REVIEW

The influence of inter-limb asymmetries in muscle strength and power on athletic performance: a review

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Abstract

The aim of this review was to examine the available literature on inter-limb strength and power asymmetries and their effect on sports performance. In total, 31 studies were included. The findings indicate a negative effect of strength asymmetries on change of direction, sprinting, cycling and kicking performance. They may also be detrimental to jumping performance, however, more research is needed to confirm this. The findings on power asymmetries are more inconsistent and indicate that asymmetries measured with various power tests may affect some performance measures. For example, jumping performance is affected by the power asymmetries measured with jumps, but not by those measured with change of direction tests. Furthermore, the correlation between asymmetry tests and performance outcomes can be affected by the type of sport, training period and the magnitude of the asymmetry. To better understand the effects of strength and power asymmetries on athletic performance, further research is needed, particularly on the effects on sport-specific performance tests.

Keywords: *imbalance, muscle performance, sport performance, neuromuscular assessment*

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Introduction

Body asymmetries are divided into local (joint-level strength) and global (jumping performance). Local asymmetries can be further divided into contralateral (often referred to as inter-limb asymmetries), comparing left and right side of the body, and ipsilateral, comparing opposite muscle groups on the same side of the body. In this review, we focus on contralateral asymmetries in strength and power and their effect on sports performance. These types of asymmetries have been reported to be present in various team sports (Bailey, Sato, Alexander, Chiang & Stone, 2013; Bell, Sanfilippo, Binkley & Heiderscheit, 2014; Bishop, Read, McCubbine & Turner, 2021a; Bishop et al., 2019; Bishop et al., 2022a; Bishop, Rubio, Gullon, Maloney & Balsalobre-Fernandez, 2022b; Coratellaa, Beatoc & Schenab, 2018; Dos'Santos, Thomas, Jones & Comfort, 2017; Fort-Vanmeerhaeghe et al., 2020; Hart, Nimphius, Spiteri & Newton, 2016; Hoffman, Ratamess, Klatt,

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Faigenbaum & Kang, 2007; Işın, Akdağ, Özdoğan & Bishop, 2022; Kozinc & Šarabon, 2020; Lockie, Schultz, Jeffriess & Callaghan, 2012; Lockie et al., 2014; Madruga-Parera et al., 2021b; Madruga-Parera et al., 2020b; Madruga-Parera et al., 2021a; Maloney, Richards, Nixon, Harvey & Fletcher, 2016; Pardos-Mainer et al., 2021; Philipp, Crawford, Garver, Davis & Hair, 2022; Schons et al., 2019), swimming (Phukan et al., 2021; Morouço, Marinho, Fernandes & Marques, 2015; Dos'Santos, Pereira, Papoti, Bento & Rodacki, 2013), cycling (Bini & Hume, 2015; Rannama, Port, Bazanov & Pedak, 2015), tennis (Madruga-Parera et al., 2020a) and sprint (Exell, Irwin, Gittoes & Kerwin, 2017). Although long-distance running is considered to be a fairly symmetrical sport, it has also been discussed with regard to contralateral asymmetries (Blagrove et al., 2021). Limb dominance, previous injuries, specific requirements of sports and the extent of exposure to a particular sport or activity may contribute to the further development of asymmetries (Newton et al., 2006). In addition to research proving the presence of asymmetries in adults (Bailey et al., 2013; Bell et al., 2014; Bini et al., 2015; Bishop et al., 2019; Bishop et al., 2021b; Bishop et al., 2022a; Coratella et al., 2018; Dos Santos et al., 2013; Dos Santos et al., 2017; Exell et al., 2017; Hart et al., 2016; Hoffman et al., 2007; Lockie et al., 2012; Lockie et al., 2014; Madruga-Parera et al., 2021a; Maloney et al., 2016; Philipp et al., 2022; Rannama et al., 2015; Schons et al., 2019), many recent studies also consider the younger population (Atkins et al., 2016; Bishop et al., 2021a; Bishop et al., 2022b; Blagrove et al., 2021; Fort-Vanmeerhaeghe et al., 2020; Işın et al., 2022; Kozinc et al., 2020; Madruga-Parera et al., 2021b; Madruga-Parera et al., 2020a; Madruga-Parera et al., 2020b; Morouço et al., 2015; Pardos-Mainer et al., 2021; Phukan et al., 2021). The magnitude of the asymmetry is also affected by the way it is calculated. Many approaches of quantifying these differences have been established including dominant vs. non-dominant, stronger vs. weaker, as well as injured vs. non-injured leg. The wide range of classifications has emerged to accommodate specific purposes of asymmetry evaluation. In any case, the asymmetries are almost exclusively reported as the percentage difference from one limb in respect to the other (Bishop, Read, Chavda & Turner, 2016; Bishop, Turner & Read, 2018).

In recent years, the magnitude of these asymmetries has been brought to the forefront. In rehabilitation, a threshold of < 10% is typically used to discharge a patient recovering from an injury. However, it should be noted that this is an arbitrary threshold (Bishop et al., 2018). Although it is thought that asymmetries > 15% are associated with increased injury risk, recent literature is showing that these asymmetry magnitudes are test-specific, which means that individual tests require specific "critical" thresholds (Bishop et al., 2021a; Bishop et al., 2019; Dos'Santos et al., 2017; Hart et al., 2016; Kozinc et al., 2020; Lockie et al., 2014; Maloney et al., 2016; Parkinson, Apps, Morris, Barnett & Lewis, 2021; Philipp et al., 2022; Read et al., 2021). The same goes for the direction of the asymmetry, which has been brought to attention only in the recent years. It is increasingly being shown that the more capable limb depends on the performance test used (Bishop et al., 2022b; Kozinc et al., 2020; Pardos-Mainer et al., 2021).

Although the effect of asymmetries in power on sports performance has already been discussed in several older studies, it has intensely been researched only in the recent years. The studies showed contradictory results. Some of them reported a negative effect of the asymmetries on performance (Bell et al., 2014; Bishop et al., 2021a; Bishop et al., 2019; Bishop et al., 2021b; Exell et al., 2017; Fort-Vanmeerhaeghe et al., 2020; Kozinc et al., 2020; Madruga-Parera et al., 2021b; Madruga-Parera et al., 2020a; Madruga-Parera et al., 2020b; Madruga-Parera et al., 2021a; Maloney et al., 2016; Philipp et al., 2022). They found that asymmetries measured with jumps, isoinertial tests, crossover and lateral shuffle steps, and change of direction (CoD) tests negatively affect jumping, CoD and sprinting performance as well as some sport-specific skills such as swimming sprint. In contrary, other studies did not find a relationship between asymmetry and performance (Bishop et al., 2022a; Bishop et al., 2022b; Dos'Santos et al., 2017; Hoffman et al., 2007; Isin et al., 2022; Lockie et al., 2014; Pardos-Mainer et al., 2021; Phukan et al., 2021).

Studies discussing the effect of strength asymmetries on sport performance showed contradictory results. Some confirm the asymmetries measured with isokinetic dynamometry, isometric squats and pulls and sport specific test negatively affect CoD, jump and sprint ability along with cycling sprint, kicking accuracy and swimming sprint (Bailey et al., 2013; Bini et al., 2015; Coratella et al., 2018; Dos'Santos et al., 2013; Kozinc et al., 2020; Hart et al., 2016; Lockie et al., 2012; Rannama et al., 2015). Others could not find a correlation between asymmetries and performance, suggesting their independence (Blagrove et al., 2021; Morouço et al., 2015; Schons et al., 2019). To a lesser extent, the effect of different magnitudes of asymmetries is observed in the studies. While Lockie et al., (2014) and Hoffman et al., (2007) state that there is no difference in performance between individuals with smaller and larger asymmetries, Bell et al., (2014) demonstrated that asymmetries between limbs > 10% negatively affect jump height. Philipp et al., (2022) also suggest the threshold of 10 – 15% to reflect the magnitude where a negative effect of asymmetries occurs, however, it is again important to note that this threshold varies from one test to another.

As summarized throughout the introduction, the influence of inter-limb asymmetries in muscle strength and power on sports performance is still equivocal. The purpose of this review is to collect and summarize all available literature on this topic. This way, specific gaps in the literature will be recognized, while coaches and other professionals will be able to use this information to address the most critical asymmetries that may present in their athletes.

Methods

From January to May 2022, we searched for relevant studies and articles that were accessed through the PubMed and Google Scholar online scientific database. To avoid excessive quantities of unrelated articles, we combined the phrase »sports performance« with different phrases: »inter-limb asymmetry«, »strength asymmetry« and »power asymmetry«. The papers were considered eligible if they a) reported at least one inter-limb asymmetry variable based on strength or power assessment; b) reported at least one general (e.g., jump height, sprint time, CoD time) or sport-

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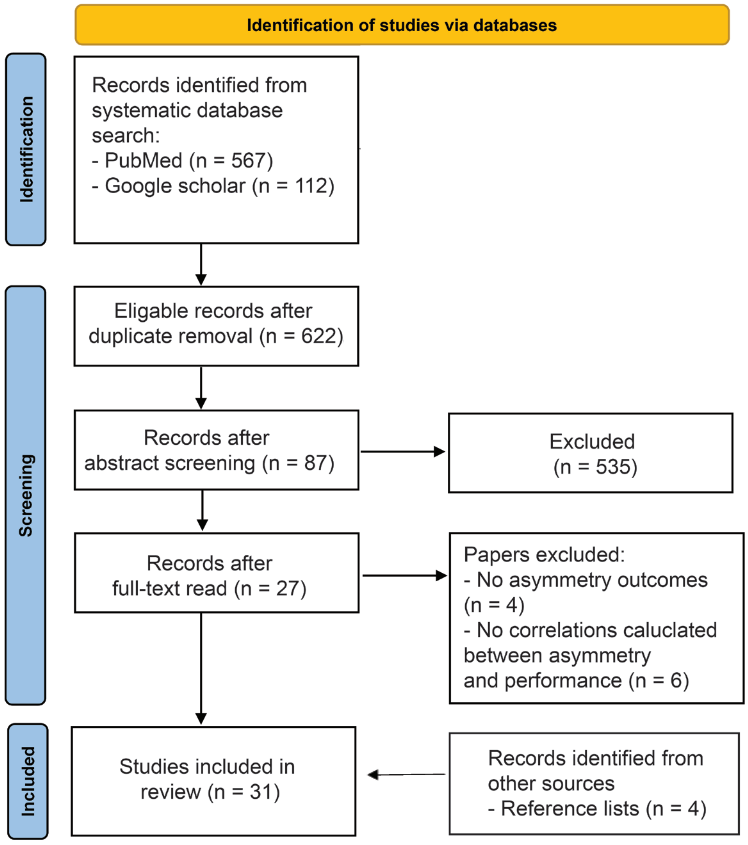

Figure 1. PRISMA flowchart of showing identified, included and excluded studies.

specific (e.g., kicking accuracy task) performance variable; and c) either reported correlation coefficients between the two types of variables or compared the mean performance between groups of participants, established based on the magnitude of the asymmetry. We made no restrictions regarding the population. The details on study search are shown in Figure 1. Upon database search, 27 papers were included in the review. Four additional studies were obtained from the reference lists of the included studies. When the research was not available in full-text, the authors were contacted. All 31 papers were made available eventually, therefore, all were included in the final review.

Results

Of all 31 studies included in the final analysis, 11 of them were conducted on soccer and football players, three on swimmers, two on cyclists, two on handball players, two on runners, two on volleyball players, one on tennis players and one on basketball players. Of all studies, five of them measured strength asymmetry with isokinetic dynamometry, three with isometric squats or pulls, and three with sport specific tests. Power asymmetries in 20 of the studies were calculated from jumps. Three of them measured asymmetry in power with isoinertial device and one with the Bulgarian split squat. Of the six studies researching asymmetries in CoD, two of them also calculated change of direction deficit. 12 studies observed the effect of asymmetries on jumping performance, 19 on CoD performance, 13 on sprint performance and seven on sport-specific tests such as maximal running or crawl,

Table 1. Studies investigating asymmetries in strength

Author & year	Population	Asymmetry measurement	Performance tests	Results
Bailey et al., 2013	36 students, actively participating in various team sports. Average age = 20	Isometric mid-thigh pull Equation: (stronger leg – weaker leg) / total × 100	SJ, CMJ with and without the bar	Asymmetry in peak force is negatively correlated with jump height (r = – 0.34 to – 0.52) and peak power (r = – 0.28 to – 0.43).
Blagrove et al., 2021	43 runners of which 31 were included in the asymmetry part of the study. They did not perform strength training. Age = 15-18	Bilateral quarter-squat Equation: (stronger leg – weaker leg)/ total x 100 Single leg isometric hip extension and abduction Equation: (stronger leg – weaker leg)/ stronger x 100	Sub-maximal and maximal running assessment	The correlations between asymmetries in strength and running assessment were negligible. Only the asymmetry in hip abductor strength and running assessment were weakly and negatively correlated (r = -0.47).

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Author & year	Population	Asymmetry measurement	Performance tests	Results
Coratella et al., 2018	21 elite soccer players, U21. Age = 18-21	Quadriceps and hamstring isokinetic dynamometry at 30 and 300°/s. Equation: (stronger leg – weaker leg)/ stronger x 100	SJ, CMJ, 10 m and 30 m sprint, 180° CoD test and T-test	Asymmetry in eccentric peak torque at different angular velocities for both quadriceps and hamstrings were weakly to moderately negatively correlated with 180° CoD test (r = 0.404 – 0.426) and T-test (r = 0.394 – 0.614) performance and weakly negatively correlated with SJ and CMJ performance (r = – 0.015 do – 0.218). Hamstring concentric peak torque asymmetry at 300°/s was moderately negatively correlated with sprint time (r = 0.343 – 0.466).
Hart et al., 2016	31 sub-elite Australian football players, training for at least five years and at least two of those at the current level. Average age = 22	Bilateral and unilateral isometric squat Equation: (kicking leg – standing leg) / 0,5 × (kicking leg + standing leg) × 100	10 drop punt kicks over twenty meters to a player target	They found that the kicking accuracy was moderately positively correlated with the relative bilateral and relative unilateral strength of both legs (r = 0.25 – 0.40). Asymmetry in strength on both standing and kicking leg was strongly negatively correlated with kicking accuracy (r = – 0.52).
Kozinc et al., 2020	25 male and 29 female volleyball players that have been training more than three times a week for the last three years. Average age = 17	SLCMJ, SLHJ, SLLJ, THOP maximal unilateral isometric knee extension, rapid isometric pulses Equation: (D leg – ND leg) / max (D, ND) × 100	SLCMJ, 90° and 180° CoD test	180° CoD test performance was weakly negatively correlated wtih asymmetry in RTD-SF (r = 0.30).
Lockie et al., 2012	16 males participating in various team sports. At the time they were performing at least 3 hours of resistance training a week. Average age = 23	Quadriceps and hamstring isokinetic dynamometry (concentric: 60, 180, 240°/s eccentric: 30°/s) Equation: (stronger leg – weaker leg) / stronger leg x 100	40 m sprint (0 – 10 m, 0 – 20 m, 0 – 40 m), T-test	Asymmetry in torque and work at 60°/s did not affect performance. Asymmetry in torque at 180°/s and 240°/s was negatively correlated with 0-10 m (r = – 0.554 to – 0.902), 0-20 m (r = – 0.579 to – 0.869) and 0-40 m (r = – 0.525 to – 0.772) sprint velocity. Asymmetry in work at 180°/s and 240°/s was also negatively correlated with 0-10 m (r = – 0.740), 0-20 m (r = – 0.521) and 0-40 m (r = – 0.548) sprint velocity. While asymmetry in torque at 30°/s negatively affected T-test performance (r = 0.669), asymmetry in word at 30°/s negatively affected the 0 – 20 m (r = 0.534) and 0 – 40 m (r = 0.597) sprint performance and T-test performance (r = 0.638)
Rannama et al., 2015	16 competitive male road cyclists with at least 6 years of focused cycling training and competitive experience and season's cycling total distance over 15000 km.	Isokinetic dynamometry of the ankle plantar and ankle dorsal flexors, knee and hip extensors and flexors (60, 180 in 240°/s). Equation: (left – right) / max (left, right) × 100	Cycling sprint on three cadences (100,120 and 140 rpm)	Knee extensors peak torque asymmetry negatively affected maximal power production during cycling sprint (r = -0.50).
Schons et al., 2019	11 professional volleyball players with at least two years of competitive experience and 4 hours of training daily.	Quadriceps and hamstring isokinetic dynamometry: 60, 180, 300°/s Equation: ((D leg – ND leg) / D leg) × 100	CMJ	Strength asymmetries were not significantly correlated with CMJ performance.

CMJ = counter-movement jump, CoD = change of direction, SJ = squat jump, SLCMJ = single leg counter-movement jump, SLHJ = single leg horizontal jump, SLLJ = single leg lateral jump, THOP = triple hop, D = dominant, ND = non-dominant

kicking accuracy and others. Of all studies, three of them divided asymmetries into groups of different magnitudes. Most of the studies were conducted on elite athletes, 22 of them included male population, three included female population and six included both. In 19 studies the athletes were adults aged 18 and above, while the other 13 studies included a younger population. More details regarding the population, assessments and results are given in Tables 1-3.

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Table 2. Asymmetries in sport-specific tests

Author & year	Population	Asymmetry measurement	Performance tests	Results
Bini et al., 2015	10 cyclists with competitive experience in cycling or triathlon. Average age = 32	Bilateral pedal forces measured using a pair of strain gauge instrumented pedals during a 4 km cycling test Equation: (D leg – ND leg) / 0,5 × (D leg + ND leg) × 100%	Time on a 4 km cycling test on a stationary cycloergometer	While asymmetries in resultant force and index of effectiveness did not affect performance, larger asymmetry in effective force was positively correlated with cycling performance on the 4 km test (r = 0.72).
Dos'Santos et al., 2013	16 swimmers. For the last two years they have been training three times per week and competing on a national level. Average age = 21	2-minute front crawl tethered-swimming. 6 strokes were collected – 3 for each side at the beginning, in the middle and at the end of the test Absolute asymmetry in force between the right and left hand	Participants best performance in the 200 m frontcrawl swimming.	They found that the fastest swimmers had the smallest asymmetries in average and peak force.
Morouço et al, 2015	18 swimmers with at least five years of competitive experience in sprint or middle-distance swimming. Average age = 15	30 seconds of maximal front crawl tethered-swimming test Equation: ((D arm – ND arm) / 0,5 × (D arm + ND arm)) × 100	Maximal 50 m front crawl bout with an underwater start	The asymmetry in the produced force between D and ND arm, but it did not affect crawl performance.

D = dominant, ND = non-dominant

Table 3. Asymmetries in power

Author & year	Population	Asymmetry measurement	Performance tests	Results
Bell et al., 2014	167 students, participating in various team sports. Average age = 20	CMJ Equation: (right leg – left leg) / 0,5 × (right leg + left leg) × 100%	CMJ	Participant were divided into four groups of different asymmetry magnitudes (0-5, 5-10. 10-15 and >15%). Asymmetries >10% lowered the jump height for approximately 9 cm.
Bishop et al., 2022b	30 basketball players with at least 4 years of competitive experience and 2 years of conditioning traning. Average age = 17	SLCMJ, SLDJ, 505 test No asymmetry calculation data is given	SLCMJ, SLDJ, 505 test	Negative correlation were found between asymmetry and jump height in SLDJ on the left (r = – 0.44), reactive strength index on the left (r = – 0. 46) and 505 test performance both on left and right (r = 0.45 – 0.48).
Bishop et al., 2021b	41 professional soccer and cricket players with at least 6 years of competitive experience and 2 years of conditioning training twice a week. Average age = 20	SLCMJ, SLDJ Equation: 100/(max value) x (min value) x (-1) + 100	10 m sprint, 505 test	505 test performance in cricket players was negatively affected by asymmetries in SLDJ height (r = 0.56 – 0.59) and reactive strength index (r = 0.63 – 0.74). There were no other correlations found.
Bishop et al., 2022a	18 professional soccer players with at least 6 years of competitive experience and 2 years of conditioning training. Average age = 19	SLCMJ, SLDJ, CoDD Equation: 100/(max value) x (min value) x (-1) + 100	10 m and 30 m sprint, 505 test	No correlations between jump height asymmetry and performance tests were found in pre and mid-season. At the end of the season negative correlations between asymmetry in SLDJ and 10 m sprint performance (r = 0.62) and 505 test performance on the right leg (r = 0.65) were found.
Bishop et al., 2021a	19 female soccer players, performing 30 minutes of conditioning training twice a week. Average age = 10	SLCMJ, SLHJ, THOP, XHOP Equation: 100/(max value) x (min value) x (-1) + 100	SLCMJ, SLH, THOP, XHOP, 5 m, 10 m and 20 m sprint	Larger asymmetry in SLCMJ negatively affected sprint (r = 0.49 – 0.59) and SLCMJ (r = – 0.47 to – 0.53) performance. Asymmetry in THOP reduced horizontal jump performance (r = – 0.47 do – 0.58).
Bishop et al., 2019	16 soccer players with at least 6 years of competitive experience and 1 year of conditioning and ballistic training twice a week. Average age = 20	SLCMJ, SLDJ, 505 test Equation: 100/(max value) x (min value) x (-1) + 100	10 m and 30 m sprint, 505 test	While asymmetry in SLCMJ did not affect performance, asymmetry in jump height and reactive strength index during SLDJ negatively affected 10 m (r = 0.52) and 30 m (r = 0.58) sprint performance and 505 test performance (r = 0.52 – 0.66).

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Author & year	Population	Asymmetry measurement	Performance tests	Results
Dos'Santos et al., 2017	22 male team-sport players with at least one year of experience with resistance training. Average age = 21	SLHJ, THOP Equation 1: (right leg – left leg/ right leg × 100) Equation 2: (D leg – ND leg/ D leg × 100)	Modified 505 test, 90° CoD test	Asymmetries in jumps were not correlated to CoD performance. This may be due to the fact that only few participants displayed asymmetries greater than 10-15%.
Exell et al., 2017	8 sprint-trained athletes with at least two years of competitive experience. Average age = 22	SJ Equation 1: (45° – arctan (Xleft/ Xright)) / 90° × 100% Equation 2: (45° – arctan (Xleft/ Xright) - 180°) / 90° × 100%	60 m sprint	Ankle work during sprint was positively correlated with asymmetry in peak vertical ground reaction force (r = 0.895) and asymmetry in peak power (r = 0.761).
Fort-Vanmeerhaeghe et al., 2020	81 female and male team-sport players. 90-120 minutes of training 8-10 times a week and a match at the weekends. Age = 14-18	SLCMJ, SLHJ Equation: (highest performing limb – lowest performing limb / highest performing limb) ×100	SLCMJ, SLH, 30 m sprint and V-test	Asymmetry in SLCMJ was weakly negatively correlated with its performance on the lower performing limb (r = – 0.26 do – 0.48) and sprint performance (r = 0.26). Moderate to large negative correlation were found between the asymmetry in SLHJ and its performance (r = – 0.56 do – 0.64).
Hoffman et al., 2007	62 American football players. Average age = 19	CMJ, SLCMJ No asymmetry calculation data is given	L-test	Asymmetries in power between D and ND leg did not affect L-test performance. Additionally, they were divided into quartiles, however no differences were found.
Isin et al., 2022	42 sub-elite soccer players divided into horizontal and vertical asymmetries. These two groups were further divided into three magnitudes < 5%, 5 – 10%, > 10%.	SLCMJ, SLHJ Equation: (max. value – min. value / max. value) ×100	505 test, 30 m sprint	Jump height, sprint and CoD performance did not differ between the groups of different magnitudes. Although no significant differences were found, groups with larger asymmetry reached higher velocity, however these differences were small. No significant correlation between asymmetries in both jumps and performance tests were found.
Kozinc et al., 2020	25 male and 29 female volleyball players that have been training more than three times a week for the last three years. Average age = 17	SLCMJ, SLHJ, SLLJ, THOP maximal unilateral isometric knee extension, rapid isometric pulses Equation: (D leg – ND leg) / max (D, ND) × 100	SLCMJ, 90° and 180° CoD test	180° CoD test performance was weakly negatively correlated wtih asymmetry in SLCMJ (r = 0.29). Asymmetry in SLLJ was negatively correlated with 90° CoD test performance (r = 0.3). A negative correlation was also found between SLCMJ asymmetry and its performance in female participants (r = – 0.42).
Lockie et al., 2014	30 recreative males participating in various team sports at least two times a week and maintaining their physical fitness level during the research. Average age = 22	SLVJ, SLLJ, SLHJ Equation: (better performing leg - lesser performing leg) / better performing leg) x 100	20 m sprint (0-5 m, 0-10 m, 0-20 m), 505 test, modified T-test	They found that higher and longer jumps, mainly horizontal and lateral jumps, indicated a better time in the performance tests used (r = – 0.729 to – 0.306), however the asymmetry in the jumps was not significantly correlated with the CoD performance tests. This may be due to the absence of larger asymmetries (>15%) in the participants.
Madruga-Parera et al., 2020a	22 elite tennis players with at least 8 years of tennis experience. 150 minutes of training six times a week (on court, fitness) Average age = 16	SLCMJ, SLHJ, SLLJ, 180° CoD test, isoinertial tests: crossover and lateral shuffle step Equation: (D leg – ND leg) / D leg × 100	SLCMJ, SLHJ, SLLJ, 180° CoD test, isoinertial tests: crossover and lateral shuffle step	180° CoD asymmetry was negatively correlated with SLCMJ performance on the D (r = – 0.50) and ND leg (r = – 0.53) and 180° CoD performance on the D (r = – 0.50) and ND leg (r = – 0.63).

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Author & year	Population	Asymmetry measurement	Performance tests	Results
Madruga-Parera et al., 2020b	42 handball players with at least 7 years of competitive experience and three handball training sessions per week. Average age = 16	SLCMJ, SLHJ, SLLJ Equation: 100/(max value) x (min value) x (-1) + 100	SLCMJ, SLHJ, SLLJ, 2x180° CoD test, V-test, repeated sprints (8x10 m), 20 m sprint	SLCMJ and SLHJ asymmetries were negatively correlated with their performances (r = – 0.32 to – 0.52). A negative correlation was also found between SLCMJ asymmetry and repeated sprints performance (r = 0.35 – 0.40). SLHJ asymmetry negatively affected V-test (r = 0.32) and 2x180° CoD test (r = 0.31) performance.
Madruga-Parera et al., 2021a	16 soccer players who performed eight hours of training a week. Average age = 25	Knee extension and flexion and crossover step with isoinertial resistance, 180° CoD test Equation: 100/(max value) x (min value) x (-1) + 100	Knee extension and flexion and crossover step with isoinertial resistance, 180° CoD test	Asymmetry during the concentric phase of knee extension negatively affected performance during the eccentric phase of the crossover step (r = -0.63). Asymmetry during the concentric phase of the crossover step impaired 180° CoD performance (r = 0.51-0.59).
Madruga-Parera et al., 2021b	26 handball players, actively participating in high level youth handball league with at least 5 years of competitive experience and 2 years of resistance training. They performed 120 minutes of training three times a week and played one match a week. Average age = 16	SLCMJ, SLHJ, SLLJ, 90° and 180° CoD test, CoDD, isoinertial tests: crossover and lateral shuffle step Equation: 100/(D leg) x (ND leg) x (-1) + 100	20 m sprint, 90° and 180° CoD test	Asymmetry in crossover step was negatively correlated with the performance of both CoD tests (r = 0.41 – 0.51) and 20 m sprint (r = 0.46). Asymmetry during the concentric phase of the lateral shuffle step negatively affected 90° CoD test performance on the ND leg (r = 0.44). They also found negative correlations between 180° CoD test performance on the ND leg and SLLJ asymmetry (r = 0.39),180° CoD asymmetry (r = 0.42) and 180° CoDD asymmetry (r = 0.46).
Maloney et al., 2016	18 recreative male, who were active for at least two hours a week. Average age = 22	SLDJ Equation 1: (45° – arctan (Xleft/Xright)) / 90° × 100% Equation 2: (45° – arctan (Xleft/Xright) - 180°) / 90° × 100%	U-test	Asymmetry in SLDJ was positively correlated with U-test time (r = 0.60)
Pardos-Mainer et al., 2021	54 female soccer players with at least four years of soccer experience. Age groups: U-18, U-16 and U-14	SLHJ, SLCMJ, 505 test Equation: 100/(max value) x (min value) x (-1) + 100	SLHJ, SLCMJ, 505 test, 40 m sprint (0 – 10 m, 0 – 20 m, 0 – 40 m)	There were no correlation found between asymmetries in both jumps and sprint or 505 test performance. Furthermore 505 test asymmetry did not affect sprint or jump performance.
Phillip et al., 2021	24 professional American football players. Average age = 19	SLCMJ, SLDJ, 3-RM Bulgarian split squat Equation: (max. value – min. value / max. value) ×100	L-test, 505 test, 40-yard dash, VJ, HJ	A negative correlation between L-test performance and asymmetry in mPP (rs = 0.467) and mAP (rs = 0.455) during Bulgarian split squat was found. These asymmetries affecting L-test performance ranged from 10-15%. Larger SLCMJ asymmetry negatively affected VJ performance (r = – 0.578).
Phukan et al., 2021	38 swimmers competing on a national level. They practiced multiple swimming styles and were engaged in multiple recreational sports activities (not more than 2 h/week) Average age = 12	SLCMJ, SLHJ Equation: ((D leg – ND leg) / D leg) × 100	front crawl (25 m and 50 m), front crawl kick with push (25 m and 50 m)	No correlation was found between jump asymmetries and sport-specific swimming performance.

CMJ = counter-movement jump, CoD = change of direction, CoDD = change of direction deficit, D = dominant, ND = non-dominant, SJ = squat jump, SLCMJ = single leg counter-movement jump, SLHJ = single leg horizontal jump, SLLJ = single leg lateral jump, SLDJ = single leg drop jump, SLVJ = single leg vertical jump, VJ = vertical jump, HJ = horizontal jump, THOP = triple hop for distance, XHOP = crossover hop for distance

Discussion

The aim of this review was to examine the available literature pertaining to inter-limb asymmetries in strength and power and critically evaluate their effect on sports performance. In general, the literature suggests a negative effect of asymmetries on sports performance, however, the findings depend on the test used to assess asymmetry and the performance outcome measure.

Asymmetries in strength

Bailey et al., (2013) researched the effect of strength asymmetries in isometric mid-thigh pull on squat jump (SJ) and counter-movement jump (CMJ) performance. Larger asymmetries were moderately and negatively correlated with the height (r = – 0.34 to – 0.52) and peak power (r = – 0.,28 to – 0.43) during vertical jumps. Coratella et al., (2018) also reported a negative correlation between strength asymmetry and jumping ability, however this correlation was negligible. When measuring strength with isokinetic dynamometry they found that larger quadriceps and hamstrings peak torque asymmetries at different angular velocities somewhat reduce SJ and CMJ ability (r = – 0.02 to – 0.22). On the contrary, Schons et al., (2019) found no correlation between quadriceps or hamstring strength asymmetry, also measured with isokinetic dynamometry, and CMJ ability. These results indicate that larger asymmetries could be detrimental to jumping performance, however the correlations were weak, therefore further research is needed.

Lockie et al., (2012) researched the effect of quadriceps and hamstrings strength asymmetries on sprint performance. Larger asymmetries in torque and work during the concentric phase of knee extension at the speed of 180°/s and 240°/s were significantly and negatively correlated with sprint time (r = – 0,521 do – 0,902), suggesting that faster individuals exhibited greater bilateral differences. It is important to note that these asymmetries scored below the 15% threshold, therefore, despite slightly larger asymmetries in the faster group compared to the slower group, individuals were able to reach high velocities. Sprint velocity was impaired by the asymmetry in torque and work during the eccentric phase of knee flexion at the speed of 30°/s (r = 0,534 – 0,638). The findings of Coratella et al., (2018) reported a negative effect of asymmetry in peak torque during the concentric phase of knee flexion at the speed of 300°/s (r = 0,343 – 0,466). Based on these results, it is important to ensure between-limb balance in hamstring strength. This is consistent with research showing the great significance of producing the horizontal force component, which is provided by hamstring performance.

Alongside the effect of asymmetries on sprint performance, Lockie et al., (2012) also researched their effect on CoD ability. Larger asymmetries in torque and work during the eccentric phase of knee flexion at the speed of 30°/s was associated with inferior the T-test performance (r = 0.67). This was confirmed by Coratella et al., (2018), who, in addition to the effect of torque asymmetries during knee flexion, also found a negative correlation between torque asymmetry during the eccentric phase of the knee extension and T-test performance (r = 0.39 – 0.61). The participants also performed a CoD test with a 180° turn and a similar correlation was obtained (r = 0.40 – 0.43). Furthermore, Kozinc et al., (2020) reported a somewhat weaker correlation between 180° CoD performance and asymmetry in rate of torque development scaling factor (r = 0.30), measured during rapid isometric pulses on an isometric dynamometer. Based on the findings, we can conclude that asymmetries in strength of the lower extremities negatively affect CoD performance and it is therefore advisable to reduce them.

Asymmetries in strength could also have a detrimental effect on sport specific skills. Hart et al., (2016) researched how asymmetry, measured with unilateral and bilateral isometric squats, affects football kicking accuracy at a 20-meter distance from the target. The results indicate that larger asymmetries reduced the accuracy of the kicks (r = -0,52). Furthermore, Rannama et al. (2015), who conducted the research on cyclists, also reported a negative impact of strength asymmetries. Asymmetries in the extensors and flexors of the ankle, knee and hip were measured on an isokinetic dynamometer. The findings showed that greater asymmetry in peak torque of the knee extensors was negatively correlated with maximal power production during cycling sprint (r = – 0.50). Blagrove et al. (2021) discussed the effect of strength asymmetries, measured with isometric quarter-squat and isometric hip extension and abduction, on the maximal and submaximal running performance in middle- and long-distance runners. With the exception of a weak negative correlation between asymmetry in hip abductor strength and running economy in women (r = – 0.47) that suggest a detrimental effect to running performance, no other relationship was found. This is most likely due to the fact that long-distance running is considered a fairly symmetrical sport.

Asymmetries in sport-specific tests

Strength asymmetries in a study written by Bini et al., (2015) were measured using a pair of strain gauge instrumented pedals during a 4-kilometer cycling test. The authors reported a strong positive correlation between the asymmetry in effective force and the performance during the 4-kilometer time trial (r = –0.72), which somewhat surprisingly suggests that cyclists presenting larger asymmetries may be more successful. Dos'Santos et al., (2013) reported that the fastest swimmers in the 200 m sprint crawl had smaller asymmetries in peak and mean force measured during a 2-minute maximal crawl. A similar study, researching the effect of asymmetry in force, produced during a 30-second maximal crawl, on the performance during a 50-meter sprint crawl, was conducted by Morouço et al., (2015). However no correlation was found. The conflicting findings suggest that the impact of asymmetries measured with sport-specific tests varies from sport to sport, and that additional research is needed.

Asymmetries in power

Bishop et al., (2021a) researched the effect of asymmetries in power, measured with different jumps, on sprint performance. They found a positive correlation between asymmetry in single leg counter-movement jump (SLCMJ) and sprint time (r = 0.49 – 0.59; direction of correlation implying slower sprinting). Fort-Vanmeerhaeghe et al., (2020) also reported a similar finding, however the correlation was slightly weaker (r = 0.26). In a study conducted by Isin et al., (2022), participants were divided based on asymmetries measured SLCMJ and the single leg horizontal jump (SLHJ) (5%, 5 – 10% and 10 – 15%). Although no statistically significant correlations were found, groups with greater asymmetry generally achieved

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higher sprint speed, but these differences were small. Furthermore, Madruga Parera et al., (2020b), Lockie et al., (2014) and Pardos-Mainer et al., (2021) also did not find a correlation between asymmetries, measured with the SLHJ and SLCMJ, and sprint performance. This independence was partly confirmed by Bishop et al., (2019), however only with asymmetry measured with SLCMJ. Additionally, they latter study measured the asymmetry with the single leg drop jump (SLDJ) and found that higher asymmetries in jump height and reactive strength index impaired sprint performance on the 10-m (r = 0.52) and 30-m (r = 0.58) sprint. Bishop et al. (2022a) compared the effect of SLCMJ and SLDJ asymmetries on sprint performance in soccer players in three different parts of the season. No correlations were evident during preseason and midseason. Only at the end of the season, a significant correlation was found between SLDJ asymmetry and 10-m sprint time (r = 0.62). Exell et al., (2017) researched the effect of asymmetry in power, measured with the SJ, on sprint performance in sprint-trained athletes. They reported that asymmetries in work in the ankle joint during sprint and asymmetry in maximal vertical ground reaction force were related (r = 0.895), however, sprint performance was not affected by the asymmetries. Alongside asymmetries in jumps, which were weakly and negatively correlated with sprint ability (r = 0.18 – 0.27), Madruga Perera et al., (2021b) also measured the asymmetry with isoinertial resistance device. The participants performed a crossover and a lateral shuffle step, during which maximal power was measured. The results indicate that asymmetries during the concentric phase of the crossover step are associated with impaired 20-meter sprint performance (r = 0.46). Overall, the results of the studies are contradictory, with some confirmed the negative effect of asymmetry measured with SLCMJ on sprint ability, others rejected it and simultaneously showed the detrimental effect of asymmetry measured with SLDJ. Although with both SLCMJ and SLDJ the asymmetry is measured in the vertical direction, the previous finding shows that its effect may vary from test to test. The correlation between asymmetry in power and sprint performance may also depend on the training period and the joint under consideration.

Besides the effect of asymmetry in power on sprint performance, Bishop et al., (2021a) also researched their effect on jumping performance. Their findings showed that SLCMJ performance was negatively affected by SLCMJ asymmetries (r = −0.47 to −0.53). Furthermore, the length of horizontal jumps was impaired by the asymmetry measured with single leg triple hop for distance (THOP) (r = −0.47 to −0.58). These results were confirmed by Madruga Parera et al., (2020b), who reported a moderate correlation between asymmetries in SLCMJ and SLLJ and the performances in the same tests (r = −0.32 to −0.52). The detrimental effect was also shown in a study conducted by Fort-Vanmeerhaeghe et al., (2020), reporting a negative correlation between SLHJ asymmetry and its performance (r = −0.56 to −0.64). The same authors also reported the detrimental effect of asymmetry in SLCMJ on impaired performance in the same jump (r = −0.26 to −0.48). Philipp et al., (2022) reported similar findings; specifically, they reported a somewhat stronger correlation in a study conducted on American football players (r = – 0.578). Kozinc et al. (2020) included both male and female volleyball players in their study, however, a negative correlation between asymmetry in SLCMJ and its performance was found only in female participants (r = −0.42). Furthermore Bell et al., (2014) divided the participants into four groups of different magnitudes: 0 – 5%, 5 – 10%, 10 – 15% in > 15% and found that asymmetries in SLCMJ larger than 10% impaired its performance by an average of 9 cm. In a research conducted on basketball players, Bishop et al., (2022b) also paid attention to the consistency of correlations between two testing sessions. The results of the second session confirm the results of the first, indicating a negative correlation between the asymmetry in SLDJ and its performance on the left leg (r = −0.44). Two of the studies researched the effect of asymmetries in CoD on jumping performance. Madruga-Parera et al., (2020a) conducted a study on tennis players and found that asymmetry in 180° CoD negatively affected SLCMJ performance on the dominant (r = −0.50) and non-dominant leg (r = −0.53). In contrary, Pardos-Mainer et al., (2021) did not find a correlation between asymmetry in 505 CoD test and jumping ability in female soccer players. Jumping ability therefore depends on the asymmetries in power measured with jumping, and perhaps on those measured with CoD tests. The impact of the latter is not yet fully clear and further research is needed.

Lockie et al., (2014) researched the effect of asymmetries in power, measured with single leg vertical jump (SLVJ), SLHJ and SLLJ, on the 505 test and T-test performance. The results showed no correlation between asymmetries and CoD tests. Fort-Vanmeerhaeghe et al., (2020) and Dos'Santos et al., (2017) also reported no correlations; they measured the asymmetries with SLCMJ, SLHJ and THOP, however none of the asymmetries affected the performance in 505 test, V-test or 90° CoD test. The same jump types were used by Pardos-Mainer et al., (2021), who also found no correlation between the asymmetries in 505 test performance in female soccer players. Isin et al., (2022) and Hoffman et al., (2007) additionally divided the population of soccer players into groups based on the asymmetry magnitudes. They both could not find an influence of the magnitude of asymmetry in CMJ, SLCMJ and SLHJ and performance in 505 test and L-test. In contrary, three of the studies have reported the negative effect of vertical, horizontal and lateral asymmetries on CoD performance. Kozinc et al., (2020) found a weak negative correlation between performance in 90° and 180° CoD tests and asymmetries measured with SLCMJ in female and male volleyball players (r = 0.29 – 0.30). The negative effect on 180° CoD test on the non-dominant leg (r = – 0.39) is confirmed by Madruga-Parera et al., (2021b), but only for the asymmetry measured with the SLLJ. No connection was found between asymmetries in SLCMJ and SLHJ and 90° or 180° CoD performance. This last finding is in contrast with the other study by Madrua-Parera et al., (2020b) that reported a negative effect of asymmetry in SLCMJ and performance in repeated sprints with CoD (r = 0.35 – 0.40) and asymmetry in SLHJ length and CoD performance (r = 0.31 in 0.32). Many of the studies also measured the asymmetry with the SLDJ. Bishop et al., (2022a) conducted a study on soccer players and monitored the effect of asymmetries through three different parts of the season. In the preseason and mid-season no correlation was found. Only at the end of the season a positive correlation was found between the asymmetry in SLDJ and 505 test time (r = 0.65). The effect of asymmetry in SLDJ on 505 test and U-test performance was also researched by Bishop et al., (2019) and Maloney et al., (2016). The former reported a negative correlation with 505 test performance (r = 0.52 – 0.66) in female football players, while others reported a negative effect of asymmetries on the U-test (r = 0.60) in recreational males. The negative effect of asymmetries measured with SLDJ is partly confirmed by Bishop et al., (2021b), who alongside soccer players also included a group of cricket players. The effect was only present in the latter group.

A few of the studies also measured the asymmetries with CoD tests. Madruga-Parera et al., (2020a) reported a moderate negative correlation between asymmetry in 180° CoD test and its performance on dominant (r = 0.50) and non-dominant (r = 0.63) leg. A similar correlation was found by Madruga-Parera et al., (2021b), however only on the non-dominant leg (r = 0.42). In their article, Nimphius, Callaghan, Spiteri in Lockie (2016) highlight the CoD deficit (CoDD). It is a subtraction of 10-m sprint time from 505 test time, which better isolates the actual CoD time. Asymmetries in CoDD are therefore more pronounced, as confirmed by Madruga-Parera et al., (2021b). They reported a moderate negative correlation between asymmetry in CoDD and 180° CoD performance (r = 0.46). Additionally, the authors measured the asymmetries with the lateral-shuffle step and crossover step performed on an isoinertial device. They found a negative correlation between asymmetry in the crossover step and performance in 90° CoD (r = 0.41 – 0.51) and 180° CoD (r = 0.48 – 0.51). The asymmetry during the concentric phase of the lateral-shuffle step also negatively affected the CoD performance (r = 0.44). The correlation between the asymmetry during the concentric phase of the crossover step and 180° CoD performance (r = 0.51 – 0.59) was also found by Madruga-Parera et al., (2021a). Philipp et al., (2022) measured the asymmetry in average and peak power with the Bulgarian split squat and reported its negative effect on L-test performance (r = 0.45 – 0.46). The magnitude of asymmetry that most affected L-test performance scored slightly above 10% for average power and around 15% for peak power. As seen, the authors of the studies tried to link CoD performance with many different tests. The results were the most consistent for asymmetries in SLDJ. For other jumps in all three directions, the results seem to be more contradictory. Despite the fact that asymmetry in power obtained from isoinertial tests, CoD tests, CoDD and Bulgarian split squat negatively affected the results of various CoD tests, studies that integrate these measurements are scarce, thus, additional literature is needed to confirm this effect.

Conclusion

In conclusion, inter-limb asymmetries in strength seem to negatively affect CoD and sprint performance, as well as certain sport-specific skills. Furthermore, a few correlations between these asymmetries and jumping performance were reported so far, indicating a negative effect of asymmetries. These correlations were mostly weak/moderate and not always consistent across studies, therefore further research is needed. The findings in the field of asymmetry in power are more contradictory, especially their effect on sprint and CoD performance. Jumping performance seems to only be affected by the power asymmetries measured with jumps, while the effect of power asymmetries measured with CoD tests is less well known. To better understand this complex relationship between strength and power asymmetries and sports performance further research is needed, especially on the effect on sport specific tests.

Conflict of interests

The authors declare that there is no conflict of interests arising from this paper.

References

Atkins, S. J., Bentley, I., Hurst, H. T., Sinclair, J. K., & Hesketh, C. (2016). The Presence of Bilateral Imbalance of the Lower Limbs in Elite Youth Soccer Players of Different Ages. *The Journal of Strength & Conditioning Research*, *30*(4), 1007–1013. https://doi.org/10.1519/JSC.0b013e3182987044

Bailey, C., Sato, K., Alexander, R., Chiang, C.-Y., & Stone, M. H. (2013). Isometric force production symmetry and jumping performance in collegiate athletes. *Journal of Trainology*, *2*(1), 1–5. https://doi.org/10.17338/trainology.2.1_1

Bell, D. R., Sanfilippo, J. L., Binkley, N., & Heiderscheit, B. C. (2014). Lean Mass Asymmetry Influences Force and Power Asymmetry During Jumping in Collegiate Athletes. *The Journal of Strength & Conditioning Research*, *28*(4), 884–891. https://doi.org/10.1519/JSC.0000000000000367

Bini, R. R., & Hume, P. A. (2015). Relationship between pedal force asymmetry and performance in cycling time trial. *The Journal of Sports Medicine and Physical Fitness*, *55*(9), 892–898. Retrieved from https://pubmed.ncbi.nlm.nih.gov/26470634/

Bishop, C., Perez-Higueras Rubio, M., Gullon, I. L., Maloney, S., & Balsalobre-Fernandez, C. (2022). Jump and Change of Direction Speed Asymmetry Using Smartphone Apps: Between-Session Consistency and Associations With Physical Performance. *The Journal of Strength & Conditioning Research*, *36*(4), 927–934. https://doi.org/10.1519/JSC.0000000000003567

Bishop, C., Read, P., Brazier, J., Jarvis, P., Chavda, S., Bromley, T., & Turner, A. (2021). Effects of Interlimb Asymmetries on Acceleration and Change of Direction Speed: A Between-Sport Comparison of Professional Soccer and Cricket Athletes. *The Journal of Strength & Conditioning Research*, *35*(8), 2095–2101. https://doi.org/10.1519/JSC.0000000000003135

Bishop, C., Read, P., Bromley, T., Brazier, J., Jarvis, P., Chavda, S., & Turner, A. (2022). The Association Between Interlimb Asymmetry and Athletic Performance Tasks: A Season-Long Study in Elite Academy Soccer Players. *The Journal of Strength & Conditioning Research*, *36*(3), 787–795. https://doi.org/10.1519/JSC.0000000000003526

Bishop, C., Read, P., Chavda, S., & Turner, A. (2016). Asymmetries of the Lower Limb: The Calculation Conundrum in Strength Training and Conditioning. *Strength & Conditioning Journal*, *38*(6), 27–32. https://doi.org/10.1519/SSC.0000000000000264

Bishop, C., Read, P., McCubbine, J., & Turner, A. (2021). Vertical and Horizontal Asymmetries Are Related to Slower Sprinting and Jump Performance in Elite Youth Female Soccer Players. *The Journal of Strength & Conditioning Research*, *35*(1), 56–63. https://doi.org/10.1519/JSC.0000000000002544

Bishop, C., Turner, A., Maloney, S., Lake, J., Loturco, I., Bromley, T., & Read, P. (2019). Drop Jump Asymmetry is Associated with Reduced Sprint and Change-of-Direction

 DOI 10.26773/mjssm.230310

Speed Performance in Adult Female Soccer Players. *Sports*, *7*(1), 29. https://doi.org/10.3390/sports7010029

Bishop, C., Turner, A., & Read, P. (2018). Effects of inter-limb asymmetries on physical and sports performance: A systematic review. *Journal of Sports Sciences*, *36*(10), 1135–1144. https://doi.org/10.1080/02640414.2017.1361894

Blagrove, R. C., Bishop, C., Howatson, G., & Hayes, P. R. (2021). Inter-limb strength asymmetry in adolescent distance runners: Test-retest reliability and relationships with performance and running economy. *Journal of Sports Sciences*, *39*(3), 312–321. https://doi.org/10.1080/02640414.2020.1820183

Coratella, G., Beato, M., & Schena, F. (2018). Correlation between quadriceps and hamstrings inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-players. *Human Movement Science*, *59*, 81–87. https://doi.org/10.1016/j.humov.2018.03.016

Dos'Santos, K. B. dos, Pereira, G., Papoti, M., Bento, P. C. B., & Rodacki, A. (2013). Propulsive Force Asymmetry during Tethered-Swimming. *International Journal of Sports Medicine*, *34*(07), 606–611. https://doi.org/10.1055/s-0032-1327575

Dos'Santos, T., Thomas, C., Jones, P. A., & Comfort, P. (2017). Asymmetries in single and triple hop are not detrimental to change of direction speed. *Journal of Trainology*, *6*(2), 35–41. https://doi.org/10.17338/trainology.6.2_35

Exell, T., Irwin, G., Gittoes, M., & Kerwin, D. (2017). Strength and performance asymmetry during maximal velocity sprint running. *Scandinavian Journal of Medicine & Science in Sports*, *27*(11), 1273–1282. https://doi.org/10.1111/sms.12759

Fort-Vanmeerhaeghe, A., Bishop, C., Buscà, B., Aguilera-Castells, J., Vicens-Bordas, J., & Gonzalo-Skok, O. (2020). Inter-limb asymmetries are associated with decrements in physical performance in youth elite team sports athletes. *PLOS ONE*, *15*(3), e0229440. https://doi.org/10.1371/journal.pone.0229440

Hart, N. H., Nimphius, S., Weber, J., Spiteri, T., Rantalainen, T., Dobbin, M., & 6 Newton, R. U. (2016). Musculoskeletal asymmetry in football athletes: A product of limb function over time. *Medicine in Science and Sports and Exercise 48*, 1379-1387. https://doi.org/10.1249/MSS.0000000000000897

Hoffman, J. R., Ratamess, N. A., Klatt, M., Faigenbaum, A. D., & Kang, J. (2007). Do Bilateral Power Deficits Influence Direction-Specific Movement Patterns? *Research in Sports Medicine*, *15*(2), 125–132. https://doi.org/10.1080/15438620701405313

Işın, A., Akdağ, E., Özdoğan, E. Ç., & Bishop, C. (2022). Associations between differing magnitudes of inter-limb asymmetry and linear and change of direction speed performance in male youth soccer players. *Biomedical Human Kinetics*, *14*(1), 67–74. https://doi.org/10.2478/bhk-2022-0009

Kozinc, Ž., & Šarabon, N. (2020). Inter-Limb Asymmetries in Volleyball Players: Differences between Testing Approaches and Association with Performance. *Journal of Sports Science & Medicine*, *19*(4), 745–752. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7675626/

Lockie, R. G., Callaghan, S. J., Berry, S. P., Cooke, E. R. A., Jordan, C. A., Luczo, T. M., & Jeffriess, M. D. (2014). Relationship Between Unilateral Jumping Ability and Asymmetry on Multidirectional Speed in Team-Sport Athletes. *The Journal of Strength & Conditioning Research*, *28*(12), 3557–3566. https://doi.org/10.1519/JSC.0000000000000588

Lockie, R. G., Schultz, A. B., Jeffriess, M. D., & Callaghan, S. J. (2012). The relationship between bilateral differences of knee flexor and extensor isokinetic strength and multi-directional speed. *Isokinetics and Exercise Science*, *20*(3), 211–219. https://doi.org/10.3233/IES-2012-0461

Madruga-Parera, M., Bishop, C., Beato, M., Fort-Vanmeerhaeghe, A., Gonzalo-Skok, O., & Romero-Rodríguez, D. (2021). Relationship Between Interlimb Asymmetries and Speed and Change of Direction Speed in Youth Handball Players. *The Journal of Strength & Conditioning Research*, *35*(12), 3482–3490. https://doi.org/10.1519/JSC.0000000000003328

Madruga-Parera, M., Bishop, C., Fort-Vanmeerhaeghe, A., Beltran-Valls, M. R., Skok, O. G., & Romero-Rodríguez, D. (2020). Interlimb Asymmetries in Youth Tennis Players: Relationships With Performance. *The Journal of Strength & Conditioning Research*, *34*(10), 2815–2823. https://doi.org/10.1519/JSC.0000000000003152

Madruga-Parera, M., Bishop, C., Read, P., Lake, J., Brazier, J., & Romero-Rodriguez, D. (2020). Jumping-based Asymmetries are Negatively Associated with Jump, Change of Direction, and Repeated Sprint Performance, but not Linear Speed, in Adolescent Handball Athletes. *Journal of Human Kinetics*, *71*(1), 47–58. https://doi.org/10.2478/hukin-2019-0095

Madruga-Parera, M., Dos'Santos, T., Bishop, C., Turner, A., Blanco, D., Beltran-Garrido, V., … Romero-Rodríguez, D. (2021). Assessing Inter-Limb Asymmetries in Soccer Players: Magnitude, Direction and Association with Performance. *Journal of Human Kinetics*, *79*(1), 41–53. https://doi.org/10.2478/hukin-2021-0081

Maloney, S. J. (2019). The Relationship Between Asymmetry and Athletic Performance: A Critical Review. *The Journal of Strength & Conditioning Research*, *33*(9), 2579–2593. https://doi.org/10.1519/JSC.0000000000002608

Maloney, S. J., Richards, J., Nixon, D. G. D., Harvey, L. J., & Fletcher, I. M. (2016). Do stiffness and asymmetries predict change of direction performance? *Journal of Sports Sciences*, *35*(6), 547–556. https://doi.org/10.1080/02640414.2016.1179775

Morouço, P. G., Marinho, D. A., Fernandes, R. J., & Marques, M. C. (2015). Quantification of upper limb kinetic asymmetries in front crawl swimming. *Human Movement Science*, *40*, 185–192. https://doi.org/10.1016/j.humov.2014.12.012

Newton, R. U., Gerber, A., Nimphius, S., Shim, J. K., Doan, B. K., Robertson, M., … Kraemer, W. J. (2006). Determination of functional strength imbalance of the lower extremities. *Journal of Strength and Conditioning Research*, *20*(4), 971–977. https://doi.org/10.1519/R-5050501x.1

Nimphius, S., Callaghan, S. J., Spiteri, T., & Lockie, R. G. (2016). Change of Direction Deficit: A More Isolated Measure of Change of Direction Performance Than Total 505 Time. *The Journal of Strength & Conditioning Research*, *30*(11), 3024–3032. https://doi.org/10.1519/JSC.0000000000001421

Pardos-Mainer, E., Bishop, C., Gonzalo-Skok, O., Nobari, H., Pérez-Gómez, J., & Lozano, D. (2021). Associations between Inter-Limb Asymmetries in Jump and Change of Direction Speed Tests and Physical Performance in Adolescent Female Soccer Players. *International Journal of Environmental Research and Public Health*, *18*(7), 3474. https://doi.org/10.3390/ijerph18073474

Parkinson, A. O., Apps, C. L., Morris, J. G., Cleveland, T. B., & Lewis, M. G. C. (2021). The Calculation, Thresholds and Reporting of Inter-Limb Strength Asymmetry: A Systematic Review. *Journal of Sports Science and Medicine*, *20*(4), 594–617. https://doi.org/10.52082/jssm.2021.594

Philipp, N. M., Garver, M. J., Crawford, D. A., Davis, D. W. & Hair, J. N. (2022). Interlimb asymmetry in collegiate American football players: Effects on combine-related performance. Journal of Human Sport and Exercise, 17(3). https://doi.org/10.14198/jhse.2022.173.20

Philipp, N., Crawford, D., Garver, M., Davis, D. & Hair, J. (2020). Interlimb asymmetry thresholds that negatively affect change of direction performance in collegiate American football players. International journal of exercise science, 14(4), 606-612. https://doi.org/10.31236/osf.io/2u6nt

Phukan, M. I., Thapa, R. K., Kumar, G., Bishop, C., Chaabene, H., & Ramirez-Campillo, R. (2021). Inter-Limb Jump Asymmetries and Their Association with Sport-Specific Performance in Young Male and Female Swimmers. *International Journal of Environmental Research and Public Health*, *18*(14), 7324. https://doi.org/10.3390/ijerph18147324

Rannama, I., Port, K., Bazanov, B., & Pedak, K. (2015). Sprint cycling performance and asymmetry. *Journal of Human Sport and Exercise, 10,* 247-258. https://doi.org/10.14198/jhse.2015.10.Proc1.12

Read, P. J., McAuliffe, S., Bishop, C., Oliver, J. L., Graham-Smith, P., & Farooq, M. A. (2020). Asymmetry Thresholds for Common Screening Tests and Their Effects on Jump Performance in Professional Soccer Players. *Journal of Athletic Training*, *56*(1), 46–53. https://doi.org/10.4085/1062-6050-0013.20

Samozino, P., Peyrot, N., Edouard, P., Nagahara, R., Jimenez-Reyes, P., Vanwanseele, B., & Morin, J.-B. (2022). Optimal mechanical force-velocity profile for sprint acceleration performance. *Scandinavian Journal of Medicine & Science in Sports*, *32*(3), 559–575. https://doi.org/10.1111/sms.14097

Schons, P., Da Rosa, R. G., Fischer, G., Berriel, G. P., Fritsch, C. G., Nakamura, F. Y., … Peyré-Tartaruga, L. A. (2019). The relationship between strength asymmetries and jumping performance in professional volleyball players. *Sports Biomechanics*, *18*(5), 515–526. https://doi.org/10.1080/14763141.2018.1435712

 DOI 10.26773/mjssm.230310