Journal of Strength and Conditioning Research Publish Ahead of Print
DOI: 10.1519/JSC.0000000000001896

Title Page

Title

A comparison of bilateral muscular imbalance ratio calculations using functional tests.

Running head

Muscular imbalance calculations

Laboratory

Human Performance Laboratory

Authors

Theodoros M. Bampouras, PhD

Susan Dewhurst, PhD

Department

Department of Medical and Sport Sciences

Institution

University of Cumbria

Corresponding author

Theodoros M. Bampouras, University of Cumbria, Department of Medical and Sport Sciences, Bowerham road, Lancaster LA1 3JD, Lancashire, United Kingdom / +44 1524 590837 / theodoros.bampouras@cumbria.ac.uk

Abstract

Bilateral muscular imbalance can increase the risk of injury and negatively impact sporting performance. Bilateral muscular imbalances are typically calculated as ((side 1-side 2)/reference value) x 100, to provide a percentage value of the difference between limbs. Using different numerator (right-left or strong-weak) or reference values (left, right, strong, weak, average of the two) could mask or inflate the true difference value. The present study aimed to compare the bilateral muscular imbalance ratio calculations, using the absolute difference between limbs as the numerator and the five different options as reference values. Twenty three males (21.6±1.9 years, 1.80±0.06 m, 80.5±13.8 kg) and eleven females (20.8± 1.5 years, 1.62±0.03 m, 68.0±6.5 kg) performed the one-legged 6m timed test and the onelegged triple hop distance test. The five possible combinations were compared with a 2 (gender) x 2 (functional test) x 5 (calculation method) ANOVA for each test. Significant differences ($P<0.05$) were found between gender when the right leg was used as the reference value (males:6.1%, females:9.1%), and within calculation methods for males (range:5.9%-6.5%) and females (range:8.4%-9.4%), with low effect sizes (range: 0.07-0.26). The present findings demonstrate that using a different reference value for calculating bilateral muscular imbalances does not result in a practically significant difference. These findings can be used to inform a more standardised calculation method which will afford conditioning coaches a more correct evaluation and monitoring of training and rehabilitation programmes.

Keywords:
bilateral difference, injury, isokinetic dynamometry, lower limb asymmetry, muscular balance, performance

INTRODUCTION

Substantial deviation from normative data of muscle performance differences between limbs is referred to as bilateral muscular imbalance (21). This bilateral muscular imbalance may be the result of side preference, injury or specific sport demands (14,18), and can consequently increase the risk of injury (6,12,13,16). For example, bilateral muscular imbalances have been associated with higher anterior cruciate ligament injury risk in females (6,13) and elite ski racers (11) as well as increased risk for lower back pain (14). In a prospective study, Croiser et al (3) showed that professional male football players with untreated bilateral muscular imbalances were four times as likely to sustain a hamstring injury.

Further, bilateral muscular imbalances could also have an impact on various mechanical aspects and, consequently, on the relevant strength quality of the lower limbs, subsequently affecting performance (4,9,11,22). For example, it was suggested that athletes turned faster in change-of-direction tests when they were pushing off their dominant leg, with this dominance affecting overall performance (22). Further, the weaker leg applied less force during a countermovement jump (9), altering the pattern of force application and reducing the impulse (11), resulting in lower jump height. Such situations can negatively impact on the athlete's performance, due to reduced ability to turn fast or jump high.

Muscular imbalances are typically calculated as ((side 1-side 2)/reference value) x 100 [Eq. 1], to provide a percentage value of the difference between limbs. However discrepancy occurs with the values that are inserted into the equation (1). When defining side 1 and side 2, for example, researchers have reported using right and left (e.g. 15,17), stronger and weaker (e.g. 10,14), and self-reported preferred and non-preferred, for side 1 and 2, respectively (e.g.

4,18). In addition to the definition of side 1 and side 2, the selection of the reference value (right or left, strong or weak, preferred or non-preferred limb or simply an average between the two limbs) might also impact on the results (23). It is worth pointing out that 'strong' and 'weak' have been used to refer to the limb with the better (strong) or worse (weak) performance; the actual performance might be a power-based and not a strength-based per se (e.g. 10). Concernedly, use of different values in the calculations could mask or inflate the true bilateral muscular imbalance value, potentially making it difficult for practitioners to determine whether an athlete is at a higher injury risk, or whether their rehabilitation or training programme is working to reduce the strength deficit (1).

Thus, it is important to determine experimentally whether different calculations can produce significantly different results. Hence, the aim of the present study was to compare five different muscular imbalance ratio calculations (numerator: absolute difference between limbs, denominator: right, left, strong, weak, average of the two) using two functional tests. Although literature has previously also used preferred side (e.g. 4,18), no calculation was specifically used for those values in the present study, as non / preferred will be either on the right / left or strong / weak limb, and the exclusion of non / preferred selection prevents repetition . Functional tests were chosen over isokinetic dynamometry assessment, due to their practicality and affordability in testing larger groups as well as kinematic resemblance to sporting movements (10).

METHODS

Experimental approach to the problem

The study was designed to compare the different bilateral muscular imbalance calculations obtained by using the absolute difference value between limbs as the numerator and right, left, weak, strong, or average of the two limbs as the reference value in the bilateral muscular imbalance calculation ((side 1-side 2)/reference value) x 100. This was done for two functional tests, the triple hop and the 6m timed hop, as the two tests place different performance focus on the lower extremity (minimum time v maximum distance) (19). Bilateral muscular imbalances (as per the equation above) were calculated in all possible 5 combinations, which were then compared for differences between sexs and functional tests.

Subjects

Twenty three males (mean ± SD: age 21.6 ± 1.9 years (range 19 – 24 years), height 1.80 ± 0.06 m, body mass 80.5 ± 13.8 kg) and eleven females (mean ± SD: age 20.8 ± 1.5 years (range 19 – 23 years), height 1.62 ± 0.03 m, body mass 68.0 ± 6.5 kg) took part in the study. They were all competitive, team game players and free of any injuries for at least 6 months prior to testing. The sports the subjects participated in were, for males, football (n = 12), rugby union (n = 9), basketball (n = 2) and for females hockey (n=6) and netball (n = 5). The study was approved by the Institutional Ethics Committee and written informed consent was obtained from all subjects.

Procedures

All participants were familiarised with the testing procedures on a session prior to testing (2). Testing took place on a single occasion at the same time for all participants. Participants were asked to refrain from strenuous exercise forty eight hours prior to testing and to avoid food or caffeine intake for two hours prior to testing. For all tests, two trials were performed on each limb and if the coefficient of variation was above 5% (8), a third test was performed; this only happened on three occasions. To reduce order bias, the order of which limb was used to perform each test and the test executed was counterbalanced. The average score of the two trials (or the closest two trials, in case of more than two trials) was used for subsequent analysis.

Participants were required to complete both the one-legged 6m timed test (6m hop) and the one-legged triple hop distance test (3hop) (19). The 6m hop test requires participants to stand with their toes just behind a starting line and hop as quickly as possible (on the same leg) over a marked distance of 6m with large, forceful pushes. Participants were allowed to start on their own time and time taken to cover that distance was recorded. Time was measured using infrared timing gates (Brower Timing, Utah) aligned at the starting and finishing lines, set at hip height. The 3hop test requires the participants to perform three consecutive hops on the same leg aiming for maximum distance. Participants' toes were immediately behind the zero mark of a measuring tape and the distance covered was measured as the distance from the zero mark to the point their heels touched the ground following the third hop.

Bilateral muscular imbalance difference was calculated with five different calculations as the absolute difference between the two limbs divided by right, left, weak, strong, or average of the limbs and expressed as a percentage.

Statistical analyses

Normality of data was examined using the Kolmogorov-Smirnov test and confirmed for all variables. A 2 (sex) x 2 (functional test) x 5 (calculation method) ANOVA was used to examine for differences. Homogeneity of variances was examined using Levene's test and confirmed for all variables. Where differences were found between groups, an independent t-test was carried out, while for differences between tests or ratios, dependent t-tests were carried out; all pairwise comparisons were adjusted using the Holm-Bonferroni correction (7). Effect sizes (ES) were calculated for all significant differences, with 0.2, 0.5 and 0.8 representing small, moderate and large effect, respectively (5). All statistical analysis was performed in IBM SPSSv22 (Chicago, Illinois). Significance level was set at $P \leq 0.05$. All data is presented as mean ± SD unless otherwise stated.

RESULTS

The left leg was stronger in 60.9% of the males and 63.6% of the females for the 6m hop, while the left leg was weaker for 47.8% of the males and 45.5% of the females for the 3hop. All descriptive statistics for all tests and calculations for both sexes can be seen in Table 1.

TABLE 1 ABOUT HERE

There was no significant interaction for sex, test and calculation method, test and calculation method, test and sex ($P > 0.05$), but there was a significant interaction of sex and calculation method ($P = 0.002$, partial $\eta^2 = 0.124$). Follow-up analysis revealed that when the calculation method using the right leg as the denominator was used, bilateral muscular imbalance was significantly lower (P = 0.039, ES = 0.76) in males (6.1 ± 3.5%, averaged across the two functional tests) compared to females (9.1 ± 4.6%, averaged across the two functional tests). Finally, significant differences were found between the calculation methods for males (averaged across the two functional tests; Figure 1) and females (averaged across the two functional tests; Figure 2), with small ES however (range: 0.07 – 025).

FIGURE 1 ABOUT HERE

FIGURE 2 ABOUT HERE

DISCUSSION

The aim of the study was to examine the different bilateral muscle imbalance calculations used and, subsequently, the effect they may have on inferences made about an athlete's, patient's or client's bilateral muscular imbalance. The results suggest that, although some differences exist between the bilateral muscular imbalances calculations using different denominator, the small effect sizes and small mean differences (all <1.5%) suggest that these have little practically significant impact. These findings, along with recommendations on which bilateral muscle imbalance calculation methods to use, are discussed further to enable strength and conditioning coaches looking to utilise bilateral muscular imbalance assessment for monitoring purposes to be confident in the results obtained.

Although there is agreement in the literature on the way bilateral muscular imbalances can be calculated, there is a discrepancy on what values are used in that equation (1). For example, studies have previously used left and right (e.g. 15,17) or strong and weak sides (e.g. 10,14) to calculate bilateral muscular imbalances. The present study suggests that results between studies are comparable, as selection of different reference value did not substantially influence the results as suggested by the low effect sizes.

Statistical difference was revealed between sexes for the calculation using the right leg as the denominator. This is somewhat surprising, as no other calculation revealed any sex differences. Further, the patterns of stronger and weaker leg in our sample between the sexes were very similar for both functional tests, thus excluding the possibility of a substantially higher percentage of stronger right leg in one group compared to the other as a potential reason. As no explanation for this finding can be currently offered, it may be a recommendation that the right leg is used as a denominator in studies that want to compare between sex bilateral muscular imbalances, as it was the only one that was able to distinguish between each group's bilateral muscular imbalance.

Further, some statistical differences were found between comparisons, both for males and females. However, these comparisons had low effect sizes, suggesting a potentially low practical significance. Indeed, when one examined the values in Table 1, the differences in bilateral muscular imbalances range from 0.4% - 1.2%. Although what constitutes 'substantial deviation' from normative data is difficult to determine (21), studies have reported a difference of 15% in countermovement jumping (9) performances, as a threshold for substantial deviation between limbs. With this threshold in mind, consider a female athlete performing the 3hop test and having the bilateral imbalance calculated as 9.2% using the strong leg as denominator. By using the weak leg as a denominator, this bilateral muscular imbalance would only increase to 10.4%; given the inherent measurement error it is unlikely the difference in these values would lead to different interpretation of the athlete being 'at risk'. This contradicts our hypothesis that the reference value used in Eq. 1, could impact on the results. Although for standardisation purposes, the same reference value should be used, comparisons between results that have used different numerator (i.e. right, left, weak, strong, or average of the two) should be possible, as little difference would be present from the use of a different reference value.

Using two different tests, 6m hop and 3hop, that had the same overall aim (power, speed, balance, lower limb control) but different emphasis (time v distance) produced comparable results, suggesting that the ultimate aim of each test had no effect on the measured outcome and they assess the same muscle qualities (10). As both are suggested as tests of bilateral muscular imbalance, the results of the present study suggest that using one of them is sufficient to provide bilateral muscular imbalance ratios, thus increasing testing efficiency of large groups. As the 6m hop test is more prone to measurement errors with a stopwatch (2) but more difficult to conduct with timing gates, the use of the triple hop test is recommended.

Functional tests are a practical and easy way to assess bilateral muscular imbalances, with the advantage that they mimic sporting movements, thus providing assessment in a more-sport specific manner, compared to dynamometry (10). However, this type of assessment prevents the identification of specific individual muscle or muscle groups imbalances (10,15). In addition, an element of postural balance is inevitably included in the assessment, as the participant has to balance themselves on their foot before they are able to hurl themselves towards the next hop. As such, and although a large muscular component is included, the results represent more of a 'movement imbalance'. A potential solution can perhaps be the use of functional tests for large group assessment, with the participants recording higher percentage differences undergoing a more thorough dynamometry assessment.

It has been previously reported that different sports yield different bilateral muscle imbalances (e.g. American football (24) and soccer (20)). The convenience sample utilised in the present study did not allow to separate for different sports or positions. However, as the same functional test performance was used for all the difference calculations, this effect should have been minimal and not impacted on the results.

Finally, suggestions have been made (1) to utilise the symmetry angle, proposed by Zifchock et al (23), as a means of achieving a bilateral muscular imbalance score without the need for a reference value (23). The present paper adds to the choices available in bilateral muscular imbalances calculation by offering some practical recommendations for those strength and conditioning coaches, sport therapists or athletic trainers that prefer to continue using more conventional bilateral muscular imbalance calculation methods for e.g. simplicity.

PRACTICAL APPLICATIONS

The present study examined the different bilateral calculation methods by utilising two different functional tests. The results suggest that a) for comparisons between sex, the right leg should be used as the reference value (denominator) in calculations, b) the calculation method (i.e. the different reference value used for the denominator) makes little practical difference when calculating bilateral muscle imbalances, and c) the two different functional tests used in the study (i.e. the triple single leg hop and the 6m timed single leg hop) provide the same information when bilateral muscular imbalances are concerned. Strength and conditioning coaches can utilise these findings when they are assessing their own athletes as well as when comparisons between studies are made.

References

1. Bishop, C, Read, P, Chavda, S, Turner, A. Asymmetries of the lower limb: the calculation conundrum in strength training and conditioning, Strength Cond J 38(6):27-32, 2016.
2. Bolgla, LA, Keskula, DR. Reliability of lower extremity functional performance tests. J Ortho Sports Phys Ther 26:138-142, 1997.
3. Croisier, JL, Ganteaume, S, Binet, J, Genty, M, Ferret, JM. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. Am J Sports Med 36(8):1469-1475, 2008.
4. Flanagan, EP, Harrison, AJ. Muscle dynamics differences between legs in healthy adults. J Strength Cond Res 21:67-72, 2007.
5. Fritz, C.O, Morris, PE, Richler, JJ. Effect size estimates: current use, calculations, and interpretation. J Exp Psychol Gen 141(1):2-18, 2012.
6. Hewett, TE, Stroupe, AL, Nance, TA, Noyes, FR. Plyometric training in female athletes: Decreased impact torques and increased hamstring torques. Am J Sports Med 24:765-773, 1996.
7. Holm, S. A simple sequentially rejective multiple test procedure, Scan J Stat 6(2):65–70, 1979.
8. Hopkins, WG, Schabort, EJ, Hawley, JA. Reliability of power in physical performance tests. Sports Med. 31(3):211-234, 2001.
9. Impellizzeri, FM, Rampinini E, Maffiuletti, N, Marcora, SM. A vertical jump force test for assessing bilateral strength asymmetry in athletes. Med Sci Sports Exerc 39(11): 2044-2050, 2007.
10. Jones, PA, Bampouras, TM. A comparison of isokinetic and functional methods of assessing bilateral strength imbalance. J Strength Cond Res 24(6):1553-1558, 2010.

11. Jordan, MJ, Aagaard, P, Herzog, W. Lower limb asymmetry in mechanical muscle function: A comparison between ski racers with and without ACL reconstruction. Scand J Med Sci Sports 25(3):e301-e309, 2015.

12. Knapik, JJ, Bauman, CL, Jones, BH, Harris, J, Vaughan, L. Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. Am J Sports Med 19:76-81, 1991.

13. Myer, GD, Ford, KR, Hewett, TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. J Athletic Training 39:352-364, 2004.

14. Nadler, SF, Malanga, GA, Feinberg, JH, Prybicien, M, Stitik, TP, DePrince, M. Relationship between hip muscle imbalance and occurrence of low back pain in collegiate athletes: a prospective study. Am J Phys Med Rehabil 80(8):572-527, 2001.

15. Newton, RU, Gerber, A, Nimphius, S, Shim, JK, Doan, BK, Robertson, M, Pearson, DR, Graig, BW, Hakkinen, K, Kraemer, WJ. Determination of functional strength imbalance of the lower extremities. J Strength Cond Res 20:971-977, 2006.

16. Orchard, J, Marsden, J, Lord, S, and Garlick, D. Preseason hamstring muscle weakness associated with hamstring injuries in Australian footballers. Am J Sports Med 25:81-85, 1997.

17. Parkin, S, Nowicky, AV, Rutherford, OA, McGregor, A. Do oarsmen have asymmetries in the strength of their back and leg muscles? J Sports Sci 19:521-526, 2001.

18. Rahnama, N, Lees, A, Bambaecichi, E. A comparison of muscle strength and flexibility between the preferred and non-preferred leg in English soccer players. Ergonomics 48:1568 – 1575, 2005.

19. Reinman, MP, Manske, RC. Functional testing in human performance. Champaign, Illinois: Human Kinetics, 2009.

20. Ruas, CV, Minozzo, F, Pinto, MD, Brown, LE, Pinto, RS. Lower-extremity strength ratios of professional soccer players according to field position. J Strength Cond Res 29(5):1220-1226, 2015.

21. Schlumberger, A, Laube, W, Bruhn, S, Herbeck, B, Dahlinger, M, Fenkart, G, Schmidtbleicher, D, Mayer, F. Muscle imbalances – fact or fiction? Isokinetics Exer Sci 14:3-11, 2006.

22. Young, WB, James, R, Montgomery, I. Is muscle power related to running speed with changed of direction? J Sports Med Phys Fitness 42:282-289, 2002.

23. Zifchock, RA, Davis, I, Higginson, J, Royer, T. The symmetry angle: a novel, robust method of quantifying asymmetry. Gait Posture 27(4): 622-627, 2008.

24. Zvijac, JE, Toriscelli, TA, Merrick, WS, Papp, DF, Kiebzak, GM. Isokinetic concentric quadriceps and hamstring normative data for elite collegiate American football players participating in the NFL Scouting Combine. J Strength Cond Res 28(4):875-883, 2014.

Table 1. Descriptive statistics of the bilateral muscle imbalance difference (%) for both genders, and all tests and calculations. Data is presented as mean ± SD.

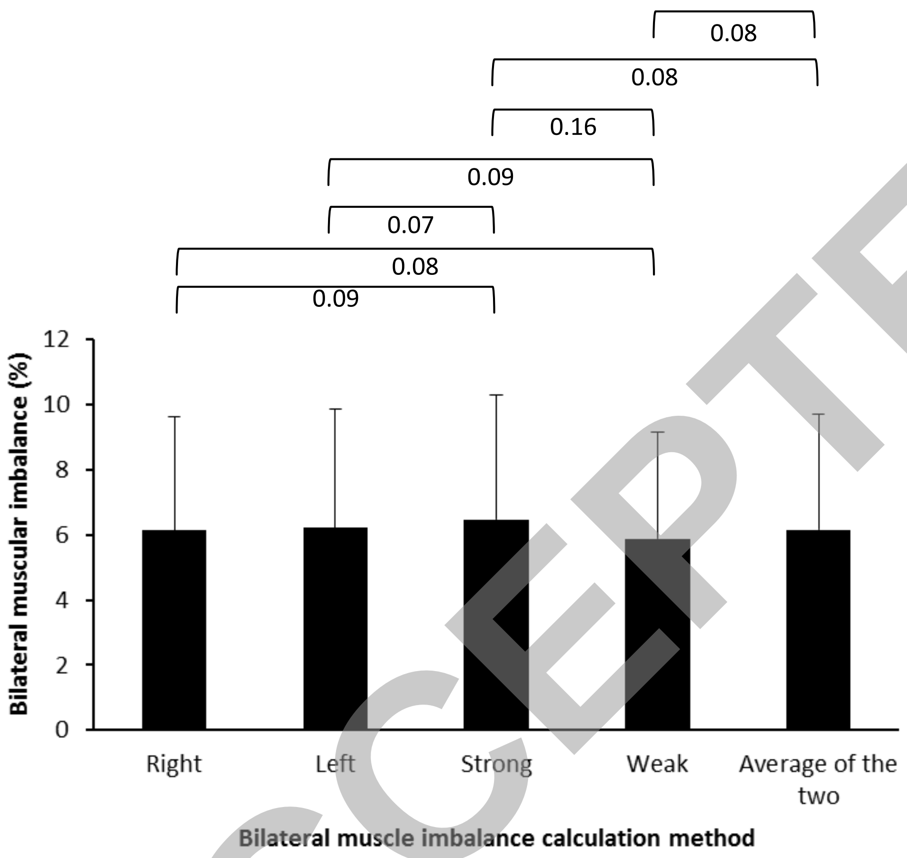
Calculation method	Absolute difference between limbs — Right	Absolute difference between limbs — Left	Absolute difference between limbs — Weak	Absolute difference between limbs — Strong	Absolute difference between limbs — Average
6m hop					
Males	5.3 ± 4.4	5.3 ± 4.5	5.5 ± 4.8	5.1 ± 4.1	5.3 ± 4.4
Females	8.5 ± 7.3	8.1 ± 6.4	8.8 ± 7.5	7.7 ± 6.7	8.2 ± 6.7
3hop					
Males	7.3 ± 4.4	7.5 ± 4.7	7.8 ± 4.9	7.0 ± 4.2	7.4 ± 4.5
Females	10.1 ± 5.6	9.6 ± 4.5	10.4 ± 5.5	9.2 ± 4.5	9.8 ± 5.0

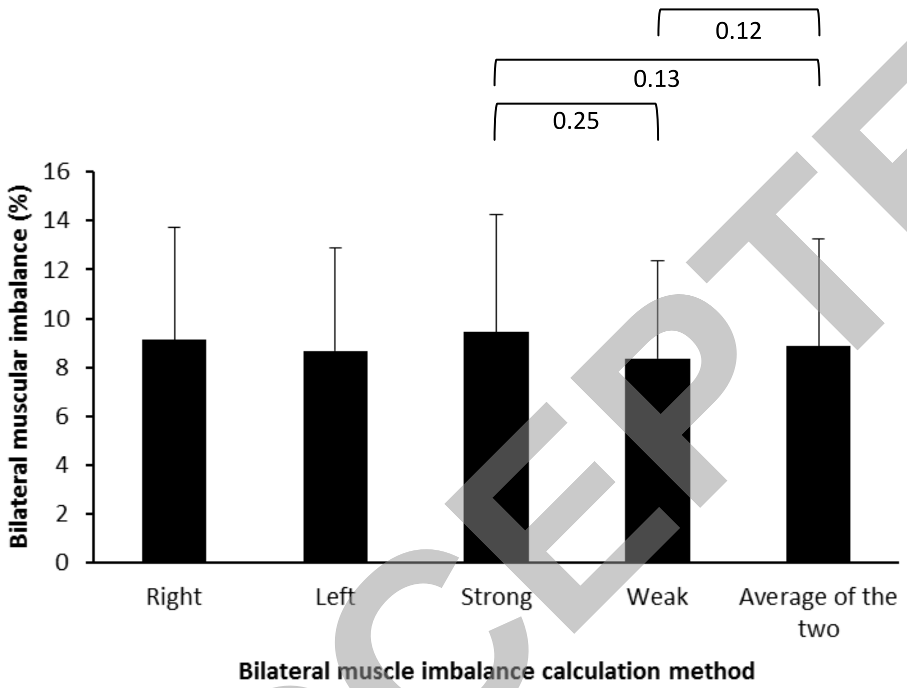
6m = 6m timed hop, 3hop = triple hop for distance

FIGURES AND CAPTIONS

Figure 1. Bilateral muscular imbalances (%) for males for all five different calculation methods (absolute difference between limbs / either right, left, strong, weak or average of the two), averaged across the two functional tests. Data is presented as mean (solid bars) and SD (vertical lines). X axis labels denote the limb used as denominator in the calculation. Significant differences in pairwise comparisons between calculation methods are indicated with the square brackets, including the effect size for each comparison.

Figure 2. Bilateral muscular imbalances (%) for females for all five different calculation methods (absolute difference between limbs / either right, left, strong, weak or average of the two), averaged across the two functional tests. Data is presented as mean (solid bars) and SD (vertical lines). X axis labels denote the limb used as denominator in the calculation Significant differences in pairwise comparisons between calculation methods are indicated with the square brackets, including the effect size for each comparison.


0.08
0.08
0.16
0.09
0.07
0.08
0.09
Bilateral muscular imbalance (%)
12
10
8
6
4
2
0
Right
Left
Strong
Weak
Average of the two
Bilateral muscle imbalance calculation method


0.12
0.13
0.25
16
14
12
10
8
6
4
2
0
Bilateral muscular imbalance (%)
Right
Left
Strong
Weak
Average of the two
Bilateral muscle imbalance calculation method