A comparison of three different unilateral strength training strategies to enhance jumping performance and decrease inter-limb asymmetries in soccer players

Abstract

Purpose: This study compared the effects of performing different unilateral strength training interventions on unilateral and bilateral jumping performance and their related asymmetries in young soccer players.

Methods: Forty-five male young (U-17) soccer players were randomly assigned to three eccentric overload training programs: The first group executed the same volume with both legs starting with the weaker leg (SVW, n=15), the second group carried out the double volume with the weaker leg and also starting with the weaker leg (DVW, n=15), and the third group performed the same volume with both legs starting with the stronger leg (SVS, n=15). Jumping performance assessment included a single-leg horizontal jump test, a triple single-leg horizontal jump test, a bilateral countermovement (CMJ) jump test and unilateral countermovement jump test. Asymmetries were also analyzed in the unilateral jumping tests.

Results: CMJ was improved (effect size [ES]: 0.27-0.48) and CMJ asymmetry was possibly reduced (ES: 0.08-0.24) in all groups. Substantial improvements were found in triple hop (ES: 0.52-0.71) in SVW and DVW, and triple hop asymmetry was substantially decreased (ES: 0.88) in DVW. Between-group analysis showed a substantial better performance in triple hop and horizontal hop with right leg in SVW and DVW compared to SVS.

Conclusions: Unilateral strength training programs were shown to substantially improve bilateral jumping performance, while unilateral jumping was substantially enhanced in those groups that started the training session with the weaker leg. Finally, between-limbs asymmetries in the triple hop were mainly reduced through performing the double volume with the weaker leg.

Keywords: eccentric overload training, resistance training, injury prevention, between-limbs asymmetry

Introduction

Between-limb asymmetries' interest has substantially increased during recent years in the context of sports performance. Such interest appears to stem from the literature reporting the prevalence of asymmetry across a range of sports such as basketball,[1] soccer[2] and rugby.[3] Furthermore, between-limb asymmetries have been found through a wide variety of physical performance tests such as strength,[4] power,[5] jumping,[6] leg stiffness,[7] dynamic balance[8] and sprinting.[3] However, recent literature has highlighted that the majority of studies on this topic have reported the prevalence of asymmetry, rather than aim to determine the association with athletic performance.[2,9] Noting that asymmetries are likely a by-product of sporting performance,[10] it seems that their prevalence alone does little to further our understanding of the relevance of asymmetries and sporting performance.

While between-limb asymmetries seem to have a solid support to detect players at high risk (i.e., four-fold in players with >10% asymmetry) of lower-extremity injury,[11] as well as return to sport successfully after an ACL injury (2.5 greater chances),[12] the influence of functional asymmetries in performance is still not conclusive. For example, jumping asymmetries (drop jump height and single-leg countermovement jump height) are related with reduced change of direction (COD) and linear sprinting performance, respectively.[2,7] Conversely, no effects of jumping asymmetries (vertical and horizontal) have been found on linear sprinting and COD performance.[6,13] Notwithstanding, despite such differences, athletes who perform their most common abilities unilaterally might benefit from training interventions aiming to decrease between-limb asymmetries and, consequently, to enhance physical performance and minimize the risk of injury.

Despite the potential benefits of incorporating unilateral exercises,[5,14-16] very little information is currently available about the influence of unilateral training strategies on decreasing between-limb asymmetries.[5] In this regard, Gonzalo-Skok et al., (2017)[5] showed that single-leg training was an effective strategy at reducing mean power between-limb asymmetry in comparison to bilateral-leg training. Furthermore, another study[17] also decreased the between-limbs horizontal force asymmetry (16% to 13%, moderate effect) using a supplementary programme for the weaker leg exclusively. It is worth noting that it was a case study (n=1) and the changes reported for the weaker leg were "unclear", so this represents a poor quality case study. Therefore, this information is scarce to build solid evidence-based recommendations. There are several questions regarding training strategies, such as the best option to start a workout with the intention of decreasing asymmetries (i.e., weaker or stronger leg) or if the training volume (i.e., similar to or higher) affects the training-induced adaptations.

Therefore, the aim of the current study was to compare the effects of performing different unilateral strength training interventions on unilateral horizontal, triple unilateral horizontal, bilateral and unilateral vertical jumping and their related asymmetries in young soccer players.

Methods

Subjects

Forty-five male young (U-17) soccer players (age: 15.6 ± 1.0 y, height: 173.9 ± 6.8 cm, body mass: 63.7 ± 8.2 kg) volunteered to participate in the study. Data collection took place during the fifth month of the competitive season after a 2-month pre-season period. Athletes belonged to a club academy squad in the second division of professional soccer in Spain. All players participated on average in ~ 9 hours of combined soccer (4 sessions) and strength/power (1 session) training session plus 1 competitive match per week. All players had a mean experience of 1.80 ± 0.72 y in strength and power training (range: 1 to 3 y). Written informed consent was obtained from both the players and their parents before beginning the investigation. The current study was approved by the institutional research ethics committee and conformed to the recommendations of the Declaration of Helsinki.

Study Design

Using a randomized study design (A-B-C), players were divided into three unilateral eccentric overload groups based on their ranked physical performance. The first group executed the same volume with both legs starting with the weaker leg (SVW, n=15), the second group carried out the double volume with the weaker leg and also starting with the weaker leg (DVW, n=15), and the third group performed the same volume with both legs starting with the stronger leg (SVS, n=15). The weaker leg was defined as the worst leg in more unilateral tests (i.e., there were 3 tests and if any player had 2 tests showing his lower performance with the left leg, such leg was defined as the weaker leg). Tests were performed 2 weeks and 1 week (reliability analysis) before training and 1 week after the training period. Tests included a single-leg horizontal jump test, a triple single-leg horizontal jump test and unilateral and bilateral countermovement jump (CMJ) tests. Furthermore, asymmetries were calculated in all unilateral tests. Players were familiarized with the exercise procedures before the commencement of each test. They were asked not to perform intense exercise on the day before a test and to consume their last meal at least 3 hours before the scheduled test time.

Procedures

Training intervention

Participants performed 1 eccentric overload training session per week, in addition to their normal soccer training, for 10 consecutive weeks. Such session was performed on Tuesday or Wednesday, at least, 48 h after the match. The training intervention consisted of 2 sets of unilateral lateral squat using a portable conical pulley (*VersaPulley, Costa Mesa, CA*; inertia 0.27 kg/m^2, speed:force ratio (i.e., as the ratio increases, the training intensity also increases) 1-3 out of 4, and transmission pulley/harness setup from the hip of the working leg) after a standardized warm-up (i.e., 5 minutes jogging, dynamic stretches and 2 sets of unilateral lateral squats with each leg of 8 repetitions doing the last 3 repetitions as fast as possible). Such exercise (i.e., lateral squat – Figure 1) was selected as soccer players frequently perform multi-directional movement patterns; thus, strength development outside of the sagittal plane was deemed appropriate given the mechanisms of injury often associated with soccer players occur in the frontal plane.[18] Furthermore, a recent study used the lateral squat positively impacted on multi-directional jumping[19] and, thus, aiming to target strength of the lower-body in a multi-directional capacity. Training load was periodized as follows; weeks 1 and 2, 6 repetitions and speed:force ratio 1, weeks 3 and 4, 8 repetitions and speed:force ratio 1, weeks 5 and 6, 8 repetitions and speed:force ratio 2, weeks 7 and 8, 10 repetitions and speed:force ratio 2 and weeks 9 and 10, 10 repetitions and speed:force ratio 3. Players were encouraged to perform the concentric phase as fast as possible, while delaying the braking action to the last third of the eccentric phase. Between-legs and sets recovery was 30 s and 3 min, respectively. Two experienced S&C coaches controlled every training session, providing verbal encouragement to each participant.

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

Functional Performance Tests

Functional performance tests were carried out one day before the training intervention in the following order: single-leg horizontal jump test, triple hop horizontal jump test, bilateral countermovement jump test and unilateral countermovement jump test. A 10-min standardized warm-up was performed (i.e., 5 min jogging, dynamic stretching, 10 bilateral squats, core exercises, 10 unilateral squats and 3 vertical unilateral jumps). All unilateral jumping tests assessments started with the left leg.

Single-leg horizontal jump test

For the hop-for-distance test, the subjects stood on the test leg and then hopped as far as possible and landed on the same leg. Free leg swing was allowed. The hands were placed behind the back. Players were instructed to perform a controlled balanced landing and to keep the landing foot in place (i.e., no extra hops were allowed) until (2–3 s) the test leader had registered the landing position. Failure to do so resulted in a non-valid hop. The distance was measured in cm from the toe at the push-off to the heel where the subject landed. Three jumps were allowed with each leg and the best result in the left (SLHL), right (SLHR), stronger (SLHS) and weaker (SLHW) legs were used for further analysis. Between-jumps and legs recovery was 30 s and 2-minutes.

Triple-leg horizontal jump test

For the triple-hop for distance test, the subjects stood on the test leg and then hopped as far as possible three times and landed on the same leg. Free leg swing was allowed. The hands were placed behind the back. Players were instructed to perform a controlled balanced landing and to keep the landing foot in place (i.e., no extra hops were allowed) until (2–3 s) the test leader had registered the landing position. Failure to do so resulted in a non-valid hop. The distance was measured in cm from the toe at the push-off to the heel where the subject landed. Three jumps were allowed with each leg and the best result in the left (TSLHL), right (TSLHR), stronger (TSLHS) and weaker (TSLHW) legs were used for further analysis. Between-jumps and legs recovery was 30 s and 2 minutes.

Bilateral countermovement jump test

Vertical jumping ability was assessed using a vertical CMJ (reported in centimeters) with flight time measured by the Optojump (*Optojump, Microgate, Bolzano, Italy*) to calculate jump height, which has been previously validated against a force platform.[20]

Players were instructed to maintain their hands on their hips during CMJ. The depth of the CMJ was self-selected. Each test was performed three times, separated by 30 seconds of passive recovery, and the best jump was recorded and used for analysis.

Unilateral countermovement jump test

Each subject started by standing solely on the designated leg, maintaining their hands on their hips during unilateral CMJ and the alternate leg flexed to 90° at the hip and knee. Players were asked to jump as high as possible and to land on the assessed leg (*Optojump, Microgate, Bolzano, Italy*). Free leg swing was allowed. Players were instructed to perform a controlled balanced landing and to keep the landing foot in place (i.e., no extra hops were allowed) during 2-3 s. Failure to maintain proper technique resulted in an invalid jump. Each jump was performed three times, separated by 30 seconds of passive recovery, and the best jump was recorded and used for analysis. Two minutes of passive recovery were allowed between legs. The variables used for analyses were: 1-legged left CMJ (CMJL), 1-legged right CMJ (CMJR), 1-legged stronger (CMJS) and 1-legged weaker (CMJW).

Statistical analyses

Data are presented as mean ± standard deviation (SD). All data were first log-transformed to reduce bias arising from non-uniformity error. Between-session reliability analysis was computed using a two-way random intraclass correlation coefficient (ICC) with absolute agreement and 90% confidence intervals and the CV. Interpretation of ICC values was in accordance with previous research by Koo and Li (2016),[21] where values > 0.9 = excellent, 0.75-0.9 = good, 0.5-0.75 = moderate, and < 0.5 = poor and CV values were considered acceptable if < 10%.[22] The effect size (ES, 90%CI) in the selected variables was calculated using the pooled pre-training SD. Threshold values for Cohen ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large).[23] For within/between-group comparisons, the chances that the differences in performance were better/greater similar or worse/smaller were calculated. Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, most likely not; >1–5%, very unlikely; >5–25%, unlikely; >25–75%, possible; >75–95%, likely; >95–99%, very likely; and >99%, most likely.[23] If the chance that the true value is >25% beneficial and >0.5% chance that it is harmful, the clinically effect was considered as unclear. This statement continued being unclear if the odds ratio of benefit/harm was <66. However, the clinical inference was declared as beneficial when odds ratio of benefit/harm was >66.[23] Two specific Excel spreadsheets from sportsci.org were used to examine both the between-group (xCompare2groups.xls) and within-group (xPostOnlyCrossover.xls) comparisons. As asymmetry is a variable concept (i.e., SD is often well over 50% of the mean), we have chosen this method of analysis. Pearson's r correlation was used to determine the magnitude of the relationship between asymmetries during unilateral jumping and jumping performance at both pre- and post-test with statistical significance set at $p < 0.05$ (*SPPS Inc., Chicago, IL, USA*).

Inter-limb asymmetries were calculated with the following formula, noting that this has been suggested as an appropriate method for computing inter-limb differences from unilateral tests:

100/Max Value (right and left) x Min Value (right and left) x – 1 + 100.[24]

Results

Participants

Only players who participated in at least 80% of the training sessions were analysed. Consequently, 10 of the 45 players were excluded for various reasons. None of the players were injured during the eccentric overload training sessions. As a result, 35 players (15.4 ± 0.7 years, 174.9 ± 5.8 cm, 64.2 ± 7.0 kg) were included in the final analyses. The final sample sizes for the training groups were 10 for SVW, 11 for DVW and 14 for SVS. In spite of dropouts, no significant differences were found between groups at baseline. Furthermore, 27 out of 35 players were considered right preferred leg (i.e., kicking leg). Regarding the dominance, 5 players showed a greater performance with the right leg and 5 with the left leg in the SWV, 3 (right) and 8 (left) in the DWV and 6 (right) and 8 (left) in the SVS in the single leg horizontal jump performance. In the triple hop horizontal jump, 2 players showed a greater performance with the right leg and 8 with the left leg in the SWV, 3 (right) and 8 (left) in the DWV and 5 (right) and 9 (left) in the SVS. Finally, 3 players showed a greater performance with the right leg and 7 with the left leg in the SWV, 4 (right) and 7 (left) in the DWV and 7 (right) and 7 (left) in the SVS in the single leg CMJ performance.

Reliability analysis

Each test had acceptable between-session consistency with all CV values < 10%, and good or excellent ICC's (Table 1).

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

Within-group changes

Results of within-group changes are presented in Table 2. CMJ and CMJW were improved (possibly to likely) and CMJ asymmetry was possibly reduced in all groups. Possibly to very likely improvements were found in SLHW, TSLHR, TSLHL, TSLHS and TSLHW in SVW and DVW, while CMJL was *possibly* improved in DVW and SVS and CMJR was substantially improved in SVW. Finally, TSLH asymmetry was substantially decreased in DVW, while SLH asymmetry was substantially increased in DVW and SVS.

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

Between-group changes

Results from between-group analysis are illustrated in Figure 2, 3 and 4. The improvement in TSLH asymmetry was substantially greater in DVW than in SVW (41.0% [CL90% -25.3; 72.2], QC = 83/9/8%) and SVS (71.9% [CL90% 2.9; 187.0], QC = 87/12/1%). Furthermore, a substantially greater SLHR (SVW: 3.6% [CL90% -0.8; 8.3], QC = 83/14/4%; DVW: 2.8% [CL90% -0.3; 6.0], QC = 82/16/2%), TSLHR (SVW: 6.7% [CL90% 0.3; 13.4], QC = 93/5/3%; DVW: 4.9% [CL90% -1.2; 11.4], QC = 85/10/5%), TSLHS (SVW: ES = 0.96 [CL90% -0.33; 2.26], 5.0% [CL90% -1.7; 12.0], QC = 84/9/7%; DVW: ES = 0.81 [CL90% -0.24; 1.86], 4.1% [CL90% -1.2; 9.8], QC = 84/11/6%) and TSLHW (SVW: ES = 0.90 [CL90% -0.03; 1.84], 6.0% [CL90% -0.2; 12.6], QC = 90/7/3%; DVW: ES = 0.83 [CL90% -0.12; 1.78], 5.5% [CL90% -0.8; 12.2], QC = 87/9/4%) performance was found in SVW and DVW in comparison to SVS. Finally, while substantial greater improvements were achieved in SVW compared to SVS in SLH asymmetry (99.5% [CL90% -3.4; 311.7], QC = 86/12/2%) and CMJR

(9.4% [CL90% -0.7; 20.7], QC = 86/12/2%), DVW showed a substantially greater performance than SVS in TSLHL (4.8% [CL90% -1.1; 10.9], QC = 84/11/5%).

******* Insert Figure 2 near here*******

******* Insert Figure 3 near here*******

******* Insert Figure 4 near here*******

Correlational analysis

At pre-test, negative relationships were found between SLHR (r= -0.46; p<0.01) and SLHL (r= -0.43; p<0.05) with single-leg horizontal asymmetry, between TSLHL with triple single-leg horizontal asymmetry (r= -0.45; p<0.01), and between CMJR with CMJ asymmetry (r= -0.37; p<0.05) in the pool data. At post-test, no significant relationships were found between asymmetries and jumping performance. Specifically, all the above-mentioned relationships decreased (r= -0.03, r= -0.15, r= -0.30 and r= 0.06, respectively).

Discussion

The aim of the current study was to examine the influence of three different unilateral strength training programs in jumping performance and their corresponding asymmetries. The main findings were as follows: 1) bilateral vertical jumping performance was possibly to likely improved in all groups and vertical jumping asymmetry was possibly decreased; 2) a moderate reduction in triple-hop asymmetry was achieved in the double volume group compared to all single-volume groups; 3) single right leg performance was substantially greater in those groups which mainly started to work with right leg (i.e., the dominant or stronger leg was defined according to test score, thus, working firstly with the right leg, that is, the weaker leg; SVW and DVW) compared to those performing the beginning of the session with the left leg, 4) weaker leg performance was enhanced in all unilateral tests in those groups which started with the weaker leg each set, and 5) larger asymmetries were significantly related with reduced unilateral jumping performance at pre-test, while no associations were shown after the training program in the pool data.

No substantial results (ES: -0.13 to 0.19) were found after all training strategies in SLH jumping. These results are lower than the range (ES: 0.35 to 0.65) of previously published reports after different training strategies with young team-sports athletes.[19,25] A previous investigation conducted in young basketball players reported greater training effects on single-leg horizontal jumping performance after a repeated-power training in the leg press (ES: 0.64 to 0.65).[25] Another investigation also showed greater training effects compared to our study, though unilateral training performing horizontal and lateral exercises achieved greater training-induced effects. As the above-mentioned studies had different training variables (i.e., traditional strength training and eccentric overload training, bilateral and unilateral training, shorter and longer recovery periods), it is difficult to establish a direct relationship to argument the between-studies' differences. However, it seems that both the training volume and exercise selection are key factors. In this regard, the greatest ES's were found in those training programs that carried out a greater volume (i.e., repeated power training: 50 reps and unilateral eccentric overload training: 36 to 60 reps). In addition, the exercise selection in the appropriated force-vector seems to be important to achieve the desired training-induced adaptations.[14,19,26] In this regard, a lateral squat exercise might influence horizontal jumping scores (also vertical jumping) and it can be selected to concurrently develop both jumping directions. Thus, it might be possible that training volume and the exercise selection are the most important variables to enhance single-leg horizontal jumping performance.

Despite all groups performed all training programs unilaterally, it is worth noting that SVS showed a trivial effect (ES: 0.05 to 0.11) in the triple single-leg horizontal jumping performance. However, those groups that started their training with the weaker leg (i.e., non-dominant leg; mainly the right leg) achieved a substantially greater performance (ES: 0.52 to 0.71) after the training period. To our knowledge, no previous studies have examined the effect of any training program on triple single-leg horizontal jumping in team-sports players. Therefore, comparisons are not possible. The only possible argument to the current between-group differences might be the leg used to start the training session as the right leg was mainly considered the weaker leg (i.e., worse performance in horizontal jumping in all groups) and it was only substantially improved in SWV and DWV. However, further studies are warranted to elucidate such differences.

Despite there was not a dynamic correspondence between the exercise performed (unilateral and lateral force-vector) and the exercise assessed (bilateral and axial force-vector), bilateral jumping was improved in all groups with no between-group differences. The magnitude effect induced (ES: 0.27 to 0.48) was within previous reports after an eccentric overload training (ES: 0.42 to 0.58) or vertical-horizontal training with conventional devices (ES: 0.31 to 0.36). It is worth noting that unilateral training seems to trigger bilateral adaptations on bilateral jumping, that is, the sum of stronger legs independently might augment bilateral performance.[27] However, the best results are found after bilateral and vertical training programs[28] showing expecting results as the force-vector and force-application theory supports.[14] In contrast and apparently contradictory, unilateral vertical jumping achieved lower results in all groups compared to bilateral jumping with the exception of CMJR in SVW group (ES: 0.82). In this regard, it seems that the force-vector (e.g., vertical) might be more important than the force-application (e.g., unilateral or bilateral) to develop the expected adaptations when following the dynamic correspondence theory.

One of the most interesting findings was the greater improvements found in the right leg in those groups which started with the weaker leg (i.e., SVW and DVW). Interestingly, the vast majority of players (i.e., 27 out of 35) were right-leg dominance, though their stronger leg was the left one. Given that soccer players usually kick the ball with most dominant leg, it is very common to find the supporting leg as the stronger leg. It is worth noting that the supporting leg is usually found as the stronger leg and strength improvement of such leg (i.e., supporting leg) can enhance kicking performance.[29] Consequently, they started each training session with the right leg and the best results were achieved in such leg. Small to moderate differences were provided in SLHR and TSLHR between SVW and DVW compared to SVS. Therefore, the impact of the starting leg on unilateral jumping performance seems to have an important effect.

As we have argued in the introduction, asymmetries might have a critical relevance for both protection against injuries and performance.[5,9,31] Furthermore, the fact that training interventions involving unilateral actions help to decrease between-limbs asymmetries shows a tendency to support such argument.[5,17,31,32] However, it is not clear what the best training strategy to decrease between-limbs asymmetry is. The current study showed as all training strategies possibly decreased CMJ asymmetry, justifying such small enhancement in the non-specific force-vector exercise used. However, the most interesting finding is the likely improvement found in the training group which performed the double volume with the weaker leg and started with the weaker leg. In addition, a likely difference was also achieved in such group compared with those groups that executed the same volume with both legs. Thus, when you perform several jumps with the same leg continuously, it seems that carry out a greater volume with the weaker leg might compensate the asymmetry presented. Notwithstanding, the task-specific and individual nature of asymmetry must be acknowledged. Thus, individual athlete monitoring is likely to be the most appropriate approach when trying to determine whether the reduction of existing side-to-side differences are warranted in respect to athletic performance.[30]

Another interesting finding was the decrement from pre-test to post-test in the relationships found between asymmetries and jumping performance (direction specific). It means that prior to the training program commencement, asymmetries had a negative influence in their specific jumping performance. Subsequently, the dissipation of correlations (the current training strategy was proposed to decrease between-limb asymmetry), that is, no influence of asymmetries on performance, might support the notion that some thresholds can exist where asymmetries either negatively or trivially impact on performance.

There are some limitations of this study. The monitorization of mean power over all sets might would help to better understand the improvements reported in both jumping performance and asymmetries. As such, further studies are warranted to analyse the influence of performing better quality repetitions (i.e., stop the set based on a minimum target power). In addition, further studies should analyse the influence of performing exclusively one exercise in a specific force-vector (i.e., vertical, horizontal or lateral) on different force-vector measurements. Finally, pre-test asymmetries may have and influence on between-group results and even on within-group results.

Conclusions

Unilateral strength training programs were shown to substantially improve bilateral jumping performance, while unilateral jumping, mostly compounded by several jumps with the same leg, was substantially enhanced in those groups that started the training session with the weaker leg. Finally, between-limbs asymmetries in the triple hop were mainly reduced through performing the double volume with the weaker leg.

Practical applications

The present findings suggest the recommendation to start any unilateral training program with the weaker leg of the specific asymmetry (i.e., if you want to improve the vertical asymmetry, you should start the training with the weaker leg of vertical jumping), as asymmetries seem to be direction-specific.[2]

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References

1. Fort-Vanmeerhaeghe A, Montalvo AM, Sitja-Rabert M, Kiefer AW, Myer GD. Neuromuscular asymmetries in the lower limbs of elite female youth basketball players and the application of the skillful limb model of comparison. *Phys Ther Sport* 2015;16:317-323.
2. Bishop C, Read P, McCubbine J, Turner A. Vertical and Horizontal Asymmetries are Related to Slower Sprinting and Jump Performance in Elite Youth Female Soccer Players. *J Strength Cond Res* 2018. In press.
3. Brown SR, Cross MR, Girard O, Brocherie F, Samozino P, Morin JB. Kinetic Sprint Asymmetries on a non-motorised Treadmill in Rugby Union Athletes. *Int J Sports Med* 2017;38:1017-1022.
4. Hart NH, Nimphius S, Spiteri T, Newton RU. Leg strength and lean mass symmetry influences kicking performance in Australian football. *J Sports Sci Med* 2014;13:157-165.
5. Gonzalo-Skok O, Tous-Fajardo J, Suarez-Arrones L, Arjol-Serrano JL, Casajus JA, Mendez-Villanueva A. Single-Leg Power Output and Between-Limbs Imbalances in Team-Sport Players: Unilateral Versus Bilateral Combined Resistance Training. *Int J Sports Physiol Perform* 2017;12:106-114.
6. Lockie RG, Callaghan SJ, Berry SP, Cooke ER, Jordan CA, Luczo TM, Jeffriess MD. Relationship between unilateral jumping ability and asymmetry on multidirectional speed in team-sport athletes. *J Strength Cond Res* 2014;28:3557-3566.
7. Maloney SJ, Richards J, Nixon DG, Harvey LJ, Fletcher IM. Do stiffness and asymmetries predict change of direction performance? *J Sports Sci* 2017;35:547-556.
8. Gonzalo-Skok O, Serna J, Rhea MR, Marin PJ. Relationships between Functional Movement Tests and Performance Tests in Young Elite Male Basketball Players. *Int J Sports Phys Ther* 2015;10:628-638.
9. Bishop C, Turner A, Read P. Effects of inter-limb asymmetries on physical and sports performance: a systematic review. *J Sports Sci* 2018;36:1135-1144.
10. Hart NH, Nimphius S, Weber J, Spiteri T, Rantalainen T, Dobbin M, Newton RU. Musculoskeletal Asymmetry in Football Athletes: A Product of Limb Function over Time. *Med Sci Sports Exerc* 2016;48:1379-1387.
11. Gustavsson A, Neeter C, Thomee P, Silbernagel KG, Augustsson J, Thomee R, Karlsson J. A test battery for evaluating hop performance in patients with an ACL injury and patients who have undergone ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc* 2006;14:778-788.
12. Ardern CL, Webster KE, Taylor NF, Feller JA. Return to the preinjury level of competitive sport after anterior cruciate ligament reconstruction surgery: two-thirds of patients have not returned by 12 months after surgery. *Am J Sports Med* 2011;39:538-543.
13. Dos'Santos T, Thomas C, Jones P, Comfort P. Asymmetries in single and triple hop are not detrimental to change of direction speed. *J Trainology* 2017:35-41.
14. Gonzalo-Skok O, Sanchez-Sabate J, Izquierdo-Lupon L, Saez de Villarreal E. Influence of force-vector and force application plyometric training in young elite basketball players. *Eur J Sport Sci* 2018:1-10.

15. Nunez FJ, Santalla A, Carrasquila I, Asian JA, Reina JI, Suarez-Arrones LJ. The effects of unilateral and bilateral eccentric overload training on hypertrophy, muscle power and COD performance, and its determinants, in team sport players. *PLoS One* 2018;13. In press.
16. Ramirez-Campillo R, Sanchez-Sanchez J, Gonzalo-Skok O, Rodriguez-Fernandez A, Carretero M, Nakamura FY. Specific Changes in Young Soccer Player's Fitness After Traditional Bilateral vs. Unilateral Combined Strength and Plyometric Training. *Front Physiol* 2018;9:265.
17. Brown SR, Feldman ER, Cross MR, Helms ER, Marrier B, Samozino P, Morin JB. The Potential for a Targeted Strength Training Programme to Decrease Asymmetry and Increase Performance: A Proof-of-Concept in Sprinting. *Int J Sports Physiol Perform* 2017. In press.
18. Walden M, Krosshaug T, Bjorneboe J, Andersen TE, Faul O, Hagglund M. Three distinct mechanisms predominate in non-contact anterior cruciate ligament injuries in male professional football players: a systematic video analysis of 39 cases. *Br J Sports Med* 2015;49:1452-1460.
19. Gonzalo-Skok O, Tous-Fajardo J, Valero-Campo C, Berzosa C, Bataller AV, Arjol-Serrano JL, Moras G, Mendez-Villanueva A. Eccentric-Overload Training in Team-Sport Functional Performance: Constant Bilateral Vertical Versus Variable Unilateral Multidirectional Movements. *Int J Sports Physiol Perform* 2017;12:951-958.
20. Glatthorn JF, Gouge S, Nussbaumer S, Stauffacher S, Impellizzeri FM, Maffiuletti NA. Validity and reliability of Optojump photoelectric cells for estimating vertical jump height. *J Strength Cond Res* 2011;25:556-560.
21. Koo TK, Li MY. A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *J Chiropr Med* 2016;15:155-163.
22. Cormack SJ, Newton RU, McGuigan MR, Doyle TL. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform* 2008;3:131-144.
23. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009;41:3-13.
24. Bishop C, Read P, Lake J, Chavda S, Turner A. Inter-limb asymmetries: Understanding how to calculate differences from bilateral and unilateral tests. *Strength Cond J* 2018. In press.
25. Gonzalo-Skok O, Tous-Fajardo J, Arjol-Serrano JL, Suarez-Arrones L, Casajus JA, Mendez-Villanueva A. Improvement of Repeated-Sprint Ability and Horizontal-Jumping Performance in Elite Young Basketball Players With Low-Volume Repeated-Maximal-Power Training. *Int J Sports Physiol Perform* 2016;11:464-473.
26. Contreras B, Vigotsky AD, Schoenfeld BJ, Beardsley C, McMaster DT, Reyneke J, Cronin J. Effects of a six-week hip thrust versus front squat resistance training program on performance in adolescent males: A randomized-controlled trial. *J Strength Cond Res* 2016.
27. Speirs DE, Bennett MA, Finn CV, Turner AP. Unilateral vs. Bilateral Squat Training for Strength, Sprints, and Agility in Academy Rugby Players. *J Strength Cond Res* 2016;30:386-392.
28. de Hoyo M, Pozzo M, Sanudo B, Carrasco L, Gonzalo-Skok O, Dominguez-Cobo S, Moran-Camacho E. Effects of a 10-week in-season eccentric-overload training program on muscle-injury prevention and performance in junior elite soccer players. *Int J Sports Physiol Perform* 2015;10:46-52.
29. Young WB, Rath DA. Enhancing foot velocity in football kicking: the role of strength training. *J Strength Cond Res* 2011;25:561-566.

30. Bishop C, Lake J, Loturco I, Papadopoulos K, Turner A, Read P. Interlimb Asymmetries: The Need for an Individual Approach to Data Analysis. *J Strength Cond Res* 2018. In press.
31. Bishop C, Turner A, Read P. Training methods and considerations for practitioners to reduce inter-limb asymmetries. *Strength Cond J* 2018. In press.
32. Sannicandro I, Cofano G, Rosa RA, Piccinno A. Balance training exercises decrease lower-limb strength asymmetry in young tennis players. *J Sports Sci Med* 2014;13:397-402.

Figure Legends.

Figure 1. Eccentric overload variable unilateral exercise and the corresponding force vector application: lateral squat (mediolateral/lateromedial).

Figure 2. Efficiency of the unilateral eccentric overload training performing the double volume with the weaker leg starting with the weaker leg (DVW) compared to the unilateral eccentric overload training performing the same volume with both legs starting with the weaker leg (SVW) training program to improve a single-leg horizontal jump with right (SLHR) and left (SLHL) leg and the corresponding asymmetry (Asy_{SLH}), triple single-leg horizontal jump with right (TSLHR) and left (TSLHL) leg and the corresponding asymmetry (Asy_{TSLH}), a bilateral countermovement jump (CMJ), single-leg countermovement jump with right (CMJR) and left (CMJL) leg and the corresponding asymmetry (Asy_{CMJ}) (bars indicate uncertainty in the true mean changes with 90% confidence limits). Trivial areas were the smallest worthwhile change (SWC) (see methods).

Figure 3. Efficiency of the unilateral eccentric overload training performing the same volume with both legs starting with the stronger leg (SVS) compared to the unilateral eccentric overload training performing the same volume with both legs starting with the weaker leg (SVW) training program to improve a single-leg horizontal jump with right (SLHR) and left (SLHL) leg and the corresponding asymmetry (Asy_{SLH}), triple single-leg horizontal jump with right (TSLHR) and left (TSLHL) leg and the corresponding asymmetry (Asy_{TSLH}), a bilateral countermovement jump (CMJ), single-leg countermovement jump with right (CMJR) and left (CMJL) leg and the corresponding asymmetry (Asy_{CMJ}) (bars indicate uncertainty in the true mean changes with 90% confidence limits). Trivial areas were the smallest worthwhile change (SWC) (see methods).

Figure 4. Efficiency of the unilateral eccentric overload training performing the same volume with both legs starting with the stronger leg (SVS) compared to the unilateral eccentric overload training performing the double volume with the weaker leg starting with the weaker leg (DVW) training program to improve a single-leg horizontal jump with right (SLHR) and left (SLHL) leg and the corresponding asymmetry (Asy_{SLH}),

triple single-leg horizontal jump with right (TSLHR) and left (TSLHL) leg and the corresponding asymmetry (Asy_{TSLH}), a bilateral countermovement jump (CMJ), single-leg countermovement jump with right (CMJR) and left (CMJL) leg and the corresponding asymmetry (Asy_{CMJ}) (bars indicate uncertainty in the true mean changes with 90% confidence limits). Trivial areas were the smallest worthwhile change (SWC) (see methods).

Figure 1.

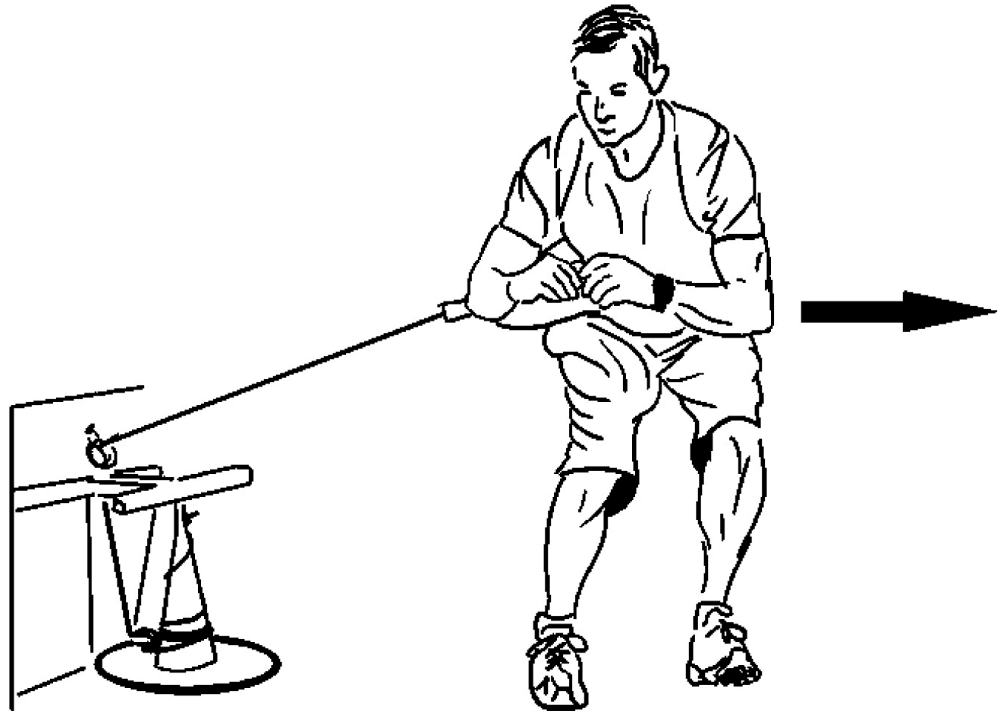


Figure 2.

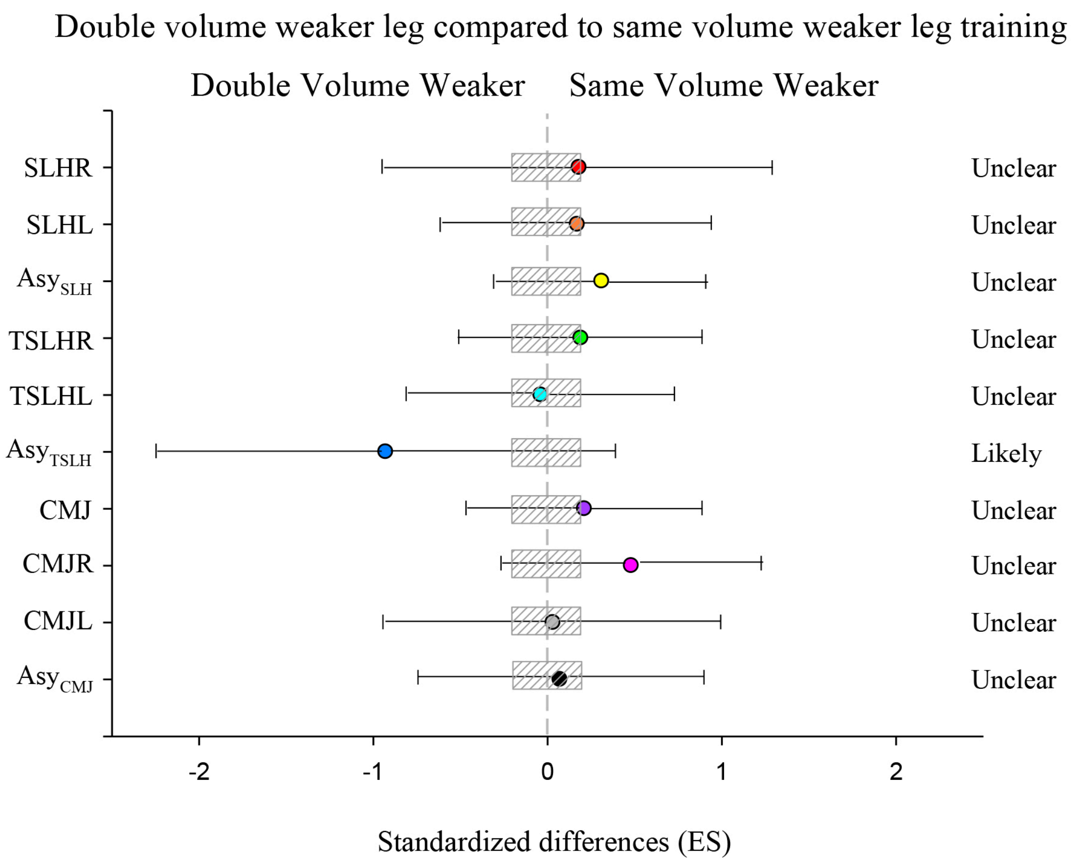

Double volume weaker leg compared to same volume weaker leg training
Double Volume Weaker
Same Volume Weaker
SLHR
SLHL
Asy$_{SLH}$
TSLHR
TSLHL
Asy$_{TSLH}$
CMJ
CMJR
CMJL
Asy$_{CMJ}$
Unclear
Unclear
Unclear
Unclear
Unclear
Likely
Unclear
Unclear
Unclear
Unclear
-2
-1
0
1
2
Standardized differences (ES)

Figure 3.

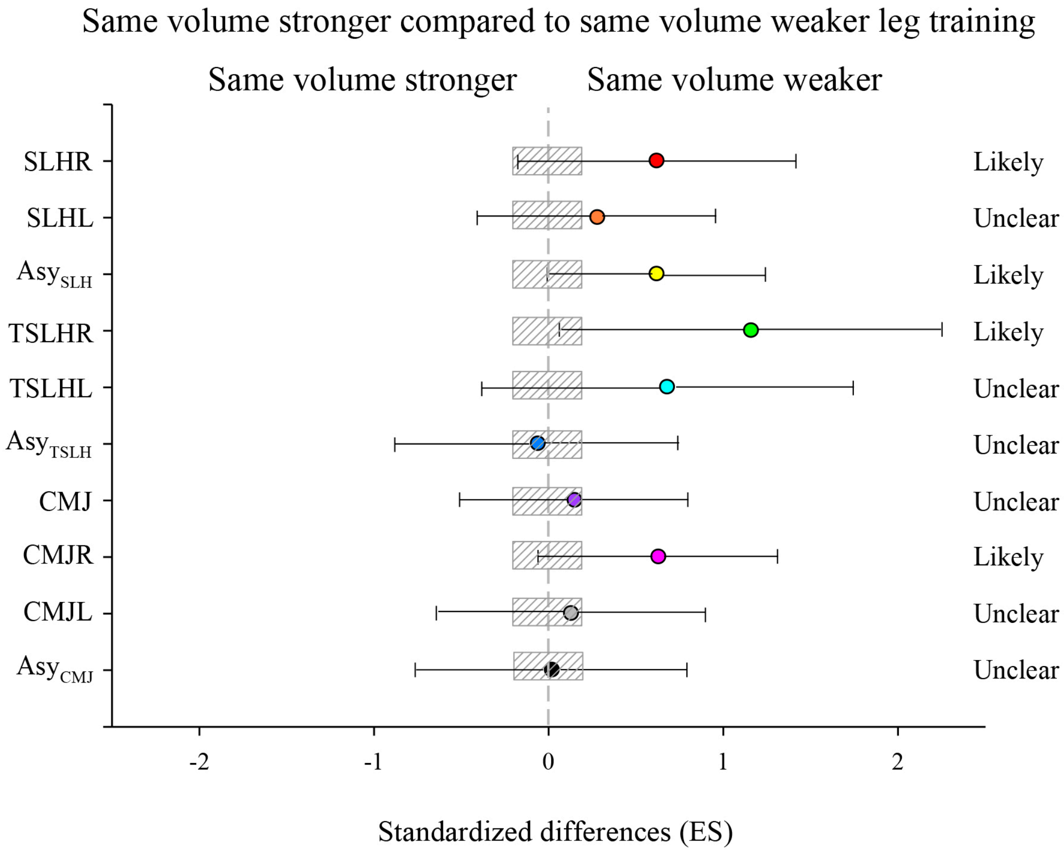
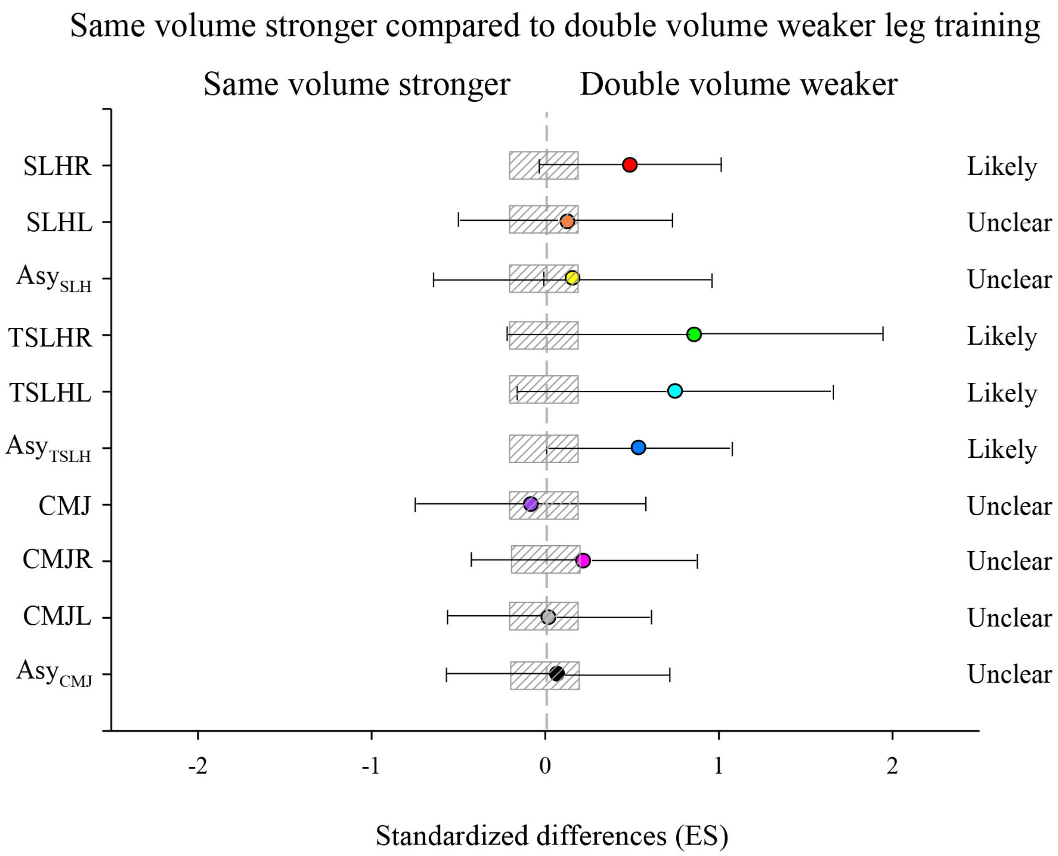

Same volume stronger compared to same volume weaker leg training
Same volume stronger
Same volume weaker
SLHR
SLHL
AsySLH
TSLHR
TSLHL
AsyTSLH
CMJ
CMJR
CMJL
AsyCMJ
Likely
Unclear
Likely
Likely
Unclear
Unclear
Unclear
Likely
Unclear
Unclear
-2
-1
0
1
2
Standardized differences (ES)

Figure 4.



Same volume stronger compared to double volume weaker leg training
Same volume stronger
Double volume weaker
SLHR
SLHL
Asy$_{SLH}$
TSLHR
TSLHL
Asy$_{TSLH}$
CMJ
CMJR
CMJL
Asy$_{CMJ}$
Likely
Unclear
Unclear
Likely
Likely
Likely
Unclear
Unclear
Unclear
Unclear
-2
-1
0
1
2
Standardized differences (ES)