

1 TRAINING METHODS AND CONSIDERATIONS FOR
2 PRACTITIONERS TO REDUCE INTER-LIMB ASYMMETRIES

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1 **ABSTRACT**

2 Inter-limb asymmetries have been a common source of investigation in recent years with the
3 majority of studies highlighting its prevalence in a range of athletic tasks. Few have tested
4 whether reducing inter-limb differences are required for improved physical performance.
5 Furthermore, there are a number of considerations that may exist which practitioners should
6 consider prior to starting training interventions to reduce these differences. This article will
7 discuss the available body of literature pertaining to the reduction of inter-limb asymmetries
8 to date and provide example training programs to show how they can be addressed if their
9 reduction is deemed necessary.

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11 **Key Words:** Inter-limb differences, imbalances, symmetry

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1 INTRODUCTION

2 The concept of inter-limb asymmetries has been widely investigated in the literature to date
3 and refers to the performance of one limb with respect to the other (2,5,20,21). To date, the
4 majority of literature has highlighted the prevalence of inter-limb differences across a range
5 of tasks and physical competencies (2,8,12,15,16,30), rather than focusing on whether these
6 differences have a measurable effect on physical or sporting performance (6,7). For those that
7 have, asymmetries have primarily been quantified during strength and jumping tasks.
8 Intuitively, practitioners may consider that notable differences between limbs are detrimental
9 to performance; however, few studies have examined if this is actually the case (1,8,16,18,25).
10 Inter-limb differences in strength of ~6-8% have been shown to be negatively associated with
11 jump performance (1), and sport-specific skills such as kicking accuracy (16). However,
12 when inter-limb differences are quantified from a variety of unilateral jumping tasks findings
13 are equivocal. Differences in peak power quantified from single leg countermovement jumps
14 (SLCMJ) or jump height from single leg drop jumps (SLDJ) have suggested that imbalances
15 ~10% are detrimental to change of direction speed (CODS) performance (18,25). In contrast,
16 asymmetries in jump height and distance reported from multi-planar unilateral jumps as high
17 as 11.4% have indicated no detrimental effects on linear speed and CODS tasks (10,22); thus,
18 it is challenging to draw sound conclusions from the available body of evidence (7). Similarly,
19 previous research has highlighted discrepancies surrounding asymmetries and injury risk. A
20 threshold of 15% has been suggested to increase injury risk when identified during a variety
21 of hop tests (3,15,20), whereas asymmetries < 10% have been proposed as a target during
22 rehabilitation (23,29). Given these inconsistencies, specific thresholds associated with
23 heightened risk should be interpreted with caution as there is currently an absence of
24 prospective data pertaining to asymmetry and injury incidence. Despite these inconsistencies,
25 practitioners may wish to monitor inter-limb differences to ensure that they never grow

1 beyond what may be deemed a ‘high risk threshold’. Consequently, it would appear that
2 physical performance may be hindered and injury risk increased if inter-limb differences are
3 not addressed; thus, specific approaches that target reductions in asymmetry are warranted.
4 With that in mind, a number of studies have reported how inter-limb asymmetries have
5 changed following a targeted training intervention (4,8,11,12,19,30). This article will provide
6 an overview of the available literature and suggest evidence-based methods to reduce inter-
7 limb differences. A range of considerations have also been included where practitioners
8 should think critically to determine if asymmetries are problematic or not for some athletes,
9 and the potential effects that reducing these differences may have on both sports performance
10 and injury risk. Finally, a hypothetical example has been included to illustrate how an athlete
11 who displays inter-limb differences in strength and power during physical performance
12 testing could be trained to address these imbalances.

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14 **TRAINING TO REDUCE INTER-LIMB ASYMMETRIES**

15 Until recently, there has been a paucity of literature pertaining to the reduction of inter-limb
16 asymmetries. To the authors’ knowledge, only six studies exist to date which included
17 specific training interventions for the purpose of reducing inter-limb differences. However,
18 one study provides no details of the methods employed to reduce these imbalances (20); thus,
19 has not been included in the subsequent discussion. The methods and results of the remaining
20 five studies can be viewed in Table 1.

21

22 *** INSERT TABLE 1 ABOUT HERE ***

23

24 Bazyler et al. (4) used a 7-week back squat training programme (performed twice a week) to
25 examine the effects on back squat 1 repetition maximum (RM) and bilateral isometric peak

1 force asymmetries at 90 and 120° knee angles. Subjects were divided into strong and weak
2 groups based off the peak force data obtained during the 120° isometric squat test. Significant
3 reductions ($p < 0.05$) in asymmetry were noted for the weaker group in both isometric
4 conditions (90° = 4.60 to 3.95%; 120° = 3.91 to 1.89%), with no changes noted for the
5 stronger group. It should be noted however, that the stronger group's asymmetry scores were
6 lower (1.89-2.23%) than their weaker counterparts to begin with. In addition, all asymmetry
7 values were reported as $< 5\%$ prior to the start of the intervention, indicating minimal
8 between-limb differences regardless of force capabilities. Notwithstanding, it would appear
9 that bilateral back squat training could be considered as a viable method to reduce inter-limb
10 asymmetries; potentially being more effective for weaker subjects.

11 Sannicandro et al. (30) devised a 6-week balance training intervention performed twice a
12 week to reduce asymmetries as measured by a single leg hop and lateral hop for distance and
13 a 4m side-side-forward CODS test in youth tennis players. The intervention was comprised of
14 unilateral and bilateral strengthening exercises (such as step ups and bodyweight squats on a
15 bosu ball), and jumping-based exercises (such as forward and diagonal bounds). The
16 strengthening exercises focused primarily on challenging balance through the use of
17 instability aids such as bosu balls and 'skimmy cushions'. Results showed that the
18 intervention group significantly ($p < 0.05$) reduced asymmetries for all tests (single leg hop =
19 9.0 to 3.7%; lateral hop = 10.8 to 3.2%; CODS = 7.2 to 2.7%), with the control group
20 demonstrating no changes from baseline testing. These data indicate that a combination of
21 unilateral and bilateral strengthening and jumping-based exercises performed for short
22 durations (all of which challenge stability) are an effective method for reducing between-limb
23 differences. However, the results of this study should be interpreted with caution. A
24 combination of unilateral and bilateral exercises and both strengthening and jumping-based
25 exercises were used; thus, it is not possible to make a clear distinction as to which mode of

1 training was more effective. Furthermore, no data were included to report the typical error
2 associated with each test. This makes it difficult to determine whether the improvement in
3 asymmetries can be considered real (whereby the percentage change is greater than the error
4 in the test). Given the high degree of variability previously acknowledged during testing
5 protocols (26,33); this is an essential aspect of interpreting performance change in respect to
6 asymmetries (6). Finally, changes in performance were also tested via acceleration and
7 CODS tests, with no changes noted post-intervention. As such, it would appear that
8 minimising asymmetries via a balance training programme does not positively impact speed
9 or CODS in youth tennis athletes. Given the previously recognised relationship between
10 lower body strength and speed and CODS (27,36), training interventions would arguably be
11 better served focusing on developing strength and power to enhance locomotive qualities.

12 Iacono et al. (19) also used an intervention and control group to detect changes in peak
13 ground reaction forces during a SLCMJ after a 6-week training intervention. However, the
14 programme's focus was primarily on training the core musculature and included exercises
15 such as superman's, quadrupeds and seated twists twice a week, 20 minutes per session. It
16 should be noted that additional exercises such as walking lunges and Nordics were also
17 included; not traditionally categorised as 'core training'. Results again favoured the
18 intervention group with ground reaction force asymmetries reducing from 5.4 to 1.6%,
19 compared to an increase from 4.8 to 7.2% for the control group. With the typical error of the
20 jump test reported at 1.96% and an intraclass correlation coefficient range of 0.93-0.98, the
21 changes in asymmetry (2.8% reduction for the intervention group, and 2.4% increase for the
22 control group) can be considered real. However, results should again be interpreted with
23 caution. It could be argued that the lower body exercises would have had a larger effect on
24 reducing asymmetries than the core training, especially considering between-limb differences
25 were measured during a unilateral jump test and core stability has previously been

1 highlighted to have a negligible effect on performance (9,31). Therefore, these data do not
2 provide sufficient support to indicate core training as a primary method to reduce inter-limb
3 asymmetries, but may suggest that developing lower body strength is most pertinent. Further
4 research is warranted focusing purely on trunk exercises and how these impact asymmetries
5 of the trunk itself.

6 More recently, Gonzalo-Skok et al. (12) compared unilateral vs. bilateral strength and power
7 training programmes to determine changes in maximal power asymmetry during a unilateral
8 squat test. Both training programmes were conducted twice a week for six weeks, and
9 involved either bilateral or unilateral squats, CMJ's and drop jumps, dependent on which
10 group subjects were assigned to. With asymmetries quantified via the unilateral squat test
11 only, it is unsurprising to note that these reductions were greater in the unilateral training
12 group (9.6 to 4.8%) compared to the bilateral group (6.9 to 4.4%). These changes represented
13 a moderate effect size (> 0.6) in favour of unilateral training for reducing inter-limb
14 asymmetries in power. In addition, seven speed and CODS tests were also included as part of
15 the fitness testing battery with standardised differences (represented by effect sizes)
16 portraying greater improvements from the unilateral training group. Based on the results of
17 this study, it could initially be suggested that unilateral training is superior to bilateral
18 training at reducing inter-limb asymmetries and may also have a more positive effect on
19 speed and CODS performance as well (12). However, it should be acknowledged that
20 asymmetries (in power) were measured during a unilateral squat test which will not provide
21 an accurate assessment of power and is also further compromised by the added instability
22 which may not allow a true examination of an athlete's strength capabilities. Furthermore,
23 power was quantified via a linear encoder measuring displacement (and thus velocity) with
24 no direct measurement of force; therefore, larger magnitudes of error in results may be
25 possible due to the double-differentiation method required to derive power. Secondly, the rear

1 foot elevated split squat exercise used is not truly unilateral, thereby substantial contributions
2 from the support leg are almost certain. Finally, the typical error of the test was not reported;
3 thus, any percentage improvement could still have been of a lower magnitude than the error
4 present within the test.

5 Finally, Brown et al. (8) conducted a case study ($N = 1$) whereby a unilateral strength and
6 'high velocity' training programme was designed to specifically target the weaker limb only
7 (previously identified) in addition to the regular bilateral strength regime being undertaken.
8 Each week consisted of exercises such as unilateral Romanian deadlifts, hip thrusts and pistol
9 squats for strength, and banded kickbacks, single leg triple bounds and split squat jumps to
10 target high velocity. Consequently, the weaker limb showed a 26% increase in horizontal
11 force (effect size = 2.2); however, it was reported that changes for the stronger limb were
12 'unclear'. From an asymmetry perspective, post-intervention testing demonstrated a reduction
13 in horizontal force asymmetry measured during sprinting, from 16 to 13% (effect size = -0.65)
14 (8). To the authors' knowledge, this is the first study of its kind to incorporate a
15 supplementary training programme for the weaker limb only in an attempt to reduce inter-
16 limb differences. Although results demonstrate a reduction in asymmetry, readers should
17 interpret these findings with caution given it remains unclear as to the effect this training
18 intervention had on the stronger limb. Furthermore, the individual nature of these results
19 cannot be ignored; thus, further research with similar methodologies and larger sample sizes
20 is warranted before sound conclusions can be drawn.

21 Cumulatively, the available evidence indicates that both unilateral and bilateral training could
22 be considered effective at reducing inter-limb differences. However, given that some studies
23 have failed to report variability data, it is difficult to quantify whether these changes can be
24 considered real. Furthermore, not all of the aforementioned studies have related their findings
25 to a measurable performance outcome; thus, it becomes challenging to justify whether

1 reducing inter-limb asymmetries is fully required. Given the inconsistencies in the available
2 body of evidence, further interventions are warranted.

3

4 **CONSIDERATIONS FOR DECIDING WHETHER OR NOT TO TRAIN ATHLETES** 5 **TO REDUCE ASYMMETRIES**

6 Intuitively, if notable inter-limb asymmetries are evident when testing athletes, it seems
7 logical that these may be considered as ‘undesirable’ and coaches would plan interventions to
8 minimise these differences. However, Sannicandro et al. (30) employed speed and change of
9 direction speed tests post-intervention to determine if correcting inter-limb differences had an
10 impact on the physical performance of youth tennis players. Despite notable reductions in
11 asymmetries (discussed earlier), performance remained unchanged for the change of direction
12 speed test and 10 or 20m sprints. In contrast, the intervention by Brown et al. (8) resulted in
13 moderate and very large improvements in maximal velocity ($5.86 \rightarrow 6.01 \text{ m}\cdot\text{sec}^{-1}$, $ES = 0.67$)
14 and maximal power ($18 \rightarrow 21 \text{ W}\cdot\text{kg}^{-1}$, $ES = 3.2$). Thus, with limited data and conflicting
15 findings, further research is warranted to determine if minimising inter-limb differences
16 results in improved physical performance (7).

17 Secondly, the issue of acute changes in motor control must be considered. For example, if a
18 coach works with a sprint hurdler, it would not be uncommon to use unilateral jump testing
19 during a fitness testing battery (28) given the nature of the event. In this hypothetical example,
20 the athlete is in an Olympic year, only a few months away from competing. The athlete’s lead
21 leg is their right and it is noted that this limb scores a jump height of 36 cm whereas the trail
22 limb scores 40 cm, resulting in an asymmetry of 10%. It is perhaps instinctive to think that
23 this should be corrected; however, the coach must understand that this has the potential to
24 alter motor control as the athlete learns how to integrate new levels of power into their
25 hurdling technique, potentially reducing performance acutely. In this case, the coach must

1 decide if the identified asymmetry is a problem or not and if attempting to 'fix' the imbalance
2 such as this in a non-injured athlete is something that should occur so close to the most
3 important stage in an athlete's career, especially when repercussions are possible that may
4 detrimentally impact performance.

5 Further considerations should also be applied in the context of injury risk. Gray et al. (14)
6 investigated how the symmetry of the abdominal muscles related to lower back pain in 25
7 adolescent cricket fast bowlers (16 with and 9 without pain). Ultrasound imaging of the
8 internal/external oblique's and transverse abdominus muscles was conducted on both the
9 dominant and non-dominant sides. Interestingly, the combined thickness of the tested
10 muscles was significantly greater ($p = 0.02$) on the non-dominant side for fast bowlers
11 without lower back pain, but also, symmetrical for bowlers with pain (14). Thus, the
12 asymmetry seen in the abdominal muscles of cricket fast bowlers is likely a product of the
13 asymmetrical action seen in bowling, a notion which has been reported in other sports (16).
14 Therefore, coaches should be mindful that it may not always be in an athlete's interest to
15 rectify side to side differences via targeted training interventions as these are adaptations
16 required to perform their sport.

17 Cumulatively, it is recommended that practitioners critically evaluate the context in which
18 interventions planned to target asymmetries are applied and caution should be taken before
19 commencing any training programme to ensure it is in the athlete's best interest considering
20 some of the factors discussed here.

21

22 **PRACTICAL APPLICATION**

23 Naturally, all training programmes should retain specificity to the aims of each mesocycle
24 and needs of the athlete; however, for the purpose of this article the training programmes
25 included (Tables 2 and 3) will refer to a hypothetical example, an elite male soccer athlete.

1 The programmes have been constructed for an athlete exhibiting > 10% inter-limb differences
2 in vertical ground reaction force during the landing phase of a SLCMJ and two programmes
3 have been included to demonstrate variety when correcting these imbalances. It should be
4 noted that the focus of the programmes are to reduce inter-limb asymmetries during eccentric
5 muscle actions given their association with injury occurrence (23) and to concurrently
6 enhance strength and power due to their importance for successful soccer performance
7 (13,32,34,35). Furthermore, it is plausible that different asymmetry thresholds exist
8 dependent on the test selected. For example, inter-limb differences in peak force of 6.6-8%
9 were shown to have a detrimental effect on jump performance (1) and kicking accuracy (16).
10 However, when jump tests are considered, asymmetries in peak power and jump height of
11 ~10% appear to have minimal effect on CODS performance (18,24). Therefore, for the
12 purpose of this hypothetical scenario, asymmetries > 10% have been proposed. Whilst this
13 may not always occur when testing athletes, the example used here allows practitioners to see
14 how traditional training programmes (inclusive of predominantly bilateral-based exercises)
15 can be manipulated in order to still meet the demands of the athlete; specifically, increasing
16 the focus on unilateral exercises to address between-limb differences identified during testing.

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18 *** INSERT TABLES 2-3 ABOUT HERE ***

19

20 **CONCLUSION**

21 Considering the potential negative effects of asymmetry on injury risk and physical
22 performance, practitioners may wish to manipulate training programmes to reduce these side
23 to side differences. Bilateral and unilateral strength and plyometric training, balance and core
24 training have all been used to successfully reduce inter-limb differences. However, it would
25 appear that based on the limited body of evidence available, the majority of studies have

1 failed to compare percentage reductions in asymmetry to the variability or error of the
2 associated tests. The implications of this are that practitioners will not be able to determine
3 with confidence if asymmetry reductions are real; thus, variability must always be considered
4 when quantifying inter-limb differences. Therefore, further research is warranted that
5 accounts for the aforementioned factor when comparing different training modalities for the
6 reduction of inter-limb asymmetries.

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Table 1: Overview of methods, outcome measures and results from six studies that have undertaken an intervention to reduce inter-limb asymmetries

Reference	Subjects	Methods	Outcome Measures	Asymmetry % Change
Bazyler et al. (4)	<i>N</i> = 16 Recreationally trained males	2 groups (strong vs. weak) based off 120° peak force data. 7-week periodized back squat programme	Peak force symmetry index at 90 and 120° knee angles	Strong group: 120° = 1.89 → 2.22%; 90° = 2.23 → 2.58% Weak group: 120° = 3.91 → 1.89%; 90° = 4.60 → 3.95%
Sannicandro et al. (30)	<i>N</i> = 23 Youth tennis players	2 groups (EG vs. CG) 2 x 30-minute sessions per week for 6 weeks for the EG	Single leg hop for distance, lateral hop for distance, 4m-SSF test	Experimental Group: SLH = 9.0 → 3.7%; LHD = 13.2 → 13.0%; 4m-SSF = 10.1 → 12.9% Control Group: SLH = 9.0 → 9.3%; LHD = 10.8 → 3.2%; 4m-SSF = 7.2 → 2.7%
Iacono et al. (19)	<i>N</i> = 20 Male football players	2 groups (EG vs. CG) 2 x 20-minute sessions per week for 6 weeks for the EG	Peak vertical ground reaction force during the SLCMJ	Experimental Group: 5.4 → 1.6% (ES = 2.01) Control Group: 4.8 → 7.2% (ES = 1.28)

Gonzalo-Skok et al. (12)	N = 22 Youth male basketball players	UNI vs. BI training groups 2 training sessions/week for 6 weeks UNI: 3 sets of RFESS (reps stopped when power fell < 10% of maximal power), 2 x 5 for SLCMJ and SLDJ BI: 3 sets of RFESS (reps stopped when power fell < 10% of maximal power), 2 x 5 for CMJ and DJ	Maximum power (determined via a linear encoder) measured during a RFESS	UNI: 9.6 → 4.8% BI: 6.9 → 4.4%
Brown et al. (8)	N = 1 (case study) Male rugby union player	Weeks 1-6: 'control block' with bilateral strength training prescribed 3x per week Weeks 7-12: strength training continued with supplementary unilateral strength and high-velocity exercises for the weak limb only	Horizontal force asymmetry (from sprinting)	Changes for stronger limb stated to be 'unclear' Weaker limb: horizontal force asymmetry reduced from 16 → 13% (ES = -0.65)
IKT = isokinetic training; ITT = isotonic training; R = right leg; L = left leg; EG = experimental group; CG = control group; SLH = single leg hop for distance; LHD = lateral hop for distance; 4m-SSF = 4 metres side step and forward; SLCMJ = single leg countermovement jump; ES =				

effect size; UNI = unilateral; BI = bilateral; RFESS = rear foot elevated split squat; SLDJ = single leg drop jump

Table 2: Example training programme aiming to reduce inter-limb asymmetries > 10% in landing force from a SLCMJ for an elite soccer player

Lift/Exercise	Sets	Repetitions	Load	Rest
Back squat	3	5	85% 1RM	4 mins
Single leg hop (for distance)	3	4 each limb	-	Do in rest
R.F.E.S.S	3	6 each limb	80% 1RM	3 mins
Single leg RDL	3	6 each limb	1 x DB/KB	2 mins
Kneeling cable wood-chop	2	10 each side	Light	-
Barbell rollouts	2	10	-	2 mins
RM = Repetition maximum; DB = Dumbbell; KB = Kettlebell; R.F.E.S.S = Rear foot elevated split squat; RDL = Romanian deadlift				

Table 3: Example training programme aiming to reduce inter-limb asymmetries > 10% in landing force from a SLCMJ for an elite soccer player

Lift/Exercise	Sets	Repetitions	Load	Rest
Barbell split squat	3	5 each limb	85% 1RM	4 mins
Triple hop (for distance)	3	3 each limb	-	Do in rest
Push Press	3	5	85% 1RM	3 mins
Nordics	3	5	-	2 mins
Standing cable rotations	2	10 each side	Light	-
Lateral pillar (with cable row)	2	10 each side	-	2 mins
RM = Repetition maximum; DB = Dumbbell; KB = Kettlebell; R.F.E.S.S = Rear foot elevated split squat; RDL = Romanian deadlift				