Bilateral Asymmetry in Sports Performance

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Asymmetry is ubiquitous in nature and humans have well-established bilateral asymmetries in their structures and functions. It is prevalent across several sports regardless of age, gender, or competitive level, and can be verified even in apparently symmetric actions (e.g., running and rowing). Assessments of bilateral asymmetries are highly task-, metric-, individual-, and sport-specific; fluctuate significantly in time (in magnitude and, more importantly, in direction); and tend to be poorly correlated among themselves, as well as with general performance measures. Most studies assessing bilateral asymmetries do not actually assess the occurrence of injuries. While injuries tend to accentuate bilateral asymmetries, there is no evidence that pre-existing asymmetries increase injury risk. While training programs reduce certain bilateral asymmetries, there is no evidence that such reductions result in increased sport-specific performance or reduced injury risk.

symmetry bilateral asymmetry interlimb asymmetry laterality injury risk

performance

1. Introduction—the Inevitability and Omnipresence of Asymmetry

In sports training and fitness contexts, symmetry intuitively seems to be a concept that practitioners chase in the hope that it may enhance performance and/or reduce injury risk. Such is the strength of this belief that several studies associate lower limb bilateral asymmetries (e.g., ground reaction forces and kinematic analyses) with increased injury risk *despite not actually having assessed any actual risk* [1][2][3][4][5][6][7][8][9][10], i.e., the occurrence of injuries was not registered in such studies. Such unsubstantiated discourse misleads the readers and may even detract from analyzing other (relevant) variables of those works. Training programs are often designed to decrease interlimb asymmetry and may achieve small to moderate (but commonly non-significant) reductions [11][12] and, more rarely, small to large reductions in asymmetry [13]. When such programs are successful in achieving what they had proposed to achieve (i.e., reducing interlimb asymmetries), the authors may (erroneously) assume that increased symmetry is beneficial, without actually assessing the effect of these changes on injury risk [2]. Even a systematic review stated that interlimb asymmetries in several so-called “functional tasks” (e.g., isokinetic knee extension and flexion, single-leg vertical jump, and single-leg hop) were undesirable and should be properly remedied [5], despite injury risk not being formally assessed in any capacity.

This search for bilateral symmetry (which includes bilateral trunk asymmetries and also interlimb asymmetries) seems to derive more from deeply held beliefs than from empirical findings [14], and risks placing performance and injury prevention programs on the wrong track. Incidentally, craniocaudal and dorsoventral asymmetries are promptly accepted (i.e., people understand that we need one head on top and two feet on the bottom, and that we have two eyes in front of the head but none in the back). Somehow, it is with bilateral asymmetry in sport that some in the profession seem to struggle to appreciate. However, there is hope: the 10th edition of the ACSM guidelines for exercise testing and prescription makes no mention of symmetry in general exercise prescription [15], unlike the 9th edition [16]. Across the entire 10th edition of the guidelines, the only reference to symmetry is the suggestion of symmetrical and rhythmical movement for people with athetoid cerebral palsy [15].

Biologically, the healthy development of human embryos requires breaking several symmetries, including dorsoventral and craniocaudal [17]; unsurprisingly, proper embryologic developmental also requires breaking left–right symmetry in vertebrates, including humans [17][18][19][20][21]. Consequently, human anatomy is abundant with bilateral asymmetries. Despite an apparent external symmetry, there is considerable asymmetry in thoracic and abdominal organs [19][21]. For example, the diaphragm is asymmetric, usually reaching one rib higher on the right side (due to the influence of the liver) and one lumbar vertebra lower on the right side (due to a longer pillar) [22]. The aorta (which is also asymmetric) presses against the vertebral column and usually produces a slight thoracic curvature with convexity towards the right side [22]. Many other asymmetries can be pinpointed with respect to internal organs (e.g., the liver, heart, lungs, colon, pancreas, etc.), which are all commonly known. However, there are many additional bilateral asymmetries in vascular networks, the lymphatic drainage system, and neural pathways [22]. In some cases, nerves not only traverse distinct paths on the right and the left side of the body, but they also present histological differences, such as in the case of the recurrent laryngeal nerve in humans [23][24].

Importantly, bilateral anatomical asymmetries in humans extend to the upper and lower limbs as well (e.g., widths, lengths, neuromuscular paths, the different number of muscle bellies, and among many other features) and have been widely described in the literature [22][25][26][27][28][29]. A recent review has synthesized interlimb asymmetries in the hamstrings' structure and functionality, highlighting that important intraindividual asymmetries may exist (some of which are not changeable with training) [30]. Naturally, laterality (i.e., a lateral preference for using one limb over the other in certain tasks) coupled with interlimb anatomical asymmetries suggests that common activities such as walking and running should result in significant interlimb asymmetries in gait (kinetic and kinematic) in healthy populations and athletes [31][32][33], and that sports may actually require magnifying certain asymmetries [14][34] (e.g., sports with highly unilaterally-biased actions).

2. Bilateral Asymmetry Is Ubiquitous in Sports Performance

Bilateral asymmetry (a broad term referring to bilateral trunk asymmetries or interlimb asymmetries) should be expected to be and is (probably) not even clinically relevant below the *arbitrary* thresholds of 5–15% [5][7][11][35][36][37][38], with an emphasis on the arbitrariness of such thresholds since they are task- and metric-specific [7][11][12][34][39][40][41][42][43][44][45][46][47] and likely also individual-specific [44][46][47][48][49][50]. Laterality (including, but not limited to, handedness, mastication, and eye dominance) is a well-established feature in the animal kingdom, including humans, and has been shown to be associated with increased functional performance [51][52][53][54][55][56]. Importantly, both limb dominance and preference may also be task-specific [34]. Therefore, interlimb asymmetries should not be automatically associated with performance impairments [14][40][57]. Team sports such as basketball, handball, or volleyball, to name some notorious examples, may boost upper limb asymmetries due to their highly specialized and differentiated demands, and the same could be said of racquet sports such as tennis, padel, or badminton. In the case of the lower limbs, bilateral asymmetries are the norm in both general populations and in athletes [12]. For example, in 38 male adult soccer players, resting tensiomyography assessments showed significant interlimb asymmetries [58]. The vastus medialis contraction time, rectus femoris sustained time and half-relaxation time, and biceps femoris sustained time were greater in the dominant limb, while vastus lateralis contraction time and delay time were greater in the non-dominant limb [58].

Moreover, the “noisy” character of asymmetry and the inconsistency of outcomes should be considered, whereby in test–retest studies the group mean asymmetry often appears to be relatively stable, but the standard deviation (SD) of the mean is almost always very large (i.e., 50–100% of the mean asymmetry value) [42][46][49][59]. In contrast to the mean, when individual datapoints are considered, changes in asymmetry’s magnitude and direction are usually quite large [42][43][46][47][49][50][59][60][61][62][63], suggesting caution when interpreting the mean value of any interlimb asymmetry data. In fact, interlimb asymmetries should not even be considered “true” asymmetries if their value is equal to or smaller than the inherent variability of any given test [44][50] (e.g., coefficient of variation and typical error of measurement). Additionally, limb preference and limb dominance are not necessarily coincident; the researchers refer the readers to the work of Virgile and Bishop [34] for an exploration of this topic. To truly elucidate the relevance of asymmetry in sports performance, the researchers must understand: (1) the occurrence and relationships of bilateral asymmetry with athletic performance, and (2) the effects of training interventions on interlimb asymmetries.

2.1. Occurrence and Relationship of Bilateral Asymmetry with Athletic Performance

A recent systematic review showed that, among several populations (including 17 studies with athletes), inter-limb strength asymmetries ranged from near symmetry to asymmetries larger than 15%, without clear relationships with independent performance tasks (such as isokinetic dynamometry, jump tests, and seated shot put, among others) [37]. Furthermore, additional research has shown that in sports research, no clear-cut associations exist between bilateral asymmetries and performance [14]. In addition, any findings from cross-sectional studies should be taken with a pinch of salt, since the relationships between interlimb asymmetry (magnitude and direction) and performance are not necessarily consistent across a sports season [34][43][44][60][61][64]. One study assessed the ground reaction forces (GRF) of 13 plyometrics-trained subjects (23 ± 3 years, 8 male and 5 female) after a 45-cm drop jump whereby the subjects had to change their lead leg (i.e., the leg initiating the movement to step off the box) [1]. Upon landing, the lead leg generated greater forces than the trail leg. Interestingly, pairwise comparisons showed that significant interlimb differences occurred only when the right leg led the movement, with the right leg making earlier ground contact and generating greater force and impulse than the left leg. Limb symmetry indices (LSI) generally showed asymmetries ≥10% [1]. This shows that even in a simple drop jump task (with low contextual interference), athletes exhibit marked interlimb asymmetry in their performance. However, the drop jump height was not assessed, and so it is unclear how the observed asymmetries impacted jump performance.

In high-level male (*n* = 38) and female judokas (*n* = 23), the maximum isometric strength of the shoulder external rotators was significantly superior (albeit with a small effect size of $\eta^2 = 0.03$) in the dominant side in comparison with the non-dominant side, but the same was not observed for internal rotation [4]. Asymmetries favoring the dominant side were also detected for the unilateral seated shot put test (small effect, $\eta^2 = 0.07$), but not for the Y balance test [4]. In summary, upper limb dominance (i.e., a bilateral asymmetry) seemed to affect the performance of shoulder external rotations and unilateral seated shot put, but the effects were very small. In 26 male handball players (U18), interlimb asymmetry across a variety of jump and change-of-direction (COD) tests ranged from ~3.7 to ~12.7% [65]. Moderately significant correlations (ρ = 0.41–0.51) were found between isoinertial crossover step asymmetry (but not lateral shuffle step) and a COD of 90° and COD of 180° in both limbs, as well as 20 m sprinting. However, interlimb asymmetries were also quantified in the several single leg jumps and COD tests, which were independent of performance [65].

When performing the volleyball spike (which is a highly asymmetric action, both for the lower and upper limbs), a systematic review showed that attackers landed asymmetrically >65% of times, mostly on the left leg, and significant interlimb kinematic asymmetries were noted for the ankle, knee, and hip joints upon landing (e.g., joint flexion angle, range of motion, maximal flexion velocity, and angle upon initial contact with floor) [66]. Even in highly controlled experimental settings where the athletes were explicitly asked to land on both feet simultaneously [67][68][69], a unilateral landing was still the norm. Therefore, asymmetric landing strategies seem to be preferred in volleyball [66]. Even in supposedly more symmetric actions such as blocking, players have been shown to be faster moving towards the right side than to the left side of the court even in highly-controlled tasks with reduced contextual interference [70]. However, it is currently unclear how these asymmetries are related to performance outcomes, such as attack or block jump height. Further, it is unknown whether volleyball players' landing asymmetries are associated with a positive, neutral, or negative effect on the performance of these key game actions.

In soccer, interlimb asymmetries ranging from −11.01 ± 12.38% (U18) to −18.43 ± 12.11% (U16) have been observed in 68 soccer players when performing 90° COD tasks [71]. Note the very large SDs, indicating a large within-group variability. The COD time was significantly lower for the dominant than for the non-dominant side (no effect size available) [71]. In addition, in soccer, a study of 46 male professional players (26 ± 6 years of age) verified 8.4 ± 6.6% and 9.0 ± 7.1% interlimb asymmetries in isometric maximal voluntary contraction (MVC) torque and isokinetic knee peak extension torque. These interlimb asymmetries were smaller than those registered for the rate of early, intermediate, late, and peak torque development (RTD), which ranged from 12.3 ± 9.9% to 20.6 ± 14.3% (note the very large SDs) [8]. However, the only asymmetries that were significantly correlated (albeit weakly, i.e., $\rho \leq 0.36$) with the International Knee Documentation Committee and the Lysholm knee-scoring scales were early and intermediate RTD [8], denoting that the different asymmetries were largely independent from performance.

In 16 male soccer players (14.7 ± 0.2 years), no significant relationships were observed between interlimb asymmetry (single-leg Abalakov test, 10 m (5 + 5) and 20 m (10 + 10) COD, and isoinertial power test) and performance tests (10, 20, and 30 m sprints plus CMJ) [72]. The average interlimb asymmetries varied from 3.02 ±

1.74 % (20 m COD) and 21.68 ± 18.85% (peak power in the isoinertial test), but there were very large interindividual variabilities (e.g., 0.14 to 57.37% in peak power in the isoinertial test) [72]. Another soccer-related study followed 18 male U23 players for one season [64]. During both the preseason and midseason, no significant relationships were found between interlimb asymmetries and performance in sprint and COD tests, nor were there significant correlations between changes in asymmetry and changes in sprint and COD performance across the entire season [64]. In the authors' own words, "suggestions for the reduction of asymmetry that may indirectly enhance athletic performance cannot be made" (p. 787) [64].

In young female basketball players (*n* = 29, 15.7 ± 1.34 years of age), significant interlimb differences were identified for all neuromuscular tasks (single leg CMJ in different directions, star excursion balance test (SEBT), and sprint with a COD) [39]. There was poor agreement (35 to 52%) between the more skilled lower limb and the limb subjectively identified as being the dominant limb, which supports previous suggestions about differences between limb dominance and limb preference [34]. While the bilateral asymmetry indices between the more and less skillful limbs varied from 3.33 ± 2.49% (lateral CMJ distance) and 14.11 ± 8.62% (vertical CMJ height) [39], the authors did not assess the correlations between the magnitudes of asymmetry and the test performances. Therefore, while there were bilateral asymmetries in performance in each test, it is unknown if asymmetries in one test correlated with performance in another test, i.e., if the asymmetries were task-specific or translated into more general performance.

Kinetic and kinematic interlimb asymmetries are frequent even in cyclic, bilateral actions such as running and cycling [31][32][33][73]. In U15 swimmers (*n* = 38; half female), the direction of asymmetry (i.e., favoring one limb or the other) was rarely consistent between single-leg CMJ and single-leg standing long jump performances [74]. This implies that the assessment of interlimb asymmetries may be highly task-specific, in line with other works [7][8][11][12][39][40][41][42][47][60][64][72]. The asymmetry scores were not significantly different between males and females and were not associated with 25 m and 50 m front crawl swimming performance [74]. Considering the means plus the SDs, the asymmetry levels were roughly within the previously mentioned 10–15% range [74]. However, it should be noted that a recent review underlined the large SDs present in many symmetry-related studies, suggesting that important interindividual variability almost always exists [11]. This may partly explain why relationships between bilateral asymmetry (noisy and fluctuating) and performance (more stable) are often weak or negligible.

The kinematic and kinetic joint parameters were assessed in 10 elite-level male rowers on a rowing ergometer [7]. An average of 5–10% interlimb asymmetry was observed when assessing the kinematic parameters of the ankle and the kinetic parameters of the hip and knee joints (i.e., accelerations) [7]. Asymmetries > 10% were observed for the kinetic ankle parameters, including resultant force and ankle joint acceleration [7]. In this study, the kinetic asymmetries were uncorrelated with kinematic asymmetries and with lower limb length asymmetry [7], further contributing to the notion that asymmetry assessments may be task- and metric-specific [7][8][11][12][39][40][41][42][43][50][62][65][72]. The authors proposed that a low inter-stroke variability in asymmetry could provide a more stable and efficient performance [7]. The inter-stroke variability was said to be associated with 5–10% interlimb asymmetries with respect to the acceleration of the hip and knee joints and in the ankle joint angle, as well as with >10%

asymmetries in the resultant force and in the acceleration of the ankle joint [7], but no values were provided to corroborate these claims.

In artistic gymnastics, all beam routines of the qualification round (19 gymnasts) of the B World Cup ’2014 were analyzed [75]: the right lower limb initiated 42.3% of all actions, the left limb 29.1%, and both limbs 28.6%, denoting the asymmetric/lateral preferences of top-level gymnasts. Moreover, 60% of the actions on the beam implied a unilateral take-off and/or landing [75]. An analysis of six high-level female artistic gymnasts showed significant kinetic and kinematic interlimb asymmetries in the upper limbs upon contact with the floor when performing the forward handspring on floor [76]. However, in both studies [75][76], the ways in which these asymmetries related to performance were not reported. In summary, asymmetries appear to be the norm in sports, but we need a deeper understanding of how they relate to performance in different tests. As the evidence presented herein shows, the relationship between performance in standardized tests and sports-specific performance is often missing in the available literature to date.

2.2. Effects of Training Interventions to Reduce Bilateral Asymmetries in Sports

The previous section illustrated that bilateral asymmetry seems to be the norm in sports. If a training program aims to reduce bilateral asymmetries (most commonly, interlimb asymmetries), how successful is it? A study aimed to reduce interlimb asymmetries in 24 male adult soccer players (amateur level) [13]. The participants were randomized into a 6-week (twice weekly) unilateral strength- and power-training program or into a control group. Despite the experimental group having improved performance, the interlimb asymmetry was unchanged for the 505 COD test and two of the three jump tests (single-leg CMJ and single-leg broad jump) [13]. There was a moderate reduction in interlimb asymmetry in the single-leg drop jump stiffness (g = 1.11) and RSI (g = 1.00) [13]. Another randomized study compared an 8-week (twice weekly) strength- and power-training program (focused on the lower limbs and trunk) with controls in 37 female U17 soccer players [77]. The intervention resulted in no meaningful differences in interlimb asymmetries from pre- to post-testing [77]. Similar results were found with a comparable sample of female soccer players (n = 36; U14), albeit with a slightly longer intervention (twice weekly for 10 weeks) [78].

A non-randomized study with 20 adult male soccer players compared a 6-week core stability training regimen with controls performing a “standard” warm-up [79], consisting of jogging, dynamic stretching, and mobility [79]. The interlimb asymmetries in single-leg CMJ were reduced after the training program for the “core” training group, but increased in the controls, while no differences in interlimb asymmetry were observed for isokinetic knee testing [79]. Given the details of the actual “core” training regimen that was implemented, it is possible to speculate that the reductions in asymmetry in the jump tests may have come from the weaker limb gaining strength and have nothing to do with core stability. Moreover, the SDs shown in table V of the original study [79] are surprisingly small in comparison with most other studies on the topic.

In 34 male handball players (U17), an 8-week randomized intervention compared the effects of isoinertial and cable-resistance training on interlimb asymmetries [80]. Interlimb asymmetry was reduced in only one of the eight performance tests (unilateral CMJ) [80]. In 22 U16 to U19 basketball players, a randomized study compared unilateral and bilateral resistance training for 6 weeks [81]. Both groups improved in the performance tests such as the CMJ and 25 m sprint, among others. Only the unilateral group showed reduced interlimb asymmetries (no effect size provided) as assessed by the bilateral difference in the maximum power in an incremental unilateral squat test [81]. However, the standardized between-group differences crossed zero (i.e., there was no significant direction of the effects) [81], even while applying 90% confidence limits, which are narrower than the more common 95% limits. A randomized 8-week (twice a week) strength-training program was contrasted with a volume-equated sport-specific training regimen in 31 male volleyball players (aged 14.5 ± 0.5 years) [82]. Despite significant changes in performance (dynamic balance test, single leg hop, CMJ, and back squat one repetition maximum), no differences were observed with respect to interlimb asymmetry as assessed by the single-leg hop tests [82].

A randomized study with U12 male weightlifters applied a 6-week (twice weekly) hamstring eccentric training program versus controls; no changes in interlimb asymmetry (derived from bilateral differences in the performance of the single leg hop test) were noted from pre- to post-intervention [83]. In a randomized study with twenty-three U14 tennis players (male and female), one group performed 12 sessions (two sessions per week over 6 weeks) focused on balance training, while the other group performed only tennis-specific drills for the same period [84]. The lower limb bilateral asymmetries were significantly reduced in the balance-training group only for the three tests that were performed (single-leg hop, side-hop and side steps, and forward 4.115 m test [4m-SSF]) [84], but there was no assessment of the effect size to quantify the magnitude of the effects. However, no post-test improvements were noted with respect to the COD and speed tests in this group (i.e., the asymmetries were reduced during jumping, but the players did not become faster).

Overall, the efficacy of training programs designed to decrease interlimb asymmetry are heterogeneous [11][12][13]. Even when training programs reduce interlimb asymmetry with a concomitant increase in the performance of the selected tests (e.g., CMJ and 10 m sprint), the findings are often mixed [12]. It is also possible that the findings are neglecting an important confounder: the ceiling effect [14][50][85]. The “weaker” limb may be further from its maximum capacity, being more sensitive to training stimuli and showing greater improvement than the “stronger” limb [14][85]. This could result in reduced interlimb asymmetry, and is even more likely to occur in the case of already injured athletes [50]. Beyond that, the previously mentioned problems with the reliability of test–retest assessments of lower limb asymmetries and with only analyzing the average values (thereby neglecting to account for the interindividual variability) limit the understanding of how well such programs work on an individual level. Additionally, the aforementioned training programs mostly used standardized physical tests. The few sport-specific assessments were performed under very analytical conditions. Therefore, *it is unclear whether any reductions in interlimb asymmetry were positive or desirable for enhanced athletic or sporting performance*.

2.3. What Does This All Mean?

The sum of these findings shows that interlimb asymmetries are an intrinsic part of high-level performance, even in supposedly more symmetric actions, and the effects of training interventions on asymmetry and their consequences for performance are unclear. Still, it is possible to speculate that even if it was established that asymmetries contribute positively to sports performance, they could produce a trade-off, increasing injury risk [86].

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