting line with the leg selected for the test. Free arm swing was allowed to help stability during landing. The jump was performed executing a countermovement immediately followed by an explosive and aggressive forward jump. Subjects were instructed to jump whenever they wanted after the signal "go". Examiners' verbal instruction was to "jump as far as possible". The tested limb began in contact with the ground, whilst the opposite leg was slightly flexed with the medial malleolus at mid-shin level for the duration of each trial, and minimal swinging of the non-jumping leg was allowed to help stability during landing (Bishop et al., 2020b). Subjects were required to maintain a stable landing for 3 seconds, for a valid trial. Jump distance in centimetres was recorded using a perpendicular tape measure fixed to the floor. The distance between the starting line and the heel was measured. The current literature reports high reproducibility (ICC = 0.95) and good correlation with lower-body muscular power ($r = 0.79$; $p < 0.05$) (Fernandez-Santos et al., 2015).

Single Leg Drop Jump. Subjects were instructed to step off an 18-cm box with the leg selected for the test and the hands placed on the hips throughout the duration of the test (Bishop et al., 2019). Subjects were required to step off the box, land on the floor and execute an explosive and aggressive vertical jump. Subjects were instructed to jump whenever they wanted after the signal "go". Examiners' verbal instruction was to "jump as high and as fast as possible, whilst minimizing ground contact time". The tested limb had to remain completely extended during the flight phase, whilst the opposite leg was slightly flexed with the medial malleolus at mid-shin level for the entire duration of each trial. No additional swinging of the non-jumping leg was allowed (Bishop et al., 2019). Subjects were required to maintain the position previously described after the landing for 3 seconds. RSI was calculated using the equation jump height ~~flight time~~/ground contact time (GCT), utilizing the "My Jump 2" smartphone app", which shows high agreement (ICC = 0.95) and validity (r = 0.94; p < 0.05) with the force plate (Bishop et al., 2020a, Haynes et al., 2019). Leg stiffness (K) was also calculated using the equation (Dalleau et al., 2004):

$$K_n = \frac{M\ x\ \pi(T_f + T_c)}{{T_c}^2\ (\frac{T_f + T_c}{\pi} - \frac{T_c}{4})}$$

where M = body mass, T_f = flight time, and T_c = ground contact time.

10-meter Sprint. Subjects were instructed to stand behind the starting line with both feet in a crouching position. They were allowed to choose independently the preferred leg to start the sprint. Vertical poles were placed at 0, 5 and 10 meters. Subjects were instructed to sprint through the poles as fast as they can, whenever they wanted after the signal "go". Examiners' verbal instruction was "sprint as fast as possible". Time was recorded when subjects crossed the starting line, and finish at the pole placed at 10 meters. All players performed sprints in their own football boots on a grass soccer pitch. Performance in seconds was recorded using "My Sprint App", using an iPhone X with a frame rate recording of 240 fps, which shows perfect agreement (ICC = 1.00) and correlation (r = 0.989; p < 0.05) with photocells (Romero-Franco et al., 2016). The device was placed on a 1-meter height tripod, 5 meters away perpendicular to the lane and at a distance of 7.5 meters from the starting line (Romero-Franco et al., 2016).

505 Change of Direction Speed Test. Subjects were instructed to stand behind the starting line with both feet in a crouching position. They were allowed to choose independently the preferred leg to start the test. Vertical poles were placed at 0, 10 and 15 meters. Subjects were instructed to sprint, whenever they wanted after the signal "go", 15 meters through the poles and then perform a 180° turn off, with both the right and the left leg, and sprint for other 5 meters. Examiners' verbal instruction was "sprint and turn off as fast as possible". Time was recorded when subjects crossed the poles placed at 10 meters, completed a 180° turn off at 15 meters, and went back at the pole placed at 10 meters. All players performed COD speed tests in their own football boots on a grass soccer pitch. Performance in seconds was recorded using "COD Timer", using an iPhone X with a frame rate recording of 240 fps, which shows high agreement (ICC = 0.97) and correlation (r = 0.964; $p < 0.05$) with timing gates (Balsalobre-Fernández et al., 2019). Change of direction deficit (CODD) was calculated as the difference between average 505 COD speed test and 10-meter linear sprint times (Nimphius et al., 2016). The device was placed on a 1-meter height tripod, 10 meters away perpendicular to the lane and at a distance of 5 meters from the starting line.

Intervention Program. The resistance training program lasted 6 weeks and consisted of 2 sessions per week of approximately 60 minutes each (see Table 2). This was conducted after the season, avoiding any confounding factor with soccer matches. The UNI group performed a standardized warm-up, consisting of 2 sets of 10 repetitions of overhead squats, crab walks, forward lunges, single leg bridges, and pogo jumps. The training program was based on coupled exercises (i.e., contrast training (Marshall et al., 2021)), consisting of strength training followed by plyometric exercises (i.e., following the order A-, B-, C-), with load progression adapted on the body weight of each subject (Table 2). Velocity ratio of exercises was set at 1:1 (i.e., concentric-eccentric velocity) (Marshall et al., 2021). Ninety-seconds of rest was provided between strength and plyometric exercises. A 180-second inter-set rest period was given within the coupled exercises. Two qualified strength and conditioning coaches supervised each training session, providing verbal feedbacks, encouragements and the correct technique of each exercise. After each training program, subjects were encouraged to cool down with dynamic stretching and mobility exercises (Opplert and Babault, 2018).

Statistical Analyses

All data were initially recorded as mean and standard deviation (SD) in Microsoft Excel and later transferred to SPSS (version 25.0; SPSS, Inc., Armonk, NY). Normality was analysed using the Shapiro-Wilk test, with p-value > 0.05 meaning that data were normally distributed. An average-measures two-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals, and coefficient of variation (CV) were used to assess the within session reliability of test measures at baseline, after the training intervention, and between-sessions. ICC values were interpreted as follows: > 0.9 = excellent, 0.75–0.9 = good, 0.5–0.75 = moderate, and < 0.5 poor (Koo and Li, 2016). The CV was calculated using the formula: (SD [trials 1–3] / average [trials 1–3] x 100), with values < 10% deemed acceptable (Cormack et al., 2008).

Mean inter-limb asymmetry was calculated as a percentage difference between limbs in the unilateral tests, utilising the equation: (100/[maximum value]x[minimum value]x-1+100), as suggested by the current literature (Bishop et al., 2018c). To determine the direction of inter-limb asymmetry, an "IF function" was used in Microsoft Excel: * IF (left>right,1,-1) (Bishop et al., 2018a). The current literature also highlights the importance of reporting asymmetry in conjunction with test variability (i.e., CV) (Bishop et al., 2018a). Thus, subjects showing a change in asymmetry (between time points) greater than the baseline CV were identified as showing a "real" change. Importantly, the positive sign of the asymmetry scores was attributed to the right limb, whereas the negative sign to the left limb (Bishop et al., 2018a). Between-group changes in asymmetry from pre- to post-training intervention were examined with a univariate analysis using one-way ANCOVA. Inter-limb asymmetry values at baseline (i.e., SLCMJ, SLBJ, and SLDJ) were used as covariates. Confidence interval adjustments using the Bonferroni correction factor was used in the post-hoc analysis where significant differences were established at $p < 0.05$. Paired samples t-tests were used to calculate changes in inter-limb asymmetry scores within the same group (i.e., UNI or CON) from pre- to post-training intervention, with statistical significance set at $p < 0.05$. Kappa coefficients were used to determine levels of agreement for how consistently asymmetry favoured the same limb between the two time points for each group and values were interpreted as: ≤ 0 = poor, 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 (Viera and Garrett, 2005). Furthermore, consistency in limb dominance from pre- to post-training intervention were also calculated as percentage values.

Hedges' g effect sizes with 95% confidence intervals, were also determined to showcase practical significance from pre- to post-intervention in the same group and for the between-group comparison (Dasborough, 2007). Owing to the fact that analyses were conducted to examine raw scores and percentage changes, the standard deviation was set as the pre-testing score, in line with recent suggestions (Bishop et al., 2021). Hedges' g was classified as follows: 0.0-0.20 = trivial, 0.20–0.60 = small, 0.60–1.20 = moderate, 1.20–2.00 = large, 2.00–4.00 = very large, > 4.00 = near perfect (Hopkins et al., 2009).

***** Insert Tables 1 and 2 about here *****

RESULTS

All data were normally distributed ($p > 0.05$). Table 3 shows within- and between-session reliability data. Relative reliability (ICC) of all metrics ranged from good to excellent, with the exception of the SLDJ-R (RSI) (ICC = 0.64) in the UNI group. Absolute reliability (CV) showed acceptable values (< 10%) in both pre-testing, post-testing, and between-session scores, apart from the SLDJ-L (K) (CV = 10.63%) in the CON group.

Table 4 reports raw jump and performance test scores from pre- to post-training intervention. For the SLBJ, moderate to large significant improvements in jump distance were found in the UNI group from pre- to post-training intervention ($p < 0.05$; g = 1.10 to 1.66). Small to moderate improvements were also found in the SLCMJ (g = 0.46 to 0.49) and in the SLDJ (RSI) (g = 0.69 to 0.83) without any statistically significant difference in the UNI group ($p > 0.05$), with the exception of the SLDJ (K) (g = -0.31 to – 0.12), which did not show any improvement in the raw scores between the two time points. By contrast, the CON group did not show any significant change in all tested metrics ($p > 0.05$), revealing even a trivial to small decrease in jump performance in the SLCMJ (g = -0.31 to -0.24) and in the SLBJ (g = -0.16 to -0.13) from pre- to post-testing scores. With regard to linear and COD speed, results showed no significant changes in 10-meter linear sprint, 505 COD speed test, and CODD from pre- to post-training intervention in both groups (i.e., UNI and CON groups) ($p > 0.05$). The UNI group showed trivial to small changes (g = -0.35 to 0.48) in 10-meter linear sprint, 505 COD speed test, and CODD, as well as the CON group (g = -0.51 to 0.01) which revealed a decrease in performance in terms of time (i.e., slower time).

Table 5 reports asymmetry percentage scores from pre- to post-training intervention. Inter-limb asymmetry indexes showed trivial to moderate decreases in all the fitness tests conducted in the UNI group (i.e., SLCMJ (g = 0.11) and SLBJ (g = 0.40)). However, a moderate significant reduction in the asymmetry index was found only in the SLDJ (RSI) ($p < 0.05$; g = 1.11) and in the SLDJ (K) ($p < 0.05$; g = 1.00) from pre- to post-training intervention. Instead, the CON group showed trivial to small increases in the asymmetry indexes in all the fitness tests (g = -0.37 to -0.14), without any statistically significant difference between the two time points. Furthermore, Table 5 shows also Kappa coefficients for each metric in both groups, which examined how consistently asymmetry favoured the same limb from pre- to post-testing scores. In the UNI group, the results showed slight levels of agreement for the SLDJ (K) (Kappa = 0.02), fair for both the SLBJ (Kappa = 0.31) and for the SLCMJ (Kappa = 0.33), and substantial for the SLDJ (RSI) (Kappa = 0.65). In the CON group, the levels of agreement were poor for the SLCMJ (Kappa = -0.17), fair for the SLBJ (Kappa = 0.25), moderate for the SLDJ (RSI) (Kappa = 0.50), and substantial for the SLDJ (K) (Kappa = 0.62).

The between-group comparison of raw jump scores, asymmetry percentages, and performance tests are reported in Figure 1. When calculating the between-group comparison of the raw jump scores, results revealed moderate to large significant effects in the SLBJ ($p < 0.05$; $g = 1.10$ to 1.24) in favour of the UNI group. All the other metrics showed small to moderate effects without any statistically significant difference ($p > 0.05$; $g = 0.24$ to 0.76) in favour of the UNI group, with the exception the SLDJ (K) which indicated small effects ($p > 0.05$; $g = -0.46$ to -0.43) in favour of the CON group. When asymmetry indexes were compared between groups (i.e., UNI vs. CON groups), the results revealed moderate significant effects in the SLDJ (RSI) and in the SLDJ (K) in favour of the UNI group ($p < 0.05$; $g = 1.01$ to 1.07). Similarly, the SLCMJ and the SLBJ showed small to moderate effects in favour of the UNI group, without any statistically significant difference ($p > 0.05$; $g = 0.50$ to 0.65). When the performance tests were examined between groups (i.e., UNI vs. CON groups), the results showed trivial to moderate effects in favour of the UNI group without any statistically significant difference ($p > 0.05$; $g = 0.00$ to 0.67). Finally, mean and individual inter-limb asymmetry values for each jump test and metrics of both groups are reported in figure 2.

***** Insert Tables 3-5 about here *****

***** Insert Figure 1 and 2 about here *****

DISCUSSION

The primary aim of this study was to investigate whether the effects of a UNI training program, compared to a CON group, were effective in reducing inter-limb asymmetry in jump tests. The second aim was to determine whether changes in asymmetry translated improvements on measures of physical performance (i.e., 10-meter linear sprint and 505 COD speed test). The results indicated that the training intervention elicited trivial to moderate reductions in the asymmetry indexes in the UNI group. However, significant changes in asymmetry indexes were found only in the SLDJ (RSI) ($p < 0.05$; $g = 1.11$) and in the SLDJ (K) ($p < 0.05$; $g = 1.00$), but such changes in inter-limb asymmetry did not translate to substantial improvements in linear or COD speed times.

With regard to the raw jump scores, this study revealed trivial to large improvements in all metrics in the UNI group, with a statistical significance found in the SLBJ ($p < 0.05$; $g = 1.10$ to 1.66) from pre- to post-training, whilst the CON group did not show any meaningful improvements (Table 4). When the two groups were compared, the results indicated moderate to large significant changes in the SLBJ in favour of the UNI group ($p < 0.05$; $g = 1.10$ to 1.24), as well as small to moderate effects in the SLCMJ and in the SLDJ (RSI) in favour of the UNI group ($g = 0.24$ to 0.76) (Figure 1). These findings reinforce the notion that adequate muscle stimuli are necessary to promote positive physical adaptations (Suchomel et al., 2018, Suchomel et al., 2016). The specific (i.e., RFESS, hip thrust, Romanian deadlift and unilateral jumps) and selected directions of the training stimuli included in our unilateral contrast training program (Table 2) were specifically chosen to promote unilateral muscle adaptations. The selected strength and plyometric exercises are capable of improving both vertical and horizontal jumping performance (Fitzpatrick et al., 2019, Arede et al., 2021). Thus, despite being small to moderate reductions in the asymmetry index, our study indicates that a training intervention which does not include unilateral strength and power exercises, may lead to a greater magnitude of between-limb imbalances. However, the performance tests (i.e., linear and COD speed) did not reveal any significant change in either group (Table 4). Unsurprisingly, between-group analysis also showed no significant differences between groups for these tests (Figure 1). This may be explained by the fact that this study did not include any specific sprint training (e.g., acceleration or sprint drills) to enhance linear sprinting (Rumpf et al., 2016).

Similarly, for the 505 COD speed tests, the technique of cutting manoeuvres (e.g., side-step, crossover cut, and split step), as well as distinct training to improve COD abilities (e.g., acceleration, deceleration, and change direction at different angles) (Dos'Santos et al., 2017b) were not included, therefore likely impeding any meaningful changes in these tests. Similarly, the CODD was specifically chosen to detect the athletes' ability to change direction (i.e., larger the deficit, the lower the athlete's ability to change direction) (Nimphius et al., 2016). As expected, the results showed trivial to moderate changes in both groups, confirming the assumption that the training program selected was unlikely to elicit significant modifications in sprinting and COD speed performance.

When examining changes in inter-limb asymmetry, this study showed trivial to small reductions in the SLCMJ (g = 0.11) and in the SLBJ (g = 0.40) in the UNI group and moderate significant reductions in the SLDJ (RSI) (g = 1.11) and in the SLDJ (K) (g = 1.00) (Table 5). In contrast, the CON group showed the opposite trend, revealing trivial to small increases in asymmetry across jump tests (g = -0.37 to -0.14). These findings were expected, owing to the fact that the UNI group was specifically trained to improve each limb's capacity, which may have equalled out any between-limb imbalances. To support this, recent investigations found consistency in selecting unilateral training interventions to reduce between-limb imbalances in youth soccer players (Pardos-Mainer et al., 2020, Pardos-Mainer et al., 2019, Bettariga et al., 2022). Interestingly, when changes in asymmetry indexes were compared between groups (i.e., UNI vs. CON groups) only the SLDJ (RSI) and the SLDJ (K) revealed a moderate significant difference in favour of the UNI group ($p < 0.05$; g = 1.01 to 1.07) (Figure 1). The small to moderate effects reported in the SLCMJ and in the SLBJ in the UNI group may be attributed to the limited outcome measures reported (i.e., jump height and distance). Indeed, metrics such as RSImod or peak force may have revealed interesting and different findings, owing to strategy metrics being previously shown to be more sensitive to change than outcome measures (Gathercole et al., 2015). Thus, future research should consider utilizing strategy-based metrics in addition to outcome measures, to provide a more complete and holistic picture of changes in jump performance and their subsequent asymmetry values (Suchomel et al., 2015). In line with this thinking, jump distance in the SLBJ was recently considered a poor indicator for horizontal jumping performance (Kotsifaki et al., 2021). Thus, it is not entirely surprising that soccer players failed to show any meaningful reductions in asymmetry.

Just as the individual magnitude of asymmetry varied between the two time points, also the direction of asymmetry showed large variability in both groups (i.e., UNI and CON groups) (Table 5 and Figure 2). In fact, Kappa values ranged from slight to substantial in all metrics in the UNI group. Similarly, in the CON group, Kappa showed from poor to substantial levels of agreement. This is in line with comparable research which has investigated the direction of asymmetry across multiple time points (Bishop et al., 2020c). However, it should be noted that both groups reported higher levels of agreement (i.e., Kappa coefficients) in the SLDJ. This may be attributed to the biomechanical and physical qualities required in this test. Indeed, the SLCMJ and the SLBJ are technically easier to manipulate take-off strategy to achieve the desired outcome, owing to the long stretch shortening cycle (SSC) nature of the jumps (Brazier et al., 2017, Turner and Jeffreys, 2010). From an asymmetry perspective, this may mean that a number of strategies are employed to achieve a similar outcome, resulting in fluctuations in movement variability, and therefore, limb dominance [32]. Instead, the SLDJ utilizes a short SSC mechanism and the movement itself is technically harder to manipulate, therefore potentially reducing the number of alternative strategies that athletes can exhibit for a given outcome (Pedley et al., 2017). Thus, this study highlighted the large inter-individual variations of the direction of asymmetry in response to either the unilateral contrast training intervention (i.e., UNI group) or the time (i.e., CON group) (Bishop et al., 2020c), which is reflected in Figure 2. Changes in asymmetry tests greater than the baseline variability (i.e., CV) were represented using a dashed line and considered “real”. However, it should be acknowledged that the consistency of such changes across the different tests was very low for each subject. Simply put, this means that a real change in inter-limb asymmetry in one test (e.g., SLCMJ) was rarely evident in another test (e.g., SLDJ), confirming the assumption about the large individual response of asymmetry and its task-specific nature.

The current study was not without limitations. Owing to the low sample size (i.e., 24 soccer players), the results should be interpreted with caution. Additionally, a 6-week training intervention may not be a sufficient time period to foster significant muscular adaptations in resistance-trained men, but in this instance, was enough for amateur soccer players. Indeed, 8 to 12 weeks of strength and plyometric trainings are generally recommended in athletes to obtain substantial muscle gains (Hughes et al., 2018). Second, quantifying not only the performance outcome measure (e.g., jump height or distance), but also how the jumps are executed (e.g., movement strategy) appears necessary (Davies et al., 2020), with data from the SLDJ supporting this suggestion. Consequently, analysing asymmetry based on one value only (e.g., jump height) is unlikely to represent asymmetry in another metric, owing to its task-specificity [31, 32]. Finally, future investigations should ensure they also include a CON group, as per the present study, so greater confidence can be provided regarding the efficacy of training interventions.

PRACTICAL APPLICATIONS

This study showed that the unilateral strength and power contrast training had trivial to moderate effects in reducing inter-limb asymmetry. Furthermore, the training intervention selected was able to foster substantial improvements in jump performance; therefore, practitioners can implement such training intervention methods in their training programs with the aim of augmenting jump performance. However, it should be acknowledged that in order to enhance linear and COD speed performance, specific field-based training methods which focus on these physical capacities should be implemented, as strength and power training alone is likely not enough. Finally, changes in inter-limb asymmetry did not translate to significant improvements in physical performance (i.e., linear and COD speed), which are therefore more dependent on the training stimuli selected rather than any reductions in side-to-side differences. Thus, when using data, a stronger focus on the original test scores, rather than any relative limb differences seems like a logical assumption for practitioners to consider.

DECLARATIONS

Funding: No funding was received for this project.

Conflict of interest

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

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Table 1. Subject characteristics with data shown as mean ± standard deviations (SD).

Group	Age (y)	Body Mass (kg)	Height (cm)	Dominant Limb
Unilateral Training group (n = 12)	27.0 ± 4.8	75.0 ± 6.0	180.0 ± 0.05	R = 11; L = 1
Control group (n = 12)	23.8 ± 4.8	76.3 ± 7.9	179.0 ± 0.06	R = 10; L = 2

Note: y = year; kg = kilogram; cm = centimetre; R = right; L = left.

Table 2. Unilateral training intervention programme.

Coupled exercises	W1	W2	W3	W4	W5	W6
A-RFESS	3 x 8 35%BW	3 x 7 40%BW	4 x 6 45%BW	4 x 5 50%BW	5 x 4 55%BW	5 x 3 60%BW
SLCMJ	3 x 4	3 x 4	4 x 4	4 x 4	5 x 4	5 x 4
B-SL Hip Thrust	3 x 8 25%BW	3 x 7 30%BW	4 x 6 35%BW	4 x 5 40%BW	5 x 4 45%BW	5 x 3 50%BW
SL Broad Jump	3 x 4	3 x 4	4 x 4	4 x 4	5 x 4	5 x 4
C-SL Romanian Deadlift	3 x 8 30%BW	3 x 7 35%BW	4 x 6 40%BW	4 x 5 45%BW	5 x 4 50%BW	5 x 3 55%BW
SL Drop Jump (20cm)	3 x 4	3 x 4	4 x 4	4 x 4	5 x 4	5 x 4

RFESS = rear foot elevated split squat; SLCMJ = single leg countermovement jump; SL = single leg; BW = body weight; cm = centimetre.

Table 3. Within session reliability for each test measures at pre-, post-training intervention, and between-session.

Test/Metric	**Pre-training**		**Post-training**		**Between-session**	
Unilateral Training group	*CV*	*ICC (95% CI)*	*CV*	*ICC (95% CI)*	*CV*	*ICC (95% CI)*
SLCMJ-R (cm)	4.60	0.96(0.89, 0.98)	2.80	0.98(0.96, 0.99)	8.21	0.93(0.83, 0.98)
SLCMJ-L (cm)	4.13	0.97(0.92, 0.99)	3.30	0.98(0.95, 0.99)	8.69	0.93(0.85, 0.98)
SLBJ-R (cm)	1.43	0.94(0.84, 0.98)	0.93	0.98(0.96, 0.99)	5.31	0.80(0.46, 0.94)
SLBJ-L (cm)	1.21	0.98(0.96, 0.99)	0.97	0.99(0.97, 0.99)	4.56	0.89(0.69, 0.97)
SLDJ-R (RSI)	6.02	0.88(0.68, 0.96)	3.43	0.96(0.89, 0.98)	9.76	0.64(0.26, 0.88)
SLDJ-L (RSI)	4.07	0.97(0.93, 0.99)	2.63	0.98(0.96, 0.99)	9.56	0.85(0.66, 0.95)
SLDJ-R (K)	6.17	0.95(0.88, 0.98)	4.44	0.98(0.95, 0.99)	8.66	0.88(0.74, 0.96)
SLDJ-L (K)	5.28	0.98(0.97, 0.99)	3.48	0.99(0.98, 0.99)	8.81	0.96(0.90, 0.99)
Control group	*CV*	*ICC (95% CI)*	*CV*	*ICC (95% CI)*	*CV*	*ICC (95% CI)*
SLCMJ-R (cm)	4.05	0.97(0.94, 0.99)	3.59	0.97(0.94, 0.99)	6.96	0.97(0.94, 0.99)
SLCMJ-L (cm)	2.24	0.99(0.98, 0.99)	2.43	0.99(0.97, 0.99)	4.28	0.98(0.97, 0.99)
SLBJ-R (cm)	2.56	0.98(0.95, 0.99)	1.18	0.99(0.98, 0.99)	3.08	0.98(0.97, 0.99)
SLBJ-L (cm)	2.05	0.97(0.93, 0.99)	1.09	0.99(0.97, 0.99)	2.87	0.98(0.95, 0.99)
SLDJ-R (RSI)	3.16	0.98(0.95, 0.99)	2.28	0.98(0.96, 0.99)	5.70	0.97(0.94, 0.99)

SLDJ-L (RSI)	4.00	0.98(0.94, 0.99)	3.15	0.96(0.89, 0.98)	8.64	0.88(0.72, 0.96)
SLDJ-R (K)	4.72	0.98(0.97, 0.99)	5.01	0.98(0.95, 0.99)	7.67	0.98(0.95, 0.99)
SLDJ-L (K)	6.36	0.98(0.96, 0.99)	5.09	0.98(0.96, 0.99)	10.63	0.96(0.91, 0.99)

CV = coefficient of variation; ICC = intraclass correlation coefficient; CI = confidence intervals; SLCMJ = single leg countermovement jump; SLBJ = single leg broad jump; SLDJ = single leg drop jump; L = left; R = right; cm = centimetre; RSI = reactive strength index; K = leg stiffness.

Table 4. Mean raw jump and performance test scores ± SDs for pre- and post-training intervention, and Hedges' *g* effect sizes.

Fitness Test (raw scores)	Pre-training	Post-training		
Unilateral Training group	*Mean ± SD*	*Mean ± SD*	*Effect Size (95% CI)*	*Descriptors*
SLCMJ-R (cm)	20.51 ± 3.24	22.09 ± 3.43	0.46(-0.40, 1.31)	small
SLCMJ-L (cm)	21.10 ± 3.57	23.05 ± 4.10	0.49(-0.37, 1.35)	small
SLBJ-R (cm)	187.33 ± 8.60	205.66 ± 12.23 *	1.66(0.66, 2.66)	large
SLBJ-L (cm)	189.66 ± 13.67	204.83 ± 12.82 *	1.10(0.19, 2.02)	moderate
SLDJ-R (RSI)	1.25 ± 0.16	1.40 ± 0.19	0.83(-0.06, 1.71)	moderate
SLDJ-L (RSI)	1.25 ± 0.21	1.40 ± 0.22	0.69(-0.18, 1.56)	moderate
SLDJ-R (K)	63.06 ± 11.73	59.91 ± 7.59	-0.31(-1.16, 0.54)	small
SLDJ-L (K)	61.62 ± 15.65	60.00 ± 9.16	-0.12(-0.97, 0.73)	trivial
Control group	*Mean ± SD*	*Mean ± SD*	*Effect Size (95% CI)*	*Descriptors*
SLCMJ-R (cm)	21.30 ± 3.84	20.07 ± 3.94	-0.31(-1.16, 0.55)	small
SLCMJ-L (cm)	21.99 ± 4.22	21.00 ± 3.77	-0.24(-1.09, 0.61)	small
SLBJ-R (cm)	192.76 ± 21.64	190.00 ± 19.50	-0.13(-0.97, 0.71)	trivial
SLBJ-L (cm)	198.34 ± 17.99	195.37 ± 16.61	-0.16(-1.01, 0.68)	trivial
SLDJ-R (RSI)	1.21 ± 0.23	1.21 ± 0.19	0.00(-0.85, 0.85)	trivial

SLDJ-L (RSI)	1.16 ± 0.20	1.17 ± 0.16	0.04(-0.81, 0.88)	trivial
SLDJ-R (K)	53.31 ± 15.11	56.64 ± 13.46	0.22(-0.62, 1.07)	small
SLDJ-L (K)	55.65 ± 16.45	61.25 ± 16.15	0.33(-0.52, 1.18)	small
Fitness Test (performance tests)	**Pre-training**	**Post-training**		
Unilateral Training group	*Mean ± SD*	*Mean ± SD*	*Effect Size (95% CI)*	*Descriptors*
10-m linear sprint (s)	2.05 ± 0.09	2.00 ± 0.09	0.48(-0.38, 1.34)	small
505 COD-R (s)	2.51 ± 0.12	2.51 ± 0.10	0.01(-0.83, 0.86)	trivial
505 COD-L (s)	2.54 ± 0.10	2.51 ± 0.12	0.27(-0.58, 1.12)	small
CODD-R (s)	0.46 ± 0.09	0.50 ± 0.13	-0.35(-1.20, 0.51)	small
CODD-L (s)	0.50 ± 0.10	0.51 ± 0.14	-0.08(-0.93, 0.77)	trivial
Control group	*Mean ± SD*	*Mean ± SD*	*Effect Size (95% CI)*	*Descriptors*
10-m linear sprint (s)	2.11 ± 0.10	2.11 ± 0.12	0.01(-0.83, 0.86)	trivial
505 COD-R (s)	2.48 ± 0.08	2.48 ± 0.05	-0.05(0.89, 0.90)	trivial
505 COD-L (s)	2.46 ± 0.11	2.50 ± 0.10	-0.35(-1.20, 0.51)	small
CODD-R (s)	0.36 ± 0.09	0.37 ± 0.10	-0.10(-0.95, 0.75)	trivial
CODD-L (s)	0.35 ± 0.07	0.39 ± 0.08	-0.51(-1.42, 0.39)	small

*SD = standard deviation; CI = confidence intervals; SLCMJ = single leg countermovement jump; SLBJ = single leg broad jump; SLDJ = single leg drop jump; L = left; R = right; cm = centimetre; RSI = reactive strength index; K = leg stiffness; m = meter; COD = change of direction; CODD = change of direction deficit; s = second; * = significant difference from pre-testing score p-value < 0.05.*

Table 5. Mean asymmetry percentage scores ± SDs and Hedges' *g* effect sizes, and Kappa coefficients and descriptive levels of agreement for the changes in asymmetry during jump tests for pre- to post-training intervention.

Asymmetry (%)	**Pre-training**	**Post-training**			**Kappa coefficients**	
Unilateral Training group	*Mean ± SD*	*Mean ± SD*	*Effect Size (95% CI)*	*Descriptors*	*Pre to Post-training*	*Descriptors*
SLCMJ (jump height)	7.85 ± 5.70	7.20 ± 5.79	0.11(-0.74, 0.96)	trivial	0.33	fair
SLBJ (jump distance)	4.73 ± 2.84	3.59 ± 2.62	0.40(-0.45, 1.26)	small	0.31	fair
SLDJ (RSI)	10.10 ± 6.19	4.29 ± 3.50 *	1.11(0.20, 2.03)	moderate	0.65	substantial
SLDJ (K)	11.60 ± 6.15	6.36 ± 3.69 *	1.00(0.10, 1.90)	moderate	0.02	slight
Control group	*Mean ± SD*	*Mean ± SD*	*Effect Size (95% CI)*	*Descriptors*	*Pre to Post-training*	*Descriptors*
SLCMJ (jump height)	6.57 ± 5.85	8.92 ± 6.47	-0.37(-1.22, 0.49)	small	-0.17	poor
SLBJ (jump distance)	3.31 ± 3.23	4.21 ± 2.70	-0.29(-1.15, 0.56)	small	0.25	fair
SLDJ (RSI)	8.09 ± 5.81	8.92 ± 5.83	-0.14(-0.99, 0.71)	trivial	0.50	moderate
SLDJ (K)	7.95 ± 6.57	9.34 ± 8.11	-0.18(-1.03, 0.67)	trivial	0.62	substantial

*SD = standard deviation; CI = confidence intervals; SLCMJ = single leg countermovement jump; SLBJ = single leg broad jump; SLDJ = single leg drop jump; RSI = reactive strength index; K = leg stiffness; * = significant difference from pre-testing score p-value < 0.05.*

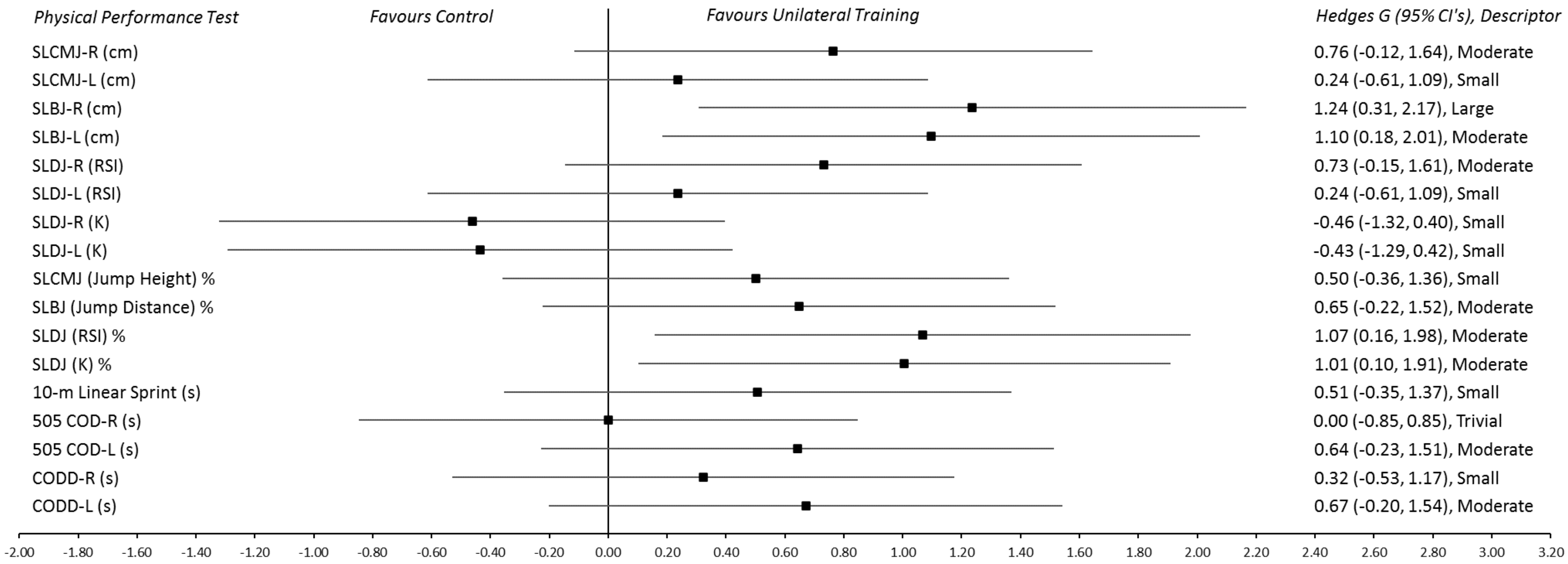

Figure 1. *Between-group comparison of mean raw jump scores, asymmetry percentage, and performance tests scores from pre- to post-training intervention, and Hedges' g effect sizes. Legend. SLCMJ = single leg countermovement jump; SLBJ = single leg broad jump; SLDJ = single leg drop jump; L = left; R = right; cm = centimetre; RSI = reactive strength index; K = leg stiffness; % = asymmetry index; COD = change of direction; CODD = change of direction deficit; s = second; m = meter.*

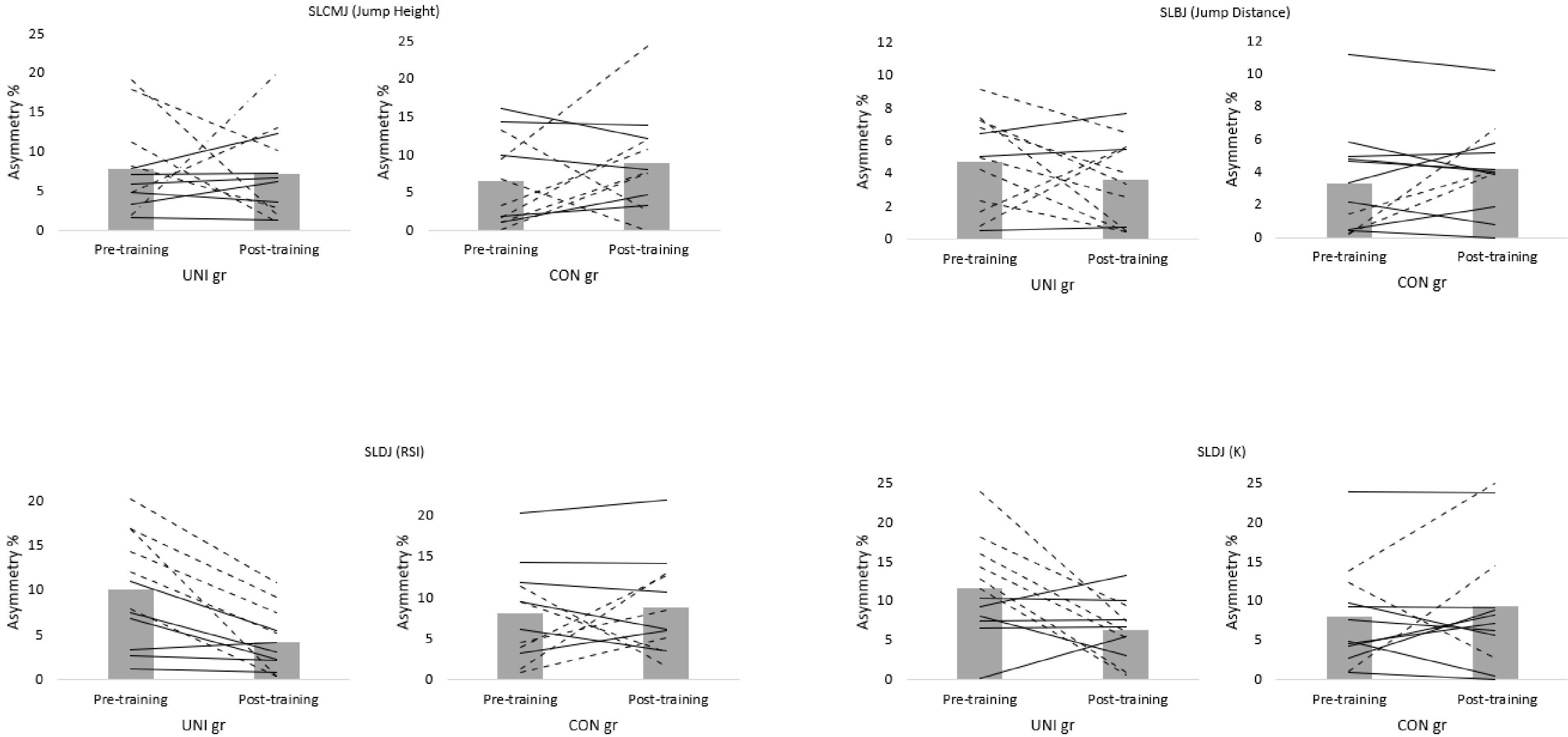

Figure 2. *Mean and individual interlimb asymmetry values for single leg countermovement jump (jump height), single leg broad jump (jump distance), single leg drop jump (RSI) and (K) at pre- and post-training intervention in the unilateral training and control group.*