Title Page

Title

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

Running head

Muscular imbalance calculations

Laboratory

Human Performance Laboratory

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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.

1 **INTRODUCTION**

2

3 Substantial deviation from normative data of muscle performance differences between limbs

4 is referred to as bilateral muscular imbalance (21). This bilateral muscular imbalance may be

5 the result of side preference, injury or specific sport demands (14,18), and can consequently

6 increase the risk of injury (6,12,13,16). For example, bilateral muscular imbalances have

7 been associated with higher anterior cruciate ligament injury risk in females (6,13) and elite

8 ski racers (11) as well as increased risk for lower back pain (14). In a prospective study,

9 Croiser et al (3) showed that professional male football players with untreated bilateral

10 muscular imbalances were four times as likely to sustain a hamstring injury.

11

12 Further, bilateral muscular imbalances could also have an impact on various mechanical

13 aspects and, consequently, on the relevant strength quality of the lower limbs, subsequently

14 affecting performance (4,9,11,22). For example, it was suggested that athletes turned faster in

15 change-of-direction tests when they were pushing off their dominant leg, with this dominance

16 affecting overall performance (22). Further, the weaker leg applied less force during a

17 countermovement jump (9), altering the pattern of force application and reducing the impulse

18 (11), resulting in lower jump height. Such situations can negatively impact on the athlete's

19 performance, due to reduced ability to turn fast or jump high.

20

21 Muscular imbalances are typically calculated as ((side 1-side 2)/reference value) x 100 [Eq.

22 1], to provide a percentage value of the difference between limbs. However discrepancy

23 occurs with the values that are inserted into the equation (1). When defining side 1 and side 2,

24 for example, researchers have reported using right and left (e.g. 15,17), stronger and weaker

25 (e.g. 10,14), and self-reported preferred and non-preferred, for side 1 and 2, respectively (e.g.

26   4,18). In addition to the definition of side 1 and side 2, the selection of the reference value

27   (right or left, strong or weak, preferred or non-preferred limb or simply an average between

28   the two limbs) might also impact on the results (23). It is worth pointing out that 'strong' and

29   'weak' have been used to refer to the limb with the better (strong) or worse (weak)

30   performance; the actual performance might be a power-based and not a strength-based per se

31   (e.g. 10). Concernedly, use of different values in the calculations could mask or inflate the

32   true bilateral muscular imbalance value, potentially making it difficult for practitioners to

33   determine whether an athlete is at a higher injury risk, or whether their rehabilitation or

34   training programme is working to reduce the strength deficit (1).

35

36   Thus, it is important to determine experimentally whether different calculations can produce

37   significantly different results. Hence, the aim of the present study was to compare five

38   different muscular imbalance ratio calculations (numerator: absolute difference between

39   limbs, denominator: right, left, strong, weak, average of the two) using two functional tests.

40   Although literature has previously also used preferred side (e.g. 4,18), no calculation was

41   specifically used for those values in the present study, as non / preferred will be either on the

42   right / left or strong / weak limb, and the exclusion of non / preferred selection prevents

43   repetition . Functional tests were chosen over isokinetic dynamometry assessment, due to

44   their practicality and affordability in testing larger groups as well as kinematic resemblance

45   to sporting movements (10).

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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 ((side 1-side 2)/reference value) x 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 ± SD: age 21.6 ± 1.9 years (range 19 – 24 years), height 1.80 ±

67 0.06 m, body mass 80.5 ± 13.8 kg) and eleven females (mean ± 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

76 **Procedures**

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 ± 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: $0.07 - 025$).

132

133   FIGURE 1 ABOUT HERE

134

135   FIGURE 2 ABOUT HERE

136

137   **DISCUSSION**

138
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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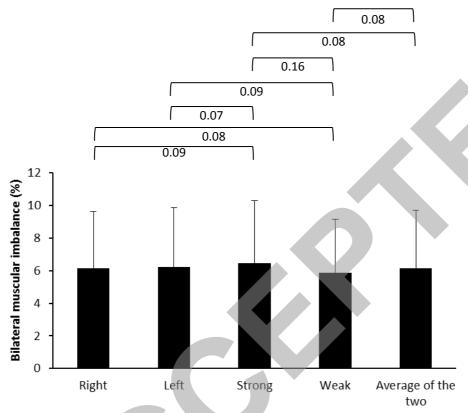
Table 1. Descriptive statistics of the bilateral muscle imbalance difference (%) for both genders, and all tests and calculations. Data is presented as mean ± SD.

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 ± 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

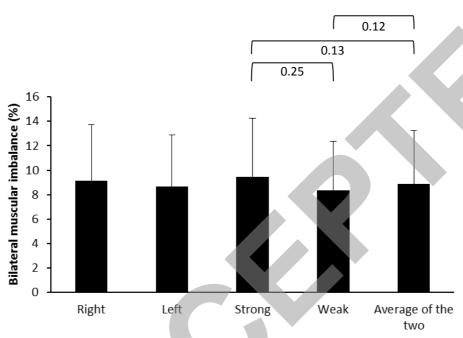6m = 6m timed hop, 3hop = triple hop for distance

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.