THE EFFECTS OF TRAINING INTERVENTIONS ON INTER-LIMB ASYMMETRIES: A SYSTEMATIC REVIEW WITH META-ANALYSIS

Authors:

Francesco Bettariga[ab], Anthony Turner[b], Sean Maloney[b], Luca Maestroni[bc], Paul Jarvis[b], Chris Bishop[b]

[a] StudioErre, Via della Badia, 18, 25127 Brescia (BS), Italy

[b] London Sport Institute, School of Science and Technology, Middlesex University, Greenlands Lane, London, United Kingdom

[c] ReAct, Via Madonna della Neve 24, 24121, Bergamo (BG), Italy

Francesco Bettariga mail: francescobettariga@gmail.com

Anthony Turner mail: A.N.Turner@mdx.ac.uk

Sean Maloney mail: S.Maloney@mdx.ac.uk

Luca Maestroni mail: lucamae@hotmail.it

Paul Jarvis mail: P.Jarvis@mdx.ac.uk

Chris Bishop mail: C.Bishop@mdx.ac.uk

Corresponding Author: Francesco Bettariga

ABSTRACT

Inter-limb asymmetries have been recently investigated in athletic populations. However, the effects of training interventions on inter-limb asymmetries have been scarcely examined. Therefore, the aim of this study was to determine the effects of training interventions on changes in inter-limb asymmetries from pre- to post-training. Furthermore, to examine the effects of training programs on intervention groups compared to control groups. A database search was completed (MEDLINE, CINAHL, and SPORTDiscus). Eight studies were then included in the meta-analysis. Results showed small reductions in inter-limb asymmetries in single leg broad jump (SLBJ) and change of direction (COD) speed from pre- to post-training interventions, whereas moderate effects were found in single leg countermovement jump (SLCMJ) and single leg (SL) lateral jump. When comparing the training interventions to the control groups, results showed small effects in favour of the training groups for reducing inter-limb asymmetries in SLBJ and large effects in SLCMJ, and COD speed. Thus, training interventions can evoke small to moderate reductions in inter-limb asymmetries from pre- to post-training programs. Strength training performed unilaterally or bilaterally may elicit these reductions. Furthermore, training interventions showed larger effects compared to the control groups in reducing inter-limb asymmetries. However, further research is needed.

Keywords

Inter-limb asymmetry, training program, physical performance.

INTRODUCTION

The concept of inter-limb asymmetries has been widely investigated in recent years [1-6]. By definition, inter-limb asymmetry refers to an imbalance or deficit between limbs (e.g., left vs. right, dominant vs. non-dominant, healthy vs. injured), and should not be confused with intra-limb asymmetry which refers to an imbalance within the same limb (e.g., quadriceps-hamstring ratio) [2, 3]. Although inter-limb asymmetries in physical qualities such as strength, power, and reactive strength have been shown to be associated with reduced physical and sporting performance, these findings are not always consistent [6, 7]. Interestingly, the correlation between inter-limb asymmetries and muscle and non-contact injuries shows equivocal results [8-10]. Historically, between-limb differences of 10-15% have been commonly assumed to be a meaningful inter-limb asymmetry after injuries [15, 16]. However, more recently, such assumptions have been challenged [17] and numerous studies have highlighted the task-specific nature of asymmetry [19-21], meaning that an asymmetry measured from one test, should not be expected to be the same in another test [22]. Thus, any specific threshold relative to asymmetry is challenging to unanimously apply when using multiple tests and metrics.

When focusing specifically on physical performance, inter-limb asymmetries in power, from the single leg countermovement jump (SLCMJ), have been shown to be associated with reduced jump height and slower linear speed and change of direction (COD) performance in youth and adult male soccer players (*r* = -0.51 to -0.77) [23]. Similarly, jump height and distance asymmetries in the SLCMJ and single leg triple hop (SLTHOP) respectively, were negatively associated with reduced sprint performance (*r* = 0.49 to 0.59)~~-~~and reduced jump performance (*r* = -0.47 to -0.58) in youth female soccer players [24]. When focusing on different tests, inter-limb differences during the single leg drop jump (SLDJ) were reported in adult soccer players, highlighting that larger imbalances in reactive strength were indicative of slower linear sprint and COD performance (*r* = 0.52 to 0.66) [25]. Similarly, in professional cricket athletes, jump height and reactive strength asymmetries during the SLDJ were indicative of slower 505 times (*r* = 0.56 to 0.74); however, the same relationships were not found in professional soccer players [26]. In support of these findings, Raya-Gonzalez et al. [27] did not find any significant relationships between asymmetry scores (e.g. SLCMJ, COD, mean and peak power) and sprinting or jumping performance in youth soccer players. Finally, between-limb asymmetries in concentric power from iso-inertial cross over tests were significantly correlated with negative performance in COD and sprint ($r = 0.41$ to 0.51) $p < 0.05$) in youth handball players, even though asymmetries in SLCMJ, single leg broad jumps (SLBJ) and single leg lateral jumps did not show any correlation with COD and sprint performance [28]. Thus, the evidence to date appears to be conflicting, which is supported in a recent systematic review [6]. However, with these studies being associative in design, we cannot truly determine any cause and effect relationship; this can only be done by assessing changes in asymmetry after training interventions.

Unilateral and bilateral training interventions have been examined to clearly elucidate the effects of such training modalities on physical performance [29, 30]. Although the volume of training interventions reporting pre and post asymmetry values are relatively rare, such training interventions have been recently investigated, with a focus on bilateral and unilateral strength exercises, plyometrics, balance, and core training [1, 31-35], in a wide variety of athletic populations. Given the evidential increase in studies conducted on this topic in recent years, understanding the effects of asymmetry on different measures of physical performance would be useful in order to determine whether practitioners should be striving for some level of symmetry in their athletes. To the best of our knowledge, no systematic reviews have been carried out on this topic. Thus, the primary aim of this systematic review was to examine if training interventions are effective in reducing inter-limb asymmetries across a range of physical qualities. The second aim was to investigate which types of training interventions are more effective in reducing these between-limb imbalances in the athletic population.

METHODS

Literature Search Methodology

A systematic search was conducted between 25 and 31 December 2020, in three different databases: MEDLINE, CINAHL, and SPORTDiscus. The PRISMA guidelines were used to conduct this systematic review (Figure 1) [36]. The literature search was related to specific search terms, combined with “asymmetries”. In addition, truncation function was used (i.e., “asymmetr*”) in order to expand the literature search of the following: “training”, “intervention”, “strength”, “jump”, “change of direction”, “single leg”, “unilateral”, and “bilateral”. An additional hand-made search was carried out in order to find other possible articles, consulting the reference lists of the studies selected.

***** Insert Figure 1 here *****

Eligibility Criteria

Studies were included if they fulfilled the following eligibility criteria: 1) minimum of a 6-week training intervention, 2) comparison groups were applied in the study design (i.e., control group vs. intervention group or intervention A vs. intervention B), 3) adult or youth athletic populations for both genders, 4) uninjured subjects only and, 5) published in English.

Study Selection

One reviewer (FB) removed duplicates, and screened titles and abstracts for eligibility, which was then agreed with a second reviewer (CB). Next, the remaining full text articles were included or excluded according to the eligibility criteria.

Data Extraction

Initially, one reviewer (FB) independently extracted data from the studies included in this systematic review. Demographic data (age and gender) and type of sports population were initially extracted. Also, training intervention modalities, physical tests used for inter-limb asymmetries, duration/frequency of interventions and the results of the training interventions (i.e., means, standard deviations, sample sizes, percentage values and effect sizes) on inter-limb asymmetries were extracted. This information was corroborated and agreed by a second reviewer (CB).

Methodological Quality and Risk of Bias Assessment

To appraise study methodological quality, the Physiotherapy Evidence Database (PEDro) scale was used [37]. Each item aimed to assess the level of evidence of the included studies. Studies were graded based on the checklist items, as either: "X" = criteria not meted, or "√" = criteria satisfied. The total score of each study included was reported in Table 1.

Risk of bias was assessed by firstly creating funnel plots. This enabled for the visualisation of the spread of the standardised effect estimates, relative to their standard error. Follow up analysis (i.e. both qualitative and quantitative analysis of the funnel plots) was only conducted where the number of entries within the analysis was equal to or exceeded 10 [38], and in these circumstances we conducted Egger's regression test ($p < 0.05$ indicating the presence of asymmetry and thus potential risk of small study bias) [39]. This analysis was conducted using jamovi (*jamovi,* Version 1.6.23.0), an open source statistical software which is developed on top of the R statistical language.

****** Insert Table 1 here ******

Statistical Analysis

Meta-Analysis

Review Manager (RevMan 5.2; Cochrane Collaboration, Oxford, United Kingdom) and Microsoft Excel (Microsoft Office 16; Microsoft Corporation, 2018) were used to carry out the meta-analysis. Effect sizes (ES) (Hedges *g*) of the same inter-limb asymmetry test (e.g., jump height from the SLCMJ) before and after training interventions were calculated as the standardized mean difference (SMD) with mean ± SD and 95% confidence intervals [40]. The calculation of Hedge's *g* was computed using the current formula [41]:

$$g = \frac{(Mean\ \mathrm{post} - Mean\ \mathrm{pre})}{SD\ \mathrm{pooled}}$$

Additionally, articles which reported the same inter-limb asymmetry tests comparing an intervention vs. a control group were analysed, as mentioned above. The Cohen scale was used to interpret effect sizes where: < 0.2 = trivial, 0.20 - 0.49 = small, 0.50 - 0.79 = moderate, and > 0.8 = large [42].

Subgroup Analyses

Subgroup analyses were performed using the subgroup analysis function in Review Manager (RevMan 5.2; Cochrane Collaboration, Oxford, United Kingdom). Firstly, analyses were conducted comparing the asymmetry test scores before and after the training programs in the intervention groups only. Secondly, The SMD was calculated as the difference from pre- to post-intervention for each variable in both groups (i.e., intervention vs. control). Owing to the fact that analyses were conducted to examine percentage changes, the standard deviation was set as the pre-testing score, in line with recent suggestions [43]. If articles reported symmetry scores, percentage values were converted to asymmetry scores, noting that this does not affect the standard deviation value.

Heterogeneity

Heterogeneity between studies was evaluated with I^2 statistics (*relative* heterogeneity) [44] and between-study variance with the tau-square (Tau^2) (*absolute* heterogeneity) [45]. The magnitude of heterogeneity for results was classified according to the following scale: < 25% = low, 25 - 75% = medium, and > 75% = high [44]. If the *p* value for the chi-square was < 0.1, this indicated the presence of heterogeneity, with a Tau^2 value > 1 suggesting the presence of substantial statistical heterogeneity [45]. A *p* value of < 0.1 indicated whether statistically significant subgroup differences were present [46, 47].

RESULTS

Study Description

The initial search strategy provided 30735 articles plus 2 additional articles were identified after consulting the reference lists of the articles selected for final analysis. After removing duplicates, and filtering articles through appropriate sports related journals (a function which can be applied in the databases), the final search provided 3212 articles.

Following the initial searches, 3031 articles were excluded after reviewing the title. After the evaluation of 181 abstracts, 160 articles were excluded. Finally, the full-text manuscripts of the remaining 21 studies were carefully assessed. Eleven articles were excluded because they did not meet the inclusion criteria; thus, 10 studies fulfilled the eligibility criteria and were therefore included in the final analysis. Two studies were ruled out because the inter-limb asymmetry test was not comparable to other studies (i.e., single leg hamstring bridge performed at failure and incremental unilateral squat) [48, 49]. Eight studies were determined to be selected for the meta-analysis. Subsequently, studies were grouped based on the inter-limb asymmetry test reported (e.g., SLCMJ), in order to examine all studies investigating the effects of training interventions on asymmetry, for any given test. Following this, studies using an intervention vs. a control group were also compared for the same inter-limb asymmetry tests. Study design, inter-limb asymmetry tests and metrics, training interventions, results, and quality scoring data, are reported in Table 2.

****** Insert Table 2 here ******

Meta-Analysis

Single Leg Broad Jump

When investigating the effects of different training interventions on SLBJ asymmetry scores 10 studies were found (Figure 2). Medium levels of heterogeneity were observed among studies (I^2 = 54%, Tau^2 = 0.17).

Compared to the pre-training intervention, the asymmetry index in SLBJ decreased with a small effect after the training protocols with no significant difference between the two time points [ES: 0.22, 95%CI (-0.12, 0.57)].

When investigating the effects of training interventions compared to the control groups 5 studies were found (Figure 3). Medium levels of heterogeneity were observed among studies (I^2 = 44%, Tau^2 = 0.12). Examining the results, the asymmetry index showed a small reduction in favour of the training intervention groups with no significant difference between the two groups [ES: 0.37, 95%CI (-0.10, 0.83)].

****** Insert Figures 2 and 3 here ******

Single Leg Countermovement Jump

When investigating the effects of different training interventions on SLCMJ asymmetry scores 8 studies were found (Figure 4). High levels of heterogeneity were observed among studies (I^2 = 84%, Tau^2 = 0.76). Compared to the pre-training intervention, the asymmetry index in SLCMJ decreased with a moderate effect after the training protocols with no significant difference between the two time points [ES: 0.53, 95%CI (-0.16, 1.23)].

When investigating the effects of training interventions compared to the control groups 3 studies were found (Figure 5). High levels of heterogeneity were observed among studies (I^2 = 94%, Tau^2 = 3.38). Examining the results, the asymmetry index showed a large reduction in favour of the training intervention groups with no significant difference between the two groups [ES: 1.78, 95%CI (-0.72, 4.28)].

****** Insert Figure 4 and 5 here ******

Single Leg Lateral Lump

When investigating the effects of different training interventions on single leg lateral jump asymmetry scores 3 studies were found (Figure 6). High levels of heterogeneity were observed among studies (I^2 = 74%, Tau^2 = 0.44). Compared to the pre-training intervention, the asymmetry index in single leg lateral jump decreased with a moderate effect after the training protocols with no significant difference between the two time points [ES: 0.62, 95%CI (-0.25, 1.50)].

When investigating the effects of training interventions compared to the control groups (Figure 7), no studies were found.

****** Insert Figure 6 here ******

Change of Direction Speed

When investigating the effects of different training interventions on COD speed asymmetry scores 4 studies were found (Figure 7). Medium levels of heterogeneity were observed among studies (I^2 = 45%, Tau^2 = 0.09). Compared to the pre-training intervention, the asymmetry index in COD decreased with a small effect after the training protocols with no significant difference between the two time points [ES: 0.23, 95%CI (-0.22, 0.68)].

When investigating the effects of training interventions compared to the control groups 2 studies were found (Figure 8). Medium levels of heterogeneity were observed among studies (I^2 = 49%, Tau^2 = 0.12). Examining the results, the asymmetry index showed a large reduction in favour of the training intervention groups with a significant difference between the two groups [ES: 0.82, 95%CI (0.15, 1.50)].

****** Insert Figure 7 and 8 here ******

Methodological Quality and Risk of Bias Assessment

The PEDro scale scores for the included studies within the meta-analyses ranged from 5 to 6 (mean ± SD: 5,75 ± 0,46) (see Table 1). These scores indicate that studies ranged in quality from fair to good.

Funnel plots are presented in Figure 9 (for all analyses with greater than two data points). Risk of small study bias (including publication bias) as denoted by Egger's regression test indicated the prevalence of small study bias for single leg broad jump (p = 0.037). Due to an insufficient number of data entries for the remaining analyses, we were unable to explicitly conduct follow up analysis and thus draw inferences from the funnel plots concerning potential risk of small study bias.

****** Insert Figure 9 here ******

DISCUSSION

The main aim of this systematic review was to examine if training interventions are effective in reducing inter-limb asymmetries across different physical qualities. The second aim was to investigate which types of training interventions are more effective in reducing these between-limb imbalances. Results suggested that training interventions have small to moderate effects on the reduction of asymmetry in SLBJ, SLCMJ, COD speed, and SL lateral jump indexes from pre- to post-training, however, no statistically significant differences were reported. Furthermore, a small to large reduction in inter-limb asymmetry indexes was found in the intervention groups compared to the control groups, with statistically significant difference found only in COD speed. Caution should be taken however when interpreting these findings (owing to the potential risk of small study/publication bias as a result of the small sample of studies included). Readers should note two important points in relation to this section: 1) changes in asymmetry are a result of changes in raw scores that create the asymmetry value in the first instance; thus, we have also discussed changes in asymmetry relative to the test in question and, 2) many studies utilised more than one test in their methodology. However, because we have divided this section up by test type (as per the statistics used in the meta-analysis), we have summarised the associated methods for each study at the earliest opportunity, but do refer back to the same study in subsequent sections.

Single Leg Broad Jump

Pre and Post Intervention

The findings of the present meta-analysis suggest that collectively, training interventions have a small effect in reducing distance asymmetry values in the SLBJ test from pre- to post-training intervention, yet no statistically significant difference was found [ES: 0.22 (-0.12, 0.57)] (Figure 2). In the study by Sannicandro et al. [50], they used a combination of bilateral and unilateral bodyweight and plyometric exercises, twice a week for six weeks, which showed large reductions in distance asymmetries (ES: 1.85). However, and somewhat surprisingly, it should be noted that the raw broad jump scores were not provided, impeding any possible conclusion regarding improvements in unilateral jump performance. Importantly though, no significant improvements were evident in linear or COD speed times ($p > 0.05$) for either the intervention or control groups. Thus, despite large reductions in distance asymmetry, this did not translate to improvements in independent measures of performance, which may be due to the training age of the participants (i.e., 12-years of age) and the duration of the intervention (i.e., 6-weeks). Despite these limitations, this does question the relevance of perfect symmetry for enhanced athletic performance; a concept which has been suggested in a recent longitudinal associative study [51].

Gonzalo-Skok et al. [52] used a combination of bilateral strength and power exercises, twice a week for six weeks. They found a moderate reduction in distance asymmetries (ES: 0.51) and moderate improvements in the raw jump scores after the training program (ES: 0.64 to 0.65). Additionally, findings revealed small to moderate improvements in repeated sprint ability (RSA) (ES: 0.49), repeated COD performance (ES: 0.60), and drop jump (DJ) followed by two hops for distance (measuring jump distance only) (ES: 0.23 to 2.29) from pre- to post-training intervention, while the control groups showed negligible or even small harmful effects in such tests (i.e., RSA (ES: -0.03), repeated COD (ES: -0.9), and DJ (ES: -0.11 to -0.04)). Therefore, it seems that reductions in inter-limb asymmetries were coupled with improvements in the raw jump scores, compared to the control groups. However, the intensity of the training intervention (i.e., RPE or %RM), which was not reported, the duration of the training program (i.e., session lasted 10 to 20 minutes), and the age of the participants (i.e., 16-years of age) limits the confidence in the results given.

In the study lead by Pardos-Mainer et al. [53], they adopted a strength training program based on core and lower limbs exercises, twice a week for eight weeks, finding small effects in reducing between-limb imbalances (ES: 0.20). This may be explained by the fact that the raw broad jump scores indicated significant improvements only on the left leg (ES: 0.58) after the training intervention. Interestingly, despite the fact that modifications on asymmetries were small, linear sprints (i.e., 10, 20, 30, 40-meter linear sprint) (ES: -1.29 to -1.02), V-Cut (ES: -0.58), bilateral broad jump (BJ) (ES: 0.29) and countermovement jump (CMJ) (ES: 0.55) performances were significantly improved after the training intervention. Interestingly, interaction analysis between the intervention and control group, showed significant changes in the strength and power training group in linear sprints, apart from 10-meter, (ES: -1.30 to -1.16) and V-Cut (ES: -0.62). The small effects in asymmetries may be attributed to the intensity selected to accomplish the training program, which was 10% of the BW, and the fact that the population was based on adolescent female soccer players (i.e., 16-years of age). However, given the reductions in asymmetry were only small, it seems likely that any improvements in physical performance were independent of any changes in asymmetry.

Pardos-Mainer et al. [54] also examined the effects of the FIFA11+ warm-up protocol, performed twice a week for ten weeks. Results showed small non-significant reductions in hop distance asymmetries (ES: 0.28) after the training protocol (calculated from the SLBJ test), even though the raw broad jump scores significantly improved between time points (ES: 0.34 to 0.40). This means that improvements in horizontal jumps did not translate to substantial reduction in asymmetries. Interestingly, the intervention did not yield improvements in bilateral BJ scores (ES: 0.07) and even induced a significant negative performance in the V-Cut test (ES: 0.59). However, DJ (ES: 0.61) and CMJ (ES: 0.48) performances were significantly improved. Thus, these controversial results may be due to the training age of participants (i.e., 12-years of age). Indeed, youth responds differently compared to adults to the training stimuli, based on the age of growth maturation [55]. Moreover, the current literature reports that the FIFA11+ protocol appears efficient in reducing injuries, but the effects on asymmetries and performance is still limited [56].

Conflicting results in distance asymmetries (ES: -0.48 to 0.10) were found in the eccentric training protocols conducted by Gonzalo-Skok et al. [57], where different volumes of training were applied to the weaker or stronger legs, previously identified. The training protocol consisted of lateral squats using flywheel technology only, and was performed once per week for ten weeks. It should be noted that the raw broad jump scores reported trivial to small changes across groups (ES: -0.21 to 0.32) and the only independent test utilised to assess physical performance was the bilateral CMJ, which reported small improvements across the groups (ES: 0.27 to 0.48). Thus, and once again, the link between reductions in asymmetry and improvements in the tests responsible for the asymmetry index appears tenuous. Whilst a true explanation for this is challenging, it is likely that the use of a single exercise, performed only once per week may have not been enough to elicit larger improvements in jump performance and/or greater reductions in asymmetry. Thus, future research should consider the efficacy of such training interventions, when aiming to concurrently enhance physical performance and impact inter-limb asymmetry.

Hammami et al. [58] used a strength training program, twice a week for six weeks, which showed small effects in reducing distance asymmetries (ES: 0.21). The authors did not calculate the pre- to post-interaction of raw broad jump scores, limiting any possible consideration concerning the actual changes in single leg jump scores. Interestingly, significant improvements in linear sprints (i.e., 10, 30-meter), agility, and BJ ($p < 0.05$) were evident, although no ES values were reported for these improvements. However, results should be interpreted with caution due to the age of participants (i.e., 11-years of age), which arguably would have had a low training age and therefore, are likely to improve in testing from most forms of training. Furthermore, given the age of the participants, this impedes any possible translation to adults [55].

Finally, Madruga-Perera et al. [59], used an 8-week training intervention performed twice a week in handball players, finding trivial to moderate effects in reducing distance asymmetries in the isoinertial (ES: 0.15) and cable-resistance (ES: -0.40) training groups. Despite this, both groups improved significantly their raw broad jump scores (ES: 1.13 to 1.67). Despite this, athletic performance tests (i.e., V-Cut (ES: -0.74 to -0.15) and repeated COD (ES: -1.35 to -0.22)) significantly improved, in both groups, while 20-meter linear sprint showed no meaningful changes (ES: -0.30 to 0.24). When considering the efficacy of the training program, it is worth noting that the intervention started with simple COD manoeuvres, but then got more complex as the intervention went on by integrating the use of sport-specific handball movements (in an attempt to replicate game demands). Additionally, velocity of a handball throw was used to determine the effectiveness of the training interventions in a more sport-specific test, which showed significant improvements in throwing velocity (ES: 0.88), but for the isoinertial group only. Thus, with some athletic performance tests showing meaningful improvements, the sport-specific test showing improvements and no clear changes in asymmetry; the link between reductions in asymmetry and athletic performance appears to be minimal.

Intervention vs. Control Groups

When examining the effects of different training interventions compared to control groups for the SLBJ asymmetries, the findings suggest a small effect in reducing the magnitude of imbalance in favour of the intervention groups, yet no statistically significant difference was found [ES: 0.37 (-0.10, 0.83)] (Figure 3). However, findings may be distorted by the results reported by Sannicandro et al. [50], due to the large effect reported (ES: 1.48). Surprisingly, two studies did not calculate or report the raw broad jump scores [50, 58], limiting our understanding of the effects on the raw jump data. For the remaining studies, either no significant or small improvements in the raw broad jump scores were found in the control groups [52-54]. Thus, it appears that training interventions likely have greater effects on the raw jump scores which create the asymmetry value, compared to the control group. However, as previously discussed, the efficacy of some of the training programmes could be questioned. As a final point for consideration, horizontal hopping tests (which report hop distance only) were recently considered a poor indicator for horizontal jumping performance [60]. Therefore, more research is required to effectively examine the strategy of horizontal jumps to provide a more in-depth understanding of how the jump is performed and subsequently, the inter-limb differences of these strategy metrics.

Single Leg Countermovement Jump

Pre and Post Intervention

The findings of the present meta-analysis suggest that collectively, training interventions have a moderate effect in reducing height or vertical ground reaction force asymmetry values in the SLCMJ test from pre- to post-training intervention, yet no statistically significant difference was found [ES: 0.53 (-0.16, 1.23)] (Figure 4).

In the study by Gonzalo-Skok et al. [57], eccentric training protocols (described in previous section) induced small to moderate changes in jump height asymmetry (ES: 0.33 to 0.58) for all three groups (e.g., 10.9% to 6.4%; 8.3% to 6.2%; and 6.8 to 5.0%). These relatively small changes can likely be explained by only trivial to moderate changes in raw jump scores after the training protocol (ES: 0.07 to 0.82). In addition, the analysis of physical performance, using the CMJ, showed small improvements after the training protocol (ES: 0.27 to 0.48). Therefore, it appears that such improvements in CMJ may be influenced by a reduction in asymmetries, given the similarity of movement. However, it is still questionable the transfer from the lateral squats to the vertical jumping actions.

Madruga-Perera et al. [59] reported small to large reductions in jump height asymmetries when comparing the isoinertial (ES: 1.30) and cable-resistance (ES: 0.43) training intervention. Interestingly, the raw jump scores significantly improved between time points (ES: 0.74 to 1.41) in both groups. Therefore, it should be plausible to presume that the training intervention selected, stimulated more adaptations in vertical jumping compared to horizontal jumps (as outlined in the previous section). Moreover, significant improvements were found in both groups in V-Cut (ES: -0.74 to -0.15) and repeated COD tests (ES: -1.35 to -0.22), whilst no significant changes were found in 20-meter linear sprint (ES: -0.30 to 0.24). Therefore, it should be investigated why linear sprint was not influenced by the enhanced symmetry index in vertical jumping actions, whilst COD tests showed positive adaptations.

In the study by Dello Iacono et al. [61], they used a combination of core, sprint, and strength exercises (e.g., hip extension, Nordics, and lunges), finding an extremely large effect (ES: 22.55) in reducing asymmetries in vertical ground reaction force. Surprisingly though, the raw jumps scores were not reported and the very low standard deviation relative to the mean asymmetry data is also surprising, given what previous research has reported [9, 21-26]. Interestingly, the authors also examined the effects of the training intervention to reduce asymmetries on isokinetic peak torque in flex/ext 1.05 rad * s^{-1} (ES: 0.61 to 0.75) and flex/ext 3.14 rad * s^{-1} (ES: 0.71 to 0.95), revealing significant improvements after the training protocol. However, it is strange that this study was classified as a 'core training intervention', given the inclusion of the lower body exercises, which are likely to have had a much greater effect on changing raw scores and asymmetry values, than any core-based exercise; owing to the fact that the current literature has shown a negligible effect of core stability on athletic performance [62].

Somewhat surprisingly, Pardos-Mainer et al. [54] reported a small increase in jump height asymmetry (ES: -0.36), when the FIFA11+ protocol was adopted. This may be attributed to the fact that the raw jump scores showed significant improvements only on the left leg (ES: 0.54), which likely explains the increase in the inter-limb imbalance. Interestingly, even though asymmetries increased, the bilateral vertical jump tests (i.e., DJ (ES: 0.61) and CMJ (ES: 0.48)), mentioned above, showed significant improvements between time points, while no significant changes were found in horizontal jumps (i.e., BJ) (ES: 0.07) or even a negative significant performance in V-Cut test (ES: 0.59). Thus, it seems that an increase in asymmetries may not be related to any reductions in vertical jump performance, when performed bilaterally, as shown recently [51].

In the study by Pardos-Mainer et al. [53], they examined the effects of a combined strength and power training intervention on jump height asymmetry, and no effects (ES: 0.00) were found after the training. The findings of the raw jump scores revealed a significant improvement only on the right leg (ES: 0.58). Therefore, it can be assumed that such a training intervention is not sufficient at driving muscular modifications to reduce asymmetries in vertical jumps. In fact, 10% of body mass is probably not enough to promote substantial changes [63, 64]. However, and surprisingly, all the physical tests conducted (mentioned above), namely 10, 20, 30, 40-meter linear sprints (ES: -1.29 to -1.02), V-Cut (ES: -0.58), BJ (ES: 0.29), and CMJ (ES: 0.55), showed significant improvements after the training intervention. Thus, no significant changes in jump height asymmetries appears not to be associated with changes in physical performance. Therefore, it is still arguable to establish if reductions in asymmetries are essential to improve athletic performance.

Intervention vs. Control Groups

When examining the results of different training interventions compared to control groups for the SLCMJ asymmetries, the findings suggest a large effect in reducing the magnitude of asymmetry in favour of the intervention group, yet no statistically significant difference was found [ES: 1.78, (-0.72, 4.28)] (Figure 5). However, this finding should be interpreted with caution, due to the extremely large effects found in Dello Iacono et al. [61], which have likely skewed the results. Moreover, the lack of the raw jump scores in the control group makes a true comparison hard to do. Interestingly, the literature is not conclusive regarding the benefits of core training on athletic performance [62]. The other studies [53, 54] showed that the raw jump scores of the control groups did not change significantly (*p* > 0.05), confirming therefore that when muscular stimuli were applied, reductions in between-limb imbalances occurred. Therefore, it is plausible to assume that training interventions which utilise isoinertial or flywheel technology can elicit reductions in vertical jump asymmetries.

Single Leg Lateral Jump

Pre and Post Intervention

The findings of the present meta-analysis suggest that collectively, training interventions have a moderate effect in reducing distance asymmetry values in the SL Lateral Jump from pre- to post-training intervention, yet no statistically significant difference was found [ES: 0.62 (-0.25, 1.50)] (Figure 6).

In the aforementioned study by Madruga-Perera et al. [59] led on handball players, they found trivial to small reductions (ES: 0.00 to 0.38) in distance asymmetries based on the aforementioned isoinertial or cable-resistance training programs. Interestingly, the findings revealed that the raw scores significantly improved only in the non-dominant leg (ES: 0.34 to 0.49) in both groups after the training intervention. Additionally, the V-Cut (ES: -0.74 to -0.15) and repeated COD (ES: -1.35 to -0.22) significantly improved; while 20-meter linear sprint did not improve (ES: -0.30 to 0.24). Despite the limitations regarding the age of participants (i.e., 16-years of age) and the training program selected (i.e., mix of exercises using or simulating ball in the hands), it appears that reduction in asymmetries in SL lateral jumps may have an impact on COD performance. Although a somewhat anecdotal explanation, it is likely that the notion of specificity plays a part here, given that these jumps occur in the frontal plane and COD movements also have frequent movement patterns in this direction [65].

Sannicandro et al. [50] found large effects (ES: 1.71) in reducing distance asymmetries. However, as discussed above, the raw jump scores were not reported, impeding any possible conclusion regarding the improvements in lateral jumps. Furthermore, and contrary to the previous study, the physical tests conducted (i.e., 10, 20-meter linear sprint and Foran test) did not show any significant change from pre- to post-training intervention (*p* > 0.05). Thus, although the study included bodyweight and plyometrics exercises, in addition to balance training (performed in the frontal plane), which appeared to be enough to stimulate meaningful reductions in inter-limb asymmetries, it was not enough to drive positive adaptations in linear or COD speed tests, which is arguably more important for a sport like Tennis [66].

Change of Direction Speed

Pre and Post Intervention

The findings of the present meta-analysis suggest that collectively, training interventions have a small effect in reducing time asymmetry values in the COD speed test from pre- to post-training intervention, yet no statistically significant difference was found [ES: 0.23 (-0.22, 0.68)] (Figure 7).

In the study by Pardos-Mainer et al. [54], previously described, they reported small changes in reducing time asymmetries (ES: 0.49) after the training program based on the FIFA11+ protocol. Surprisingly, despite the reductions in asymmetries, the raw COD scores showed an increase in time (i.e., slower performance), although these changes were not statistically significant (ES: -0.01 to 0.32), as well as, the V-Cut test which did reveal a significant increase in time (i.e., slower performance) (ES: 0.59). In addition, whilst the COD speed tests showed a reduction in performance, the vertical jumps tests conducted (i.e., DJ (ES: 0.61) and CMJ (ES: 0.48)) significantly improved. Likely, the training intervention, previously described (i.e., bodyweight in nature), did not elicit such modifications to promote changes in COD actions, which based off previous literature, is likely to require greater levels of muscular strength [67] and improvements in technique [65].

Moderate effects in reducing time asymmetries (ES: 0.70) were also found by Pardos-Mainer et al. [53], adopting a strength and power training program (previously described). By contrast to the previous study, the raw COD scores showed significant improvements (i.e., faster performance) only on the left leg (ES: -0.52). Consequently, 10, 20, 30, 40-meter linear sprint (ES: -1.29 to -1.02), V-Cut (ES: -0.58), BJ (ES: 0.29), and CMJ (ES: 0.55) showed significant improvements from pre- to post-training intervention. In this case, a reduction in asymmetries did translate to improvements in physical performance. The reasons may be attributed to the muscle stimuli given by performing sprints, drop jumps, and hip thrust exercises; which are determinants in promoting muscle adaptations during COD movements [68]. However, it should be acknowledged that minimum load (i.e., 10% body weight) was provided during strength exercises. Thus, it is still questionable if reductions in time asymmetries have a consistent impact on physical performance.

In the aforementioned study by Madruga-Perera et al. [59], a trivial effect was found in the cable-resistance group (ES: 0.03) in reducing time asymmetry, and a small effect in increasing asymmetries for time during COD tests in the isoinertial group (ES: -0.32). Surprisingly, the raw COD scores revealed a significant improvement (i.e., faster performance) (ES: -0.83 to -0.65) from pre- to post training intervention in both groups. Additionally, V-Cut (ES: -0.74 to -0.15) and repeated COD (ES: -1.35 to -0.22) significantly improved, while 20-meter linear sprint did not improve significantly (ES: -0.30 to 0.24). These results suggest that improvements in athletic performance are not strictly correlated to reductions in asymmetries. Therefore, which are the determinants to reduce inter-limb asymmetries in COD speed and which are the determinants to improve performance in COD require further research. Although somewhat anecdotal, it is feasible that the training protocol did not stimulate eccentric peak force and cutting technique, which are determinants in reducing COD speed asymmetries [69-71].

Intervention vs. Control Groups

When examining the results of different training interventions compared to control groups for the COD speed asymmetries, there is a large significant effect in reducing the asymmetry index in favour of the training intervention group [ES: 0.82 (0.15, 1.50)] (Figure 8). This may be explained by the muscular stimuli occurred in the training interventions compared to the control groups [53], but also by the fact that no significant changes were evident in the raw scores for the control groups ($p > 0.05$). Interestingly, despite the large effects found by Pardos-Mainer et al. [54], both the intervention and the control group did not significantly improve their raw COD scores ($p > 0.05$), indicating that asymmetry changes are independent to changes in raw score performance. Therefore, future research should investigate if reductions in asymmetries translate to improvements in COD speed performance. Furthermore, it should be acknowledged that the metric of total time in COD speed tests is not overly sensitive in detecting between-limb imbalances, due to the movement variability to complete such a physical test [72]. Therefore, the use of COD speed as inter-limb asymmetry tests should be analysed carefully, especially if only using the outcome measure of time [73]. In contrast, time can still be considered a stable and reliable measure if monitoring performance during COD tasks [25].

Practical Recommendations, Directions for Future Research, and Limitations

Practical Recommendations

With regard to inter-limb asymmetry changes from pre- to post-training and the comparison between intervention and control groups, the current analysis indicates that large standard deviations are often evident when compared to the mean asymmetry scores (Table 2). Therefore, the inherent variability found in inter-limb asymmetry and some equivocal results reported may be explained by this. Simply put, with such large within- and between-group variation in asymmetry often present, it is likely that this precluded any meaningful differences from being reported between time points [22]. Consequently, with asymmetry evidently being less ‘sensitive to change’ than raw test scores, it does question the usability of this as a metric during the ongoing monitoring process [17, 74]. Indeed, it is worth noting that inter-limb asymmetry raw scores did not show significant changes consistently. For this reason, it is difficult to find substantial change in asymmetry indexes. However, if practitioners still believe that asymmetry can inform the decision-making process, then an individual analysis is likely needed in order to determine true change and avoid the noise associated with group mean asymmetry data [22]. In fact, inter-limb asymmetries would be considered meaningful only if the changes of the scores are greater than the pre-testing individual coefficient of variation (CV) value, which measures the errors in the physical tests [22].

Moreover, it should be acknowledged that changes in inter-limb asymmetry scores from pre- to post-training interventions were not consistently associated with significant improvements in such physical tests. From a performance perspective, owing to the conflicting results obtained, it is still unclear whether reductions in inter-limb asymmetries may have a significant impact in physical or sporting performance and is something that future research should endeavour to investigate.

Directions for Future Research

Firstly, further research should focus on alternative study designs. For example, 1) increasing the sample size and recruit homogeneous populations (i.e., youth, adults, males, females) in well-designed randomized controlled trials [75], 2) using control groups to compare efficacy of training interventions, 3) adopting consistent and reliable metrics and physical tests to measure inter-limb asymmetries [76], 4) more long-term interventions with consistent repeated measures over time [51], 5) examining whether changes in inter-limb asymmetries are associated with changes in physical performance and, 6) also analysing the direction of asymmetries [5, 77, 78] to determine if fluctuations in limb dominance are evident, which has been noted in recent test-retest design research [21, 77].

From a training intervention perspective, researchers should be encouraged to carefully select the intensity and volume of training interventions in order to promote specific muscular adaptations (e.g., strength and power training) [63, 64, 79-84]. For instance, Sannicandro et al. [50] and Dello Iacono et al. [61] reported sets and repetitions of training interventions. However, both articles did not state the intensity used (i.e., RPE, RIR, %RM, or BW), impeding therefore, our ability to establish accurately if the adequate muscle stimuli were provided. Similarly, Pardos-Mainer et al. [54] adopted the FIFA11+ protocol, based on bodyweight exercises, which is probably insufficient to drive significant muscular strength gains in order to modify inter-limb asymmetries. Indeed, it is worth noting that muscular adaptations occur only if the stimuli are correctly administered [85]. This may be a reason for no significant changes in the raw asymmetry scores and, likely, in some of the physical performance tests used. Thus, changes in inter-limb asymmetries without any significant changes in raw physical performance scores may be considered questionable.

Finally, all the studies included in this systematic review adopted outcome measures when reporting asymmetry (e.g., jump height or distance). However, it is worth noting that such metrics are not always sensitive to change when detecting side-to-side differences [76]. In addition, and to use jump tests as an example, outcome measures provide no information on jump strategy (i.e., how the jump was performed). In contrast, metrics such as peak or mean force, and propulsive or braking impulse have been shown to provide useful information for practitioners [2, 76], and may be more useful at monitoring discrete changes in asymmetry; although further research is needed to fully corroborate this suggestion.

Limitations

This review is not without limitations. Owing to the paucity of intervention studies on this topic that used a control group, practitioners should be mindful of the true 'cause and effect' relationships being inferred from studies which only report within-group differences. This is reflected in the moderate to large cases of heterogeneity observed, and the presence of potential small study bias (inclusive of publication bias) in our findings. However, it is important to recognize that including a control group in elite or professional sport settings can be considered a luxury, and is unlikely to be available. This does not mean that the research is not worth conducting, but it does mean practitioners may wish to consider alternative methods of establishing whether changes in asymmetry are meaningful. As such, previous literature has highlighted the importance of measuring the CV alongside any reported inter-limb differences [86]. Simply put, if the between-limb imbalance is greater than the test variability (CV), the magnitude of asymmetry can be considered 'real' [86]. Consequently, if such analyses identified persistent real asymmetries to be present each time testing was undertaken, it may provide useful information on whether targeted training interventions were needed to enhance the weaker limb's capacity [5, 74].

PRACTICAL APPLICATIONS

This systematic review showed that the effects of training interventions on inter-limb asymmetries in sports population are controversial. Cumulatively, it appears that different training protocols have a small effect in reducing inter-limb asymmetries in the SLBJ and the COD speed, while a moderate effect has been found in the SLCMJ and the SL lateral jump after a minimum of a 6-week training intervention. However, it should be acknowledged that small to large effects in reducing between-limb imbalances were found favour of the training groups compared to the control groups. Simply put, the data from this systematic review pointed out that training interventions can reduce inter-limb asymmetries to a certain extent only, and presence of potential small study bias (inclusive of publication bias) should also be noted. Therefore, it is suggested that if practitioners wish to decrease inter-limb asymmetries, unilateral and bilateral training intervention should be considered. However, further research is required to examine the effects of inter-limb asymmetry reductions on physical performance.

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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. PEDro score of each study.

PEDro scale	Item 1	Item 2	Item 3	Item 4	Item 5	Item 6	Item 7	Item 8	Item 9	Item 10	Item 11	Total score
Sannicandro et al. (2014)	X	√	X	√	X	X	X	X	√	√	√	5
Dello Iacono et al. (2016)	√	√	X	√	X	X	X	X	√	√	√	6
Madruga-Perera et al. (2020)	√	√	X	√	X	X	X	X	√	√	√	6
Hammami et al. (2020)	X	√	√	√	X	X	X	X	√	√	√	6
Gonzalo-Skok et al. (2019)	X	√	√	√	X	X	X	X	√	√	√	6
Pardos-Mainer et al. (2019)	X	√	√	√	X	X	X	X	√	√	√	6
Gonzalo-Skok et al. (2016)	X	√	X	√	X	X	X	X	√	√	√	5
Pardos-Mainer et al. (2020)	√	√	X	√	X	X	X	X	√	√	√	6

Table 2. Summary of studies that have used training interventions on inter-limb asymmetries.

References	Subjects and Study Design	Tests and Metrics	Training Intervention	Results			
Sannicandro et al. (2014)	Tennis players (n=23), mean age=13 RCT (n=11 Balance Tr gr; n=12 Control gr)	SLBJ: jump distance (cm) SL Lateral Jump: jump distance (cm)	6 weeks (2 sessions per week) Balance gr: skipping (6x5), single leg bound (4x6), forward bound (3x4), low rows on inflatable disk, medicine ball chest pass (4x10), lateral raise on bosu ball (3x10), balance on skimmy cushion (2x4), two-legged successive jump (4x4), step-up on bosu ball (4x10), squat on unstable surface (3x10), step-up on bosu ball (4x8)	AI	Balance gr	Control gr	
				SLBJ	9.0 ± 3.6 % to 3.7 ± 1.5 % (*p*<0.05)	9.0 ± 3.7 % to 9.3 ± 5.2 % (*p*>0.05)	
				SL Lateral Jump	10.8 ± 5.9 % to 3.2 ± 1.4% (*p*<0.05)	13.2 ± 10.1 % to 13.0 ± 8.1 % (*p*>0.05)	
Dello Iacono et al. (2015)	Male soccer players (n=20), mean age=19; RCT (n=10 Core Stability gr; n=10 Control gr)	SLCMJ: peak vertical ground reaction force	6 weeks (5 sessions per week) Core Stability gr: seated torso + eccentric phase, kneeling superman exercise, hip extension, Nordic hamstring, walking lunge (3x10), frontal balance, lateral balance, sprint and stop in delimitated space (3x4)	AI	Core Stability gr	Control gr	
				SLCMJ	5.4 ± 0.11 % to 1.6 ± 0.2 % (ES=2.01; *p*<0.05)	4.8 ± 0.3 % to 7.2 ± 0.1 % (ES=1.28; *p*<0.05)	
Madruga-Parera et al. (2020)	Male handball players (n=20), mean age=16; RCT (n=17 Isoinertial gr; n=17 Cable-resistance gr)	SLBJ: jump distance (cm) SLCMJ: jump height (cm) SL Lateral Jump: jump distance (cm) 180° COD: seconds	8 weeks (2 sessions per week) Isoinertial and Cable-resistance gr: forward lunge, lateral squat, lateral lunge, single leg hop, acceleration (3x12 RPE 6/8), SLCMJ, crossover step, acceleration, 180° turn (3x8 RPE 8/9)	AI	Isoinertial gr	Cable-resistance gr	
				SLBJ	5.97 ± 5.29 % to 7.07 ± 5.84 % (ES=0.15; *p*>0.05)	7.97 ± 3.95 % to 5.03 ± 4.16 % (ES=-0.40; *p*>0.05)	
				SLCMJ	14.81 ± 8.82 % to 6.05 ± 2.93 % (ES=-0.70; *p*<0.05)	9.44± 7.66 % to 6.79 ± 3.80 % (ES=-0.32; *p*<0.05)	
				SL Lateral Jump	7.55 ± 7.38 % to 5.27 ± 3.53 % (ES=-0.34; *p*>0.05)	8.18 ± 8.69 % to 8.15 ± 5.53 % (ES=-0.00; *p*>0.05)	
				COD	1.96 ± 1.81 % to 2.51 ± 1.56 % (ES=0.16; *p*>0.05)	2.88 ± 2.21 % to 2.82 ± 2.19 % (ES=-0.02; *p*>0.05)	
Hammami et al. (2020)	Weightlifters (n=20), mean age=11; RCT (n=10 Eccentric gr; n=10 Control gr)	SLBJ: jump distance (cm)	6 weeks (2 sessions per week) Eccentric gr: eccentric glute-hamstring raise, glute-hamstring rise, single leg romanian deadlift, hip thrust, good morning (from 3x10 60%1RM to 5x12 80%1RM)	SI	Eccentric gr	Control gr	
				SLBJ	105.1 ± 6.8 % to 103.9 ±3.8 % (*p*>0.05)	106.1 ± 7.3 % to 106 ± 5.1 % (*p*>0.05)	
Gonzalo-Skok et al. (2019)	Male soccer players (n=45), mean age=15; RCT (n=15 Same vol both legs starting with weaker[SVW]; n=15 Double vol weaker leg starting with weaker [DVW]; n=15 Same vol	SLBJ: jump distance (cm) SLCMJ: jump height (cm)	10 weeks (1 session per week) All gr: Eccentric unilateral lateral squat (from 6 repetitions speed:force ratio 1 to 10 repetitions speed:force ratio 3)	AI	SVW	DVW	SVS
				SLBJ	4.3 ± 3.4 % to 4.0 ± 2.7 % (ES=0.06)	3.3 ± 2.8 % to 4.2 ± 1.7 % (ES=-0.51)	3.4 ± 4.2 % to 5.8 ± 5.5 % (ES=-0.58)
				SLCMJ	10.9 ± 9.8 % to 6.4 ± 4.1 % (ES=0.23)	8.3 ± 7.9 % to 6.2 ±3.7 % (ES=0.08)	6.8 ± 5.4 % to 5.0 ± 4.6 % (ES=0.24)

References	Subjects and Study Design	Tests and Metrics	Training Intervention	Results		
	both legs starting with stronger [SVS])					
Pardos-Mainter et al. (2020)	Female soccer players (n=37), mean age=16; RCT (n=19 Strength and Power gr; n=18 Control gr)	SLBJ: jump distance (m) SLCMJ: jump height (cm) 180° COD: seconds	8 weeks (2 sessions per week) Strength and Power gr: the diver, single leg box step-up, forward lunge, backward lunge (from 6 to 8x2 10%BW), one leg hip thrust, eccentric box drops, russian belt posterior and anterior chain (from 6 to 10x2), plank, lateral plank, lumbar bridge (from 15s to 20s)	AI	Strength and Power gr	Control gr
				SLBJ	6.32 ± 5.41 % to 5.26 ± 5.08 % (ES=-0.26; *p*>0.05)	4.09 ± 3.93 % to 4.48 ± 3.33 % (ES=0.07; *p*>0.05)
				SLCMJ	11.5 ± 8.99 % to 11.5 ± 11.3 % (ES=-0.21; *p*>0.05)	12.5 ± 10.2 % to 15.7 ± 10.1 % (ES=0.22; *p*>0.05)
				COD	4.42 ± 3.14 % to 2.55 ± 1.93 % (ES=-0.30; *p*>0.05)	2.62 ± 2.29 % to 2.14 ± 1.55 % (ES=-0.07; *p*>0.05)
Gonzalo-Skok et al. (2016)	Male basketball players (n=22), mean age=16; RCT (n=11 Power gr; n=11 Control gr)	SLBJ: jump distance (cm)	6 weeks (2 sessions per week) Power gr: leg press using maximal power (5x5)	SI	Power gr	Control gr
				SLBJ	94.3 ± 3.6 % to 95.9 ± 2.3 % (ES=0.39)	94.9 ± 4.4 % to 95.5 ± 4.3 % (ES=0.13)
Pardos-Mainer et al. (2019)	Female soccer players (n=36), mean age=12; RCT (n=19 Intervention gr; n=17 Control gr)	SLBJ: jump distance (m) SLCMJ: jump height (cm) 180° COD: seconds	10 weeks (2 sessions per week) Intervention gr (FIFA11+): plank, lateral plank (15s x2), chest pass, Nordic hamstring exercise, forward bend, figure-of-eight, jump over line (10x2), zig-zag shuffle, bounding	AI	FIFA11+ gr	Control gr
				SLBJ	92.9 ± 4.74 % to 94.3 ± 5.09 % (ES=0.26; *p*>0.05)	91.9 ± 6.37 % to 93.5 ± 5.31 % (ES=0.15; *p*>0.05)
				SLCMJ	90.0 ± 5.46 % to 87.3 ± 8.67 % (ES=-0.62; *p*>0.05)	93.1 ± 4.35 % to 91.3 ± 6.87 % (ES=-0.76; *p*>0.05)
				COD	96.8 ± 1.84 % to 97.7 ± 1.79 % (ES=0.49; *p*>0.05)	97.7 ± 2.13 % to 96.2 ± 2.36 % (ES=-0.44; *p*>0.05)

Legend: *AI=Asymmetry index; SI=Symmetry index; Gr=group; RCT=randomized controlled trial; ES=Effect size; p=p value; SLBJ=Single leg broad jump; SLCMJ=Single leg countermovement jump; SL=Single leg; COD=Change of direction; RPE=Rate of perceived exertion; RM=Repetition maximum; m=meter; cm=centimetre.*

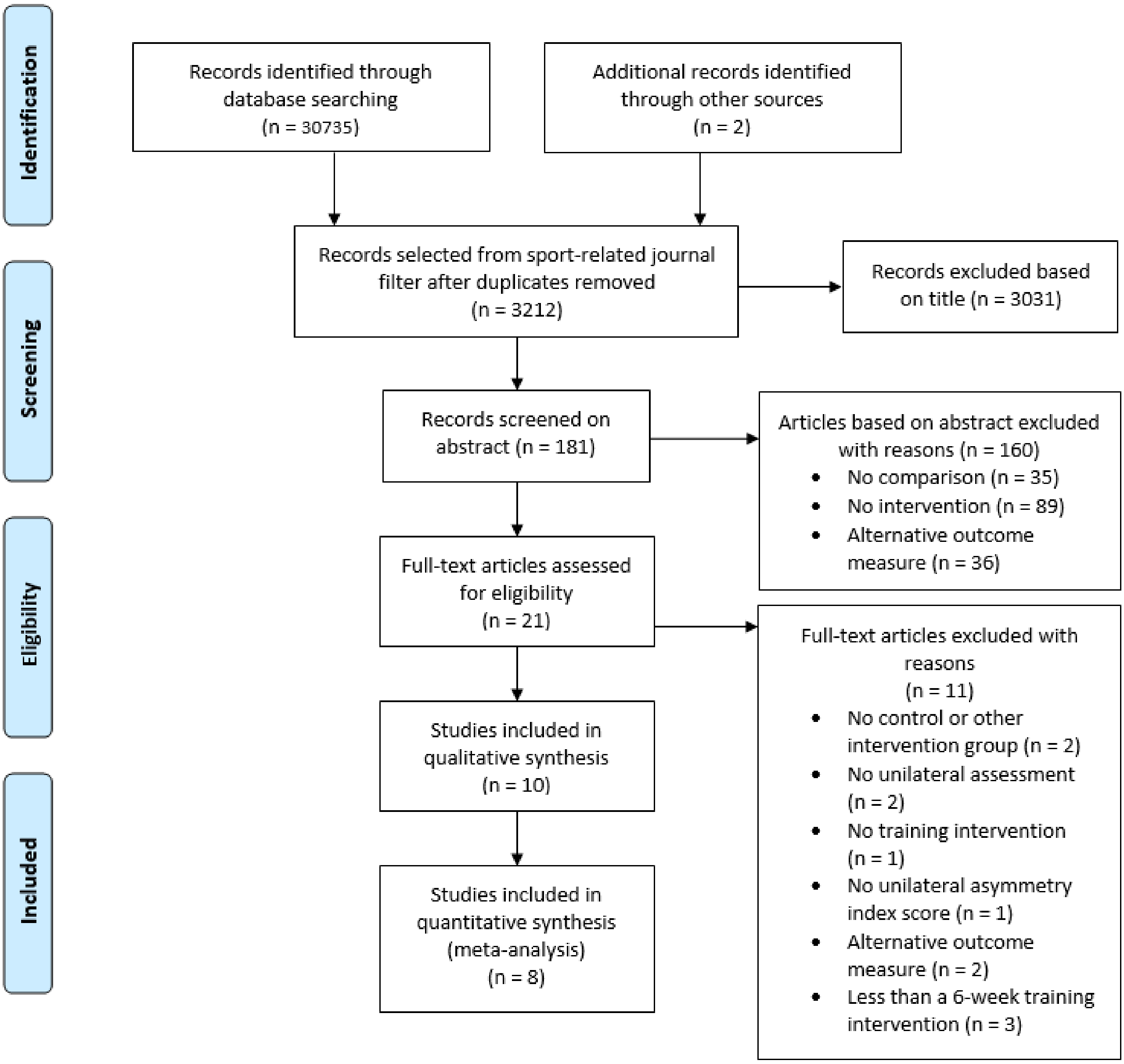
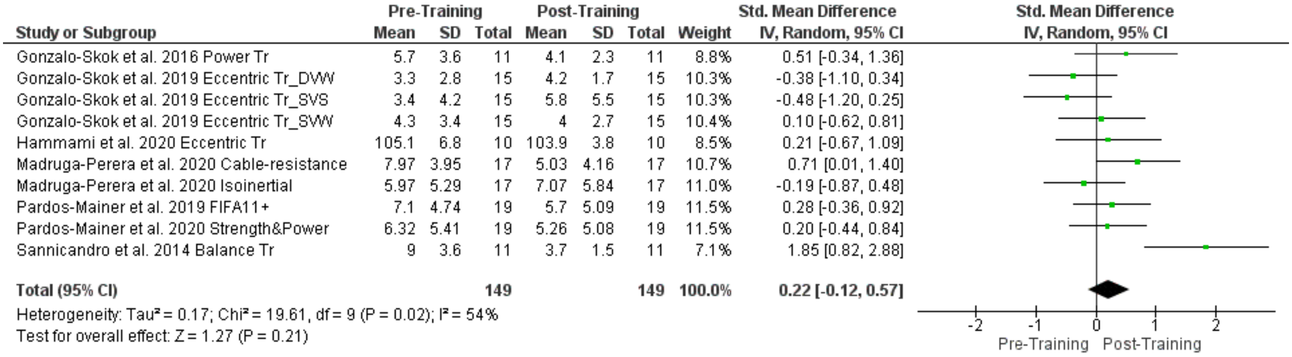


Figure 1. Flow diagram showing the identification and selection of studies on the available body of literature for the current review.

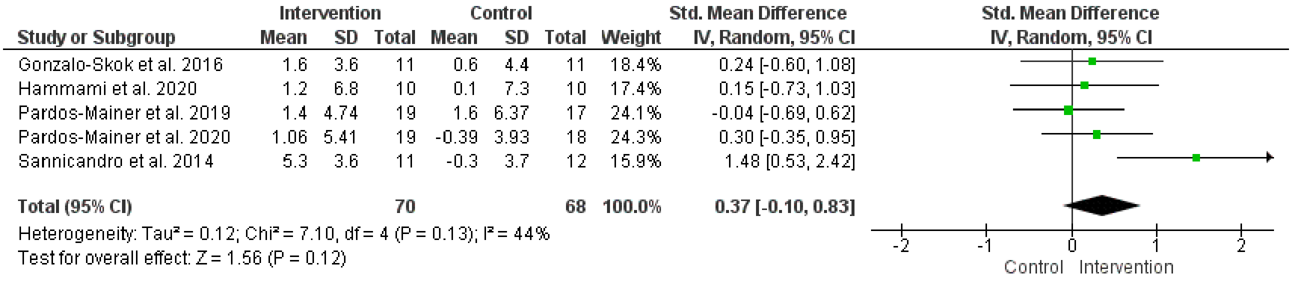


Study or Subgroup	Pre-Training Mean	Pre-Training SD	Pre-Training Total	Post-Training Mean	Post-Training SD	Post-Training Total	Weight	Std. Mean Difference IV, Random, 95% CI
Gonzalo-Skok et al. 2016 Power Tr	5.7	3.6	11	4.1	2.3	11	8.8%	0.51 [-0.34, 1.36]
Gonzalo-Skok et al. 2019 Eccentric Tr_DVW	3.3	2.8	15	4.2	1.7	15	10.3%	-0.38 [-1.10, 0.34]
Gonzalo-Skok et al. 2019 Eccentric Tr_SVS	3.4	4.2	15	5.8	5.5	15	10.3%	-0.48 [-1.20, 0.25]
Gonzalo-Skok et al. 2019 Eccentric Tr_SVW	4.3	3.4	15	4	2.7	15	10.4%	0.10 [-0.62, 0.81]
Hammami et al. 2020 Eccentric Tr	105.1	6.8	10	103.9	3.8	10	8.5%	0.21 [-0.67, 1.09]
Madruga-Perera et al. 2020 Cable-resistance	7.97	3.95	17	5.03	4.16	17	10.7%	0.71 [0.01, 1.40]
Madruga-Perera et al. 2020 Isoinertial	5.97	5.29	17	7.07	5.84	17	11.0%	-0.19 [-0.87, 0.48]
Pardos-Mainer et al. 2019 FIFA11+	7.1	4.74	19	5.7	5.09	19	11.5%	0.28 [-0.36, 0.92]
Pardos-Mainer et al. 2020 Strength&Power	6.32	5.41	19	5.26	5.08	19	11.5%	0.20 [-0.44, 0.84]
Sannicandro et al. 2014 Balance Tr	9	3.6	11	3.7	1.5	11	7.1%	1.85 [0.82, 2.88]
Total (95% CI)			**149**			**149**	**100.0%**	**0.22 [-0.12, 0.57]**

Heterogeneity: Tau² = 0.17; Chi² = 19.61, df = 9 (P = 0.02); I² = 54%
Test for overall effect: Z = 1.27 (P = 0.21)

Legend: *Tr=Training; DVW=Double volume starting with weaker leg; SVS=Same volume starting with stronger leg; SVW=Same volume starting with weaker leg.*

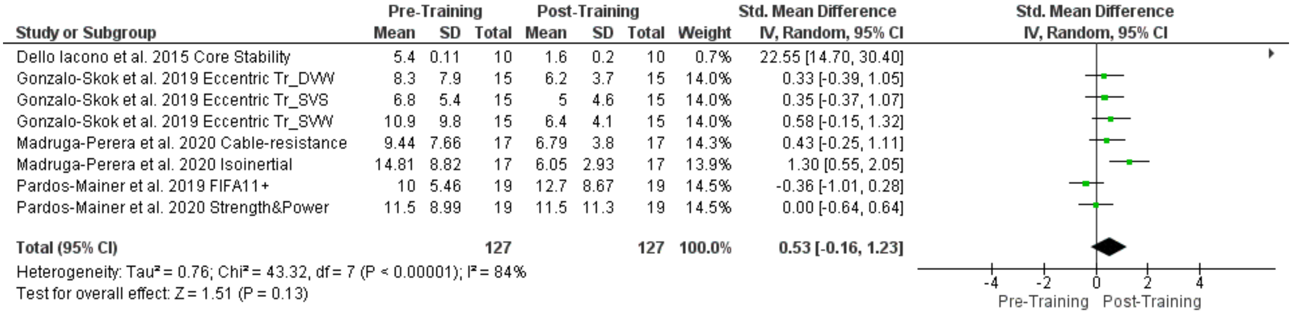
Figure 2. Effects of different training interventions on single leg broad jump asymmetry index.



Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Gonzalo-Skok et al. 2016	1.6	3.6	11	0.6	4.4	11	18.4%	0.24 [-0.60, 1.08]
Hammami et al. 2020	1.2	6.8	10	0.1	7.3	10	17.4%	0.15 [-0.73, 1.03]
Pardos-Mainer et al. 2019	1.4	4.74	19	1.6	6.37	17	24.1%	-0.04 [-0.69, 0.62]
Pardos-Mainer et al. 2020	1.06	5.41	19	-0.39	3.93	18	24.3%	0.30 [-0.35, 0.95]
Sannicandro et al. 2014	5.3	3.6	11	-0.3	3.7	12	15.9%	1.48 [0.53, 2.42]
Total (95% CI)			**70**			**68**	**100.0%**	**0.37 [-0.10, 0.83]**

Heterogeneity: Tau² = 0.12; Chi² = 7.10, df = 4 (P = 0.13); I² = 44%
Test for overall effect: Z = 1.56 (P = 0.12)

Figure 3. Comparison of intervention vs. control groups on single leg broad jump asymmetry index.

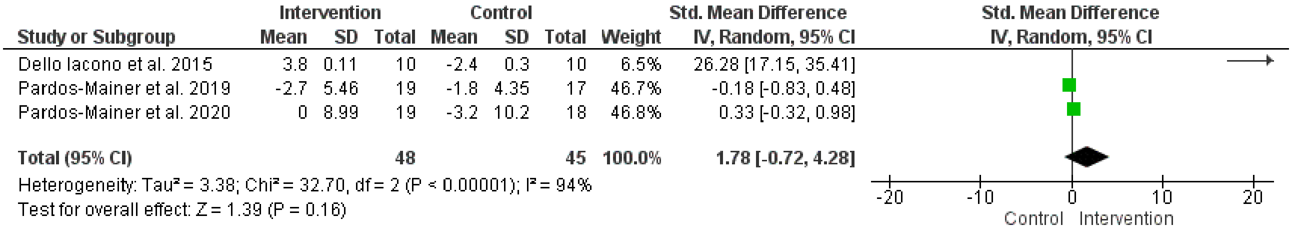


Study or Subgroup	Pre-Training Mean	Pre-Training SD	Pre-Training Total	Post-Training Mean	Post-Training SD	Post-Training Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dello Iacono et al. 2015 Core Stability	5.4	0.11	10	1.6	0.2	10	0.7%	22.55 [14.70, 30.40]
Gonzalo-Skok et al. 2019 Eccentric Tr_DVW	8.3	7.9	15	6.2	3.7	15	14.0%	0.33 [-0.39, 1.05]
Gonzalo-Skok et al. 2019 Eccentric Tr_SVS	6.8	5.4	15	5	4.6	15	14.0%	0.35 [-0.37, 1.07]
Gonzalo-Skok et al. 2019 Eccentric Tr_SVW	10.9	9.8	15	6.4	4.1	15	14.0%	0.58 [-0.15, 1.32]
Madruga-Perera et al. 2020 Cable-resistance	9.44	7.66	17	6.79	3.8	17	14.3%	0.43 [-0.25, 1.11]
Madruga-Perera et al. 2020 Isoinertial	14.81	8.82	17	6.05	2.93	17	13.9%	1.30 [0.55, 2.05]
Pardos-Mainer et al. 2019 FIFA11+	10	5.46	19	12.7	8.67	19	14.5%	-0.36 [-1.01, 0.28]
Pardos-Mainer et al. 2020 Strength&Power	11.5	8.99	19	11.5	11.3	19	14.5%	0.00 [-0.64, 0.64]
Total (95% CI)			**127**			**127**	**100.0%**	**0.53 [-0.16, 1.23]**

Heterogeneity: Tau² = 0.76; Chi² = 43.32, df = 7 (P < 0.00001); I² = 84%
Test for overall effect: Z = 1.51 (P = 0.13)

Legend: *Tr=Training; DVW=Double volume starting with weaker leg; SVS=Same volume starting with stronger leg; SVW=Same volume starting with weaker leg.*

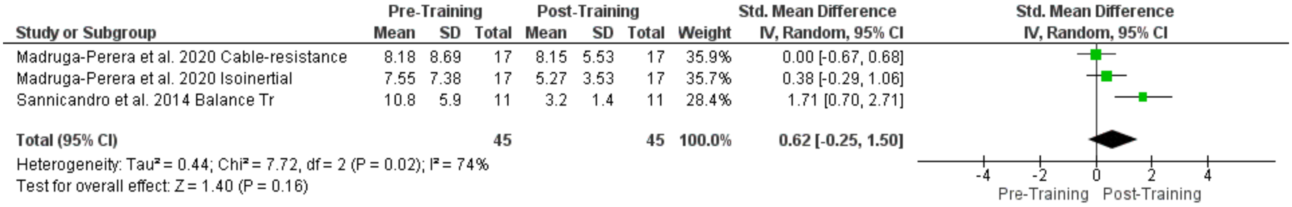
Figure 4. Effects of different training interventions on single leg countermovement jump asymmetry index.



Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Dello Iacono et al. 2015	3.8	0.11	10	-2.4	0.3	10	6.5%	26.28 [17.15, 35.41]
Pardos-Mainer et al. 2019	-2.7	5.46	19	-1.8	4.35	17	46.7%	-0.18 [-0.83, 0.48]
Pardos-Mainer et al. 2020	0	8.99	19	-3.2	10.2	18	46.8%	0.33 [-0.32, 0.98]
Total (95% CI)			**48**			**45**	**100.0%**	**1.78 [-0.72, 4.28]**

Heterogeneity: Tau² = 3.38; Chi² = 32.70, df = 2 (P < 0.00001); I² = 94%
Test for overall effect: Z = 1.39 (P = 0.16)

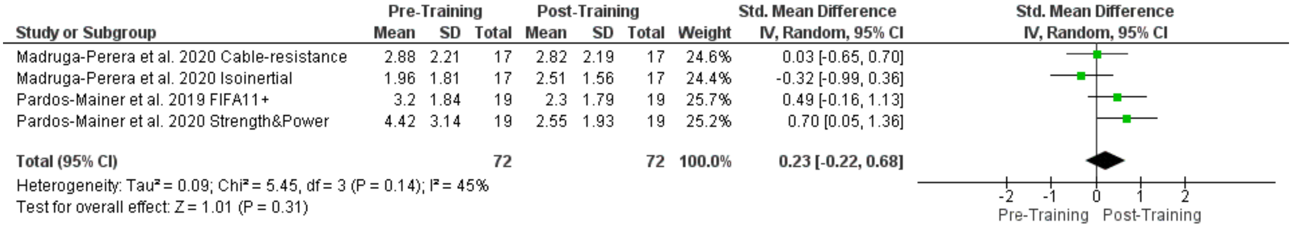
Figure 5. Comparison of intervention vs. control group on single leg countermovement jump asymmetry index.



Study or Subgroup	Pre-Training Mean	Pre-Training SD	Pre-Training Total	Post-Training Mean	Post-Training SD	Post-Training Total	Weight	Std. Mean Difference IV, Random, 95% CI
Madruga-Perera et al. 2020 Cable-resistance	8.18	8.69	17	8.15	5.53	17	35.9%	0.00 [-0.67, 0.68]
Madruga-Perera et al. 2020 Isoinertial	7.55	7.38	17	5.27	3.53	17	35.7%	0.38 [-0.29, 1.06]
Sannicandro et al. 2014 Balance Tr	10.8	5.9	11	3.2	1.4	11	28.4%	1.71 [0.70, 2.71]
Total (95% CI)			**45**			**45**	**100.0%**	**0.62 [-0.25, 1.50]**

Heterogeneity: Tau² = 0.44; Chi² = 7.72, df = 2 (P = 0.02); I² = 74%
Test for overall effect: Z = 1.40 (P = 0.16)

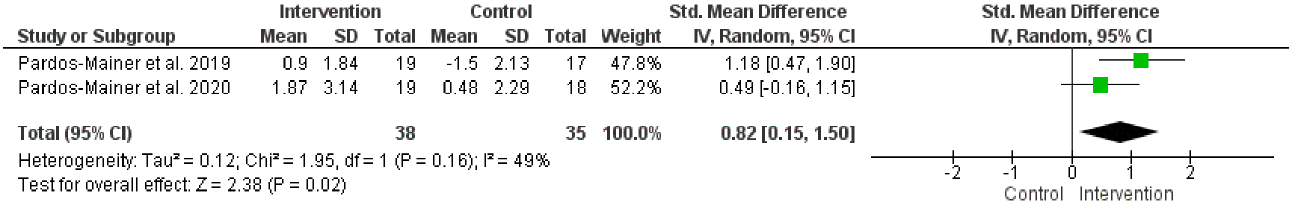
Figure 6. Effects of different training interventions on single leg lateral jump asymmetry index.



Study or Subgroup	Pre-Training Mean	Pre-Training SD	Pre-Training Total	Post-Training Mean	Post-Training SD	Post-Training Total	Weight	Std. Mean Difference IV, Random, 95% CI
Madruga-Perera et al. 2020 Cable-resistance	2.88	2.21	17	2.82	2.19	17	24.6%	0.03 [-0.65, 0.70]
Madruga-Perera et al. 2020 Isoinertial	1.96	1.81	17	2.51	1.56	17	24.4%	-0.32 [-0.99, 0.36]
Pardos-Mainer et al. 2019 FIFA11+	3.2	1.84	19	2.3	1.79	19	25.7%	0.49 [-0.16, 1.13]
Pardos-Mainer et al. 2020 Strength&Power	4.42	3.14	19	2.55	1.93	19	25.2%	0.70 [0.05, 1.36]
Total (95% CI)			**72**			**72**	**100.0%**	**0.23 [-0.22, 0.68]**

Heterogeneity: Tau² = 0.09; Chi² = 5.45, df = 3 (P = 0.14); I² = 45%
Test for overall effect: Z = 1.01 (P = 0.31)

Figure 7. Effects of different training interventions on change of direction speed asymmetry index.



Study or Subgroup	Intervention Mean	Intervention SD	Intervention Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Pardos-Mainer et al. 2019	0.9	1.84	19	-1.5	2.13	17	47.8%	1.18 [0.47, 1.90]
Pardos-Mainer et al. 2020	1.87	3.14	19	0.48	2.29	18	52.2%	0.49 [-0.16, 1.15]
Total (95% CI)			**38**			**35**	**100.0%**	**0.82 [0.15, 1.50]**

Heterogeneity: Tau² = 0.12; Chi² = 1.95, df = 1 (P = 0.16); I² = 49%
Test for overall effect: Z = 2.38 (P = 0.02)

Figure 8. Comparison of intervention vs. control group on change of direction speed asymmetry index.

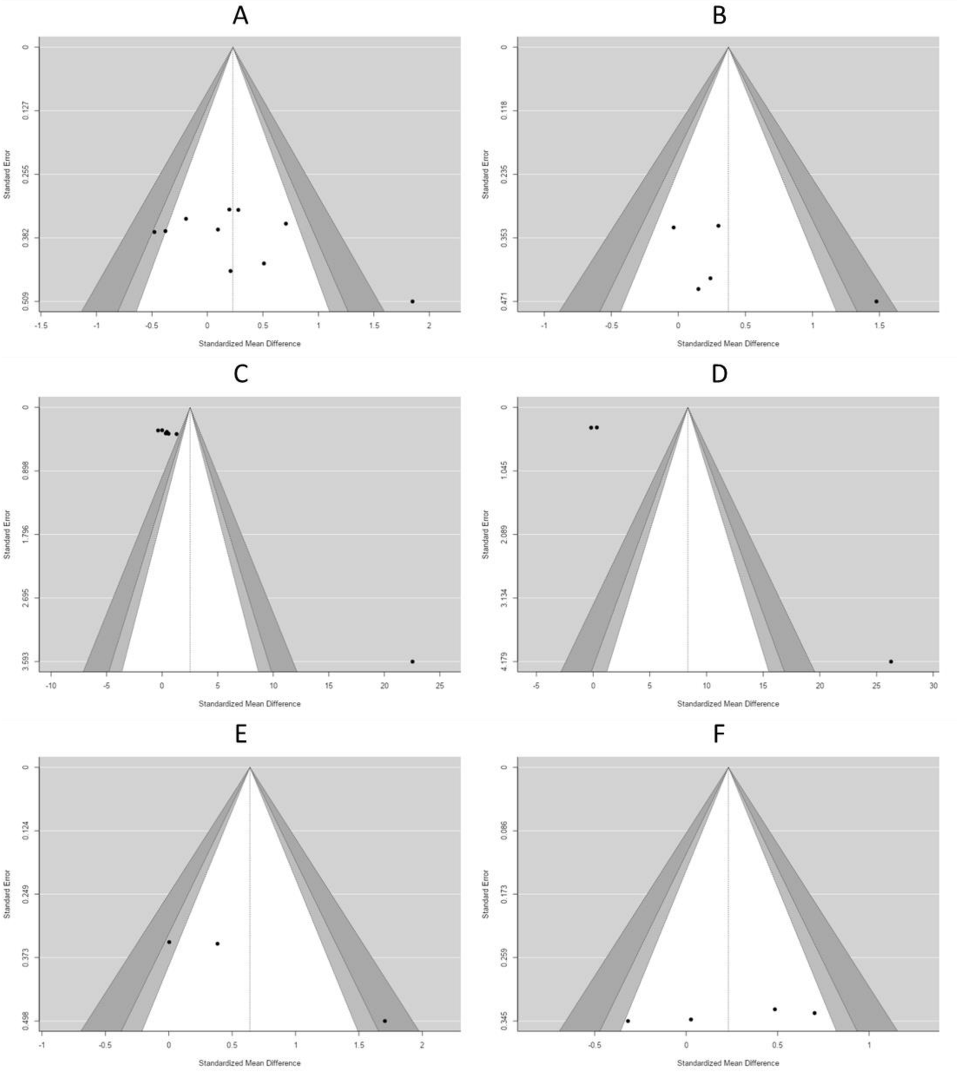


Figure 9. Contour-enhanced funnel plots displaying the spread of the standardised effect estimates, relative to their standard error.

Legend: *A = single leg broad jump, B = single leg broad jump vs control, C = single leg countermovement jump, D = single leg countermovement jump vs control, E = single leg lateral hop, F = change of direction speed.*