
Final accepted version (with author’s formatting)

This version is available at: http://eprints.mdx.ac.uk/23040/

Copyright:

Middlesex University Research Repository makes the University's research available electronically. Copyright and moral rights to this work are retained by the author and/or other copyright owners unless otherwise stated. The work is supplied on the understanding that any use for commercial gain is strictly forbidden. A copy may be downloaded for personal, non-commercial, research or study without prior permission and without charge.

Works, including theses and research projects, may not be reproduced in any format or medium, or extensive quotations taken from them, or their content changed in any way, without first obtaining permission in writing from the copyright holder(s). They may not be sold or exploited commercially in any format or medium without the prior written permission of the copyright holder(s).

Full bibliographic details must be given when referring to, or quoting from full items including the author's name, the title of the work, publication details where relevant (place, publisher, date), pagination, and for theses or dissertations the awarding institution, the degree type awarded, and the date of the award.

If you believe that any material held in the repository infringes copyright law, please contact the Repository Team at Middlesex University via the following email address:

eprints@mdx.ac.uk

The item will be removed from the repository while any claim is being investigated.

See also repository copyright: re-use policy: http://eprints.mdx.ac.uk/policies.html#copy
TRAINING METHODS AND CONSIDERATIONS FOR
PRACTITIONERS TO REDUCE INTER-LIMB ASYMMETRIES

AUTHORS:
Chris Bishop¹ (MSc), Anthony Turner¹ (PhD, CSCS*D) and Paul Read² (PhD, CSCS*D)

AFFILIATIONS:
1. School of Science and Technology, London Sports Institute, Middlesex University, London, UK
2. Athlete Health and Performance Research Centre, Aspetar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

CORRESPONDENCE:
Name: Chris Bishop
Email: C.Bishop@mdx.ac.uk
Address: 6 Linden Rise, Warley, Brentwood, Essex, UK
ABSTRACT

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

Key Words: Inter-limb differences, imbalances, symmetry
INTRODUCTION

The concept of inter-limb asymmetries has been widely investigated in the literature to date and refers to the performance of one limb with respect to the other (2,5,20,21). To date, the majority of literature has highlighted the prevalence of inter-limb differences across a range of tasks and physical competencies (2,8,12,15,16,30), rather than focusing on whether these differences have a measurable effect on physical or sporting performance (6,7). For those that have, asymmetries have primarily been quantified during strength and jumping tasks.

Intuitively, practitioners may consider that notable differences between limbs are detrimental to performance; however, few studies have examined if this is actually the case (1,8,16,18,25). Inter-limb differences in strength of ~6-8% have been shown to be negatively associated with jump performance (1), and sport-specific skills such as kicking accuracy (16). However, when inter-limb differences are quantified from a variety of unilateral jumping tasks findings are equivocal. Differences in peak power quantified from single leg countermovement jumps (SLCMJ) or jump height from single leg drop jumps (SLDJ) have suggested that imbalances ~10% are detrimental to change of direction speed (CODS) performance (18,25). In contrast, asymmetries in jump height and distance reported from multi-planar unilateral jumps as high as 11.4% have indicated no detrimental effects on linear speed and CODS tasks (10,22); thus, it is challenging to draw sound conclusions from the available body of evidence (7). Similarly, previous research has highlighted discrepancies surrounding asymmetries and injury risk. A threshold of 15% has been suggested to increase injury risk when identified during a variety of hop tests (3,15,20), whereas asymmetries < 10% have been proposed as a target during rehabilitation (23,29). Given these inconsistencies, specific thresholds associated with heightened risk should be interpreted with caution as there is currently an absence of prospective data pertaining to asymmetry and injury incidence. Despite these inconsistencies, practitioners may wish to monitor inter-limb differences to ensure that they never grow
beyond what may be deemed a ‘high risk threshold’. Consequently, it would appear that physical performance may be hindered and injury risk increased if inter-limb differences are not addressed; thus, specific approaches that target reductions in asymmetry are warranted.

With that in mind, a number of studies have reported how inter-limb asymmetries have changed following a targeted training intervention (4,8,11,12,19,30). This article will provide an overview of the available literature and suggest evidence-based methods to reduce inter-limb differences. A range of considerations have also been included where practitioners should think critically to determine if asymmetries are problematic or not for some athletes, and the potential effects that reducing these differences may have on both sports performance and injury risk. Finally, a hypothetical example has been included to illustrate how an athlete who displays inter-limb differences in strength and power during physical performance testing could be trained to address these imbalances.

**TRAINING TO REDUCE INTER-LIMB ASYMMETRIES**

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

*** INSERT TABLE 1 ABOUT HERE ***

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

Sannicandro et al. (30) devised a 6-week balance training intervention performed twice a
week to reduce asymmetries as measured by a single leg hop and lateral hop for distance and
a 4m side-side-forward CODS test in youth tennis players. The intervention was comprised of
unilateral and bilateral strengthening exercises (such as step ups and bodyweight squats on a
bosu ball), and jumping-based exercises (such as forward and diagonal bounds). The
strengthening exercises focused primarily on challenging balance through the use of
instability aids such as bosu balls and ‘skimmy cushions’. Results showed that the
intervention group significantly ($p < 0.05$) reduced asymmetries for all tests (single leg hop =
9.0 to $3.7\%$; lateral hop = 10.8 to $3.2\%$; CODS = 7.2 to $2.7\%$), with the control group
demonstrating no changes from baseline testing. These data indicate that a combination of
unilateral and bilateral strengthening and jumping-based exercises performed for short
durations (all of which challenge stability) are an effective method for reducing between-limb
differences. However, the results of this study should be interpreted with caution. A
combination of unilateral and bilateral exercises and both strengthening and jumping-based
exercises were used; thus, it is not possible to make a clear distinction as to which mode of
training was more effective. Furthermore, no data were included to report the typical error associated with each test. This makes it difficult to determine whether the improvement in asymmetries can be considered real (whereby the percentage change is greater than the error in the test). Given the high degree of variability previously acknowledged during testing protocols (26,33); this is an essential aspect of interpreting performance change in respect to asymmetries (6). Finally, changes in performance were also tested via acceleration and CODS tests, with no changes noted post-intervention. As such, it would appear that minimising asymmetries via a balance training programme does not positively impact speed or CODS in youth tennis athletes. Given the previously recognised relationship between lower body strength and speed and CODS (27,36), training interventions would arguably be better served focusing on developing strength and power to enhance locomotive qualities.

Iacono et al. (19) also used an intervention and control group to detect changes in peak ground reaction forces during a SLCMJ after a 6-week training intervention. However, the programme’s focus was primarily on training the core musculature and included exercises such as superman’s, quadrupeds and seated twists twice a week, 20 minutes per session. It should be noted that additional exercises such as walking lunges and Nordics were also included; not traditionally categorised as ‘core training’. Results again favoured the intervention group with ground reaction force asymmetries reducing from 5.4 to 1.6%, compared to an increase from 4.8 to 7.2% for the control group. With the typical error of the jump test reported at 1.96% and an intraclass correlation coefficient range of 0.93-0.98, the changes in asymmetry (2.8% reduction for the intervention group, and 2.4% increase for the control group) can be considered real. However, results should again be interpreted with caution. It could be argued that the lower body exercises would have had a larger effect on reducing asymmetries than the core training, especially considering between-limb differences were measured during a unilateral jump test and core stability has previously been
highlighted to have a negligible effect on performance (9,31). Therefore, these data do not provide sufficient support to indicate core training as a primary method to reduce inter-limb asymmetries, but may suggest that developing lower body strength is most pertinent. Further research is warranted focusing purely on trunk exercises and how these impact asymmetries of the trunk itself.

More recently, Gonzalo-Skok et al. (12) compared unilateral vs. bilateral strength and power training programmes to determine changes in maximal power asymmetry during a unilateral squat test. Both training programmes were conducted twice a week for six weeks, and involved either bilateral or unilateral squats, CMJ’s and drop jumps, dependent on which group subjects were assigned to. With asymmetries quantified via the unilateral squat test only, it is unsurprising to note that these reductions were greater in the unilateral training group (9.6 to 4.8%) compared to the bilateral group (6.9 to 4.4%). These changes represented a moderate effect size (> 0.6) in favour of unilateral training for reducing inter-limb asymmetries in power. In addition, seven speed and CODS tests were also included as part of the fitness testing battery with standardised differences (represented by effect sizes) portraying greater improvements from the unilateral training group. Based on the results of this study, it could initially be suggested that unilateral training is superior to bilateral training at reducing inter-limb asymmetries and may also have a more positive effect on speed and CODS performance as well (12). However, it should be acknowledged that asymmetries (in power) were measured during a unilateral squat test which will not provide an accurate assessment of power and is also further compromised by the added instability which may not allow a true examination of an athlete’s strength capabilities. Furthermore, power was quantified via a linear encoder measuring displacement (and thus velocity) with no direct measurement of force; therefore, larger magnitudes of error in results may be possible due to the double-differentiation method required to derive power. Secondly, the rear
foot elevated split squat exercise used is not truly unilateral, thereby substantial contributions from the support leg are almost certain. Finally, the typical error of the test was not reported; thus, any percentage improvement could still have been of a lower magnitude than the error present within the test.

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

Cumulatively, the available evidence indicates that both unilateral and bilateral training could be considered effective at reducing inter-limb differences. However, given that some studies have failed to report variability data, it is difficult to quantify whether these changes can be considered real. Furthermore, not all of the aforementioned studies have related their findings to a measurable performance outcome; thus, it becomes challenging to justify whether
reducing inter-limb asymmetries is fully required. Given the inconsistencies in the available body of evidence, further interventions are warranted.

CONSIDERATIONS FOR DECIDING WHETHER OR NOT TO TRAIN ATHLETES TO REDUCE ASYMMETRIES

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

Secondly, the issue of acute changes in motor control must be considered. For example, if a coach works with a sprint hurdler, it would not be uncommon to use unilateral jump testing during a fitness testing battery (28) given the nature of the event. In this hypothetical example, the athlete is in an Olympic year, only a few months away from competing. The athlete’s lead leg is their right and it is noted that this limb scores a jump height of 36 cm whereas the trail limb scores 40 cm, resulting in an asymmetry of 10%. It is perhaps instinctive to think that this should be corrected; however, the coach must understand that this has the potential to alter motor control as the athlete learns how to integrate new levels of power into their hurdling technique, potentially reducing performance acutely. In this case, the coach must
decide if the identified asymmetry is a problem or not and if attempting to ‘fix’ the imbalance such as this in a non-injured athlete is something that should occur so close to the most important stage in an athlete’s career, especially when repercussions are possible that may detrimentally impact performance.

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

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

**PRACTICAL APPLICATION**

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

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

CONCLUSION

Considering the potential negative effects of asymmetry on injury risk and physical performance, practitioners may wish to manipulate training programmes to reduce these side to side differences. Bilateral and unilateral strength and plyometric training, balance and core training have all been used to successfully reduce inter-limb differences. However, it would appear that based on the limited body of evidence available, the majority of studies have
failed to compare percentage reductions in asymmetry to the variability or error of the associated tests. The implications of this are that practitioners will not be able to determine with confidence if asymmetry reductions are real; thus, variability must always be considered when quantifying inter-limb differences. Therefore, further research is warranted that accounts for the aforementioned factor when comparing different training modalities for the reduction of inter-limb asymmetries.
REFERENCES


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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Subjects</th>
<th>Methods</th>
<th>Outcome Measures</th>
<th>Asymmetry % Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bazyler et al. (4)</td>
<td>N = 16&lt;br&gt;Recreationally trained males</td>
<td>2 groups (strong vs. weak)&lt;br&gt;based off 120° peak force data.&lt;br&gt;7-week periodized back squat programme</td>
<td>Peak force symmetry index at 90 and 120° knee angles</td>
<td>Strong group: 120° = 1.89 → 2.22%; 90° = 2.23 → 2.58%&lt;br&gt;Weak group: 120° = 3.91 → 1.89%; 90° = 4.60 → 3.95%</td>
</tr>
<tr>
<td>Sannicandro et al. (30)</td>
<td>N = 23&lt;br&gt;Youth tennis players</td>
<td>2 groups (EG vs. CG)&lt;br&gt;2 x 30-minute sessions per week for 6 weeks for the EG</td>
<td>Single leg hop for distance, lateral hop for distance, 4m-SSF test</td>
<td>Experimental Group: SLH = 9.0 → 3.7%; LHD = 13.2 → 13.0%; 4m-SSF = 10.1 → 12.9%&lt;br&gt;Control Group: SLH = 9.0 → 9.3%; LHD = 10.8 → 3.2%; 4m-SSF = 7.2 → 2.7%</td>
</tr>
<tr>
<td>Iacono et al. (19)</td>
<td>N = 20&lt;br&gt;Male football players</td>
<td>2 groups (EG vs. CG)&lt;br&gt;2 x 20-minute sessions per week for 6 weeks for the EG</td>
<td>Peak vertical ground reaction force during the SLCMJ</td>
<td>Experimental Group: 5.4 → 1.6% (ES = 2.01)&lt;br&gt;Control Group: 4.8 → 7.2% (ES = 1.28)</td>
</tr>
<tr>
<td>Study</td>
<td>Sample Size</td>
<td>Description</td>
<td>Training Schedule</td>
<td>Measurement</td>
</tr>
<tr>
<td>-------</td>
<td>-------------</td>
<td>-------------</td>
<td>-------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Gonzalo-Skok et al. (12)</td>
<td>N = 22 Youth male basketball players</td>
<td>UNI vs. BI training groups</td>
<td>2 training sessions/week for 6 weeks</td>
<td>Maximum power (determined via a linear encoder) measured during a RFESS</td>
</tr>
<tr>
<td>Brown et al. (8)</td>
<td>N = 1 (case study) Male rugby union player</td>
<td>Weeks 1-6: ‘control block’ with bilateral strength training prescribed 3x per week</td>
<td></td>
<td>Horizontal force asymmetry (from sprinting)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Lift/Exercise</th>
<th>Sets</th>
<th>Repetitions</th>
<th>Load</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back squat</td>
<td>3</td>
<td>5</td>
<td>85% 1RM</td>
<td>4 mins</td>
</tr>
<tr>
<td>Single leg hop (for distance)</td>
<td>3</td>
<td>4 each limb</td>
<td>-</td>
<td>Do in rest</td>
</tr>
<tr>
<td>R.F.E.S.S</td>
<td>3</td>
<td>6 each limb</td>
<td>80% 1RM</td>
<td>3 mins</td>
</tr>
<tr>
<td>Single leg RDL</td>
<td>3</td>
<td>6 each limb</td>
<td>1 x DB/KB</td>
<td>2 mins</td>
</tr>
<tr>
<td>Kneeling cable wood-chop</td>
<td>2</td>
<td>10 each side</td>
<td>Light</td>
<td>-</td>
</tr>
<tr>
<td>Barbell rollouts</td>
<td>2</td>
<td>10</td>
<td>-</td>
<td>2 mins</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Lift/Exercise</th>
<th>Sets</th>
<th>Repetitions</th>
<th>Load</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbell split squat</td>
<td>3</td>
<td>5 each limb</td>
<td>85% 1RM</td>
<td>4 mins</td>
</tr>
<tr>
<td>Triple hop (for distance)</td>
<td>3</td>
<td>3 each limb</td>
<td>-</td>
<td>Do in rest</td>
</tr>
<tr>
<td>Push Press</td>
<td>3</td>
<td>5</td>
<td>85% 1RM</td>
<td>3 mins</td>
</tr>
<tr>
<td>Nordics</td>
<td>3</td>
<td>5</td>
<td>-</td>
<td>2 mins</td>
</tr>
<tr>
<td>Standing cable rotations</td>
<td>2</td>
<td>10 each side</td>
<td>Light</td>
<td>-</td>
</tr>
<tr>
<td>Lateral pillar (with cable row)</td>
<td>2</td>
<td>10 each side</td>
<td>-</td>
<td>2 mins</td>
</tr>
</tbody>
</table>

RM = Repetition maximum; DB = Dumbbell; KB = Kettlebell; R.F.E.S.S = Rear foot elevated split squat; RDL = Romanian deadlift