

1 **TITLE**

2

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

4

5 INTRODUCTION

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

15

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

24

25 Muscular imbalances are typically calculated as $((\text{side 1} - \text{side 2}) / \text{reference value}) \times 100$ [Eq.
26 1], to provide a percentage value of the difference between limbs. However discrepancy
27 occurs with the values that are inserted into the equation (1). When defining side 1 and side 2,
28 for example, researchers have reported using right and left (e.g. 15,17), stronger and weaker
29 (e.g. 10,14), and self-reported preferred and non-preferred, for side 1 and 2, respectively (e.g.

30 4,18). In addition to the definition of side 1 and side 2, the selection of the reference value
31 (right or left, strong or weak, preferred or non-preferred limb or simply an average between
32 the two limbs) might also impact on the results (23). It is worth pointing out that ‘strong’ and
33 ‘weak’ have been used to refer to the limb with the better (strong) or worse (weak)
34 performance; the actual performance might be a power-based and not a strength-based per se
35 (e.g. 10). Concernedly, use of different values in the calculations could mask or inflate the
36 true bilateral muscular imbalance value, potentially making it difficult for practitioners to
37 determine whether an athlete is at a higher injury risk, or whether their rehabilitation or
38 training programme is working to reduce the strength deficit (1).

39

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

50

51 **METHODS**

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53 **Experimental approach to the problem**

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55 The study was designed to compare the different bilateral muscular imbalance calculations
56 obtained by using the absolute difference value between limbs as the numerator and right,
57 left, weak, strong, or average of the two limbs as the reference value in the bilateral muscular
58 imbalance calculation $((\text{side 1} - \text{side 2}) / \text{reference value}) \times 100$. This was done for two
59 functional tests, the triple hop and the 6m timed hop, as the two tests place different
60 performance focus on the lower extremity (minimum time v maximum distance) (19).

61 Bilateral muscular imbalances (as per the equation above) were calculated in all possible 5
62 combinations, which were then compared for differences between sexes and functional tests.

63

64 **Subjects**

65

66 Twenty three males (mean \pm SD: age 21.6 ± 1.9 years (range 19 – 24 years), height $1.80 \pm$
67 0.06 m, body mass 80.5 ± 13.8 kg) and eleven females (mean \pm SD: age 20.8 ± 1.5 years
68 (range 19 – 23 years), height 1.62 ± 0.03 m, body mass 68.0 ± 6.5 kg) took part in the study.
69 They were all competitive, team game players and free of any injuries for at least 6 months
70 prior to testing. The sports the subjects participated in were, for males, football (n = 12),
71 rugby union (n = 9), basketball (n = 2) and for females hockey (n=6) and netball (n = 5). The
72 study was approved by the Institutional Ethics Committee and written informed consent was
73 obtained from all subjects.

74

75 **Procedures**

76

77 All participants were familiarised with the testing procedures on a session prior to testing (2).
78 Testing took place on a single occasion at the same time for all participants. Participants were
79 asked to refrain from strenuous exercise forty eight hours prior to testing and to avoid food or

80 caffeine intake for two hours prior to testing. For all tests, two trials were performed on each
81 limb and if the coefficient of variation was above 5% (8), a third test was performed; this
82 only happened on three occasions. To reduce order bias, the order of which limb was used to
83 perform each test and the test executed was counterbalanced. The average score of the two
84 trials (or the closest two trials, in case of more than two trials) was used for subsequent
85 analysis.

86

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

97

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

101

102 **Statistical analyses**

103

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

114

115 **RESULTS**

116

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

120

121 TABLE 1 ABOUT HERE

122

123 There was no significant interaction for sex, test and calculation method, test and calculation
124 method, test and sex ($P > 0.05$), but there was a significant interaction of sex and calculation
125 method ($P = 0.002$, partial $\eta^2 = 0.124$). Follow-up analysis revealed that when the calculation
126 method using the right leg as the denominator was used, bilateral muscular imbalance was
127 significantly lower ($P = 0.039$, $ES = 0.76$) in males ($6.1 \pm 3.5\%$, averaged across the two
128 functional tests) compared to females ($9.1 \pm 4.6\%$, averaged across the two functional tests).

129 Finally, significant differences were found between the calculation methods for males
130 (averaged across the two functional tests; Figure 1) and females (averaged across the two
131 functional tests; Figure 2), with small ES however (range: 0.07 – 0.25).

132

133 FIGURE 1 ABOUT HERE

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135 FIGURE 2 ABOUT HERE

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137 **DISCUSSION**

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

148

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

155

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

165

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

180 weak, strong, or average of the two) should be possible, as little difference would be present
181 from the use of a different reference value.

182

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

191

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

202

203 It has been previously reported that different sports yield different bilateral muscle
204 imbalances (e.g. American football (24) and soccer (20)). The convenience sample utilised in

205 the present study did not allow to separate for different sports or positions. However, as the
206 same functional test performance was used for all the difference calculations, this effect
207 should have been minimal and not impacted on the results.

208

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

215

216 **PRACTICAL APPLICATIONS**

217

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

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

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

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