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1 *Title* Intra-Rater Reliability of the Multiple Single-Leg
2 Hop-Stabilization Test and Relationships with Age, Leg Dominance and Training

3

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13

14 **Background:** Balance is a complex construct, affected by multiple components such as
15 strength and co-ordination. However, whilst assessing an athlete's dynamic balance is
16 an important part of clinical examination there is no gold standard measure. The
17 multiple single-leg hop-stabilization test (MSLHST) is a functional test which may offer
18 a method of evaluating the dynamic attributes of balance, but it needs to show adequate
19 intra-tester reliability.

20 **Purpose:** The purpose of this study was to assess the intra-rater reliability of a dynamic
21 balance test, the multiple single-leg hop-stabilization test (MSLHST) on the dominant
22 and non-dominant legs.

23 **Design:** Intra-rater reliability study

24 **Methods:** Fifteen active participants were tested twice with a 10-minute break between
25 tests. The outcome measure was the multiple single-leg hop-stabilization test score,
26 based on a clinically assessed numerical scoring system. Results were analysed using an
27 Intraclass Correlations Coefficient (ICC _{2,1}) and Bland-Altman plots. Regression
28 analyses explored relationships between test scores, leg dominance, age and training (an
29 alpha level of $p = 0.05$ was selected).

30 **Results:** ICCs for intra-rater reliability were 0.85 for the dominant and non-dominant
31 legs (confidence intervals = 0.62-0.95 and 0.61-0.95 respectively). Bland-Altman plots
32 showed scores within two standard deviations. A significant correlation was observed
33 between the dominant and non-dominant leg on balance scores ($R^2=0.49$, $p<0.05$), and
34 better balance was associated with younger participants in their non-dominant leg
35 ($R^2=0.28$, $p<0.05$) and their dominant leg ($R^2=0.39$, $p<0.05$) and a higher number of
36 hours spent training for the non-dominant leg $R^2=0.37$, $p<0.05$).

37 **Conclusion:** The multiple single-leg hop-stabilisation test demonstrated strong intra-
38 tester reliability with active participants. Younger participants who trained more, have

39 better balance scores. This test may be a useful measure for evaluating the dynamic
40 attributes of balance.
41 **Level of Evidence:** 3
42 **Key words:** Assessment, balance, reliability, hop testing

43 **INTRODUCTION**

44

45 Normal balance requires the interaction between multisensory organ systems
46 (proprioceptive, visual and vestibular¹) and the brain and spinal cord, which ultimately
47 control the multi-joint musculoskeletal system. ²⁻⁴ These systems can be affected by
48 factors such as nutrition, ⁵ age, ⁶ injury ⁷ and disease. ⁸ At an optimal level they work to
49 maintain the center of gravity within a defined base of support, as well as the task
50 specific orientation of body parts. ⁹

51 Within sports medicine, assessing an athlete's balance is an important part of a clinical
52 examination. ¹⁰ It is within this domain that an emphasis is placed upon proprioceptive
53 / balance exercises as both a tool for injury prevention ¹¹ and as a rehabilitation
54 strategy. ¹⁰ However, the physical demands of sport are extremely diverse, and balance
55 and postural control appear to be influenced by other performance attributes. For
56 example, strength training programs lead to significant improvements in both static
57 (Romberg) and dynamic (Star Excursion Balance Test) measures of balance. ¹²

58 Despite the implementation of balance training for both injury prevention and
59 rehabilitation, no gold standard outcome measure exists with which to quantify balance
60 within the athletic population. ¹⁰ While it is acknowledged that balance can be measured
61 statically or dynamically, ¹² the population being examined should direct the nature of
62 the test selected. Furthermore it should not be assumed that static balance ability is
63 positively correlated with dynamic balance performance. ¹³ Therefore it appears
64 appropriate to use a dynamic measure of balance when examining the athletic
65 population, as all sports require a "dynamic" attribute of balance in some way.

66 The purpose of looking at athletic balance stems from the results of a series of single
67 case studies evaluating the use of clinically targeted compression in athletes, whereby
68 compression was delivered to the pelvic girdle via a customised orthosis in the form of

69 shorts. Questionnaire responses from the participating athletes suggested that this type
70 of external pelvic compression ¹⁴ may have had a positive effect upon balance. ¹⁵ In
71 order to investigate whether this is the case, the intention was to incorporate a functional
72 measure of athletic balance in future clinical trials. On the basis of the current literature
73 ¹⁰ and discussion with clinical colleagues, it is anticipated that a functional single leg
74 test may be an appropriate measure of dynamic balance.

75 Previous researchers have found that knee instability is positively correlated with one-
76 legged tests, ¹⁶ and that a single leg hopping test can demonstrate good test re-test
77 reliability . ¹⁷ The multiple single-leg hop-stabilization test (MSLHST) is a single leg
78 dynamic measure , ¹⁸ involving forwards, and diagonal movements in a unipedal stance,
79 that incorporates periods of statically maintaining this stance. Athletes are scored on
80 both a balance and landing scale, according to the errors that they commit in each period
81 of the test; these scores are summed to give the total error score. It has been argued that
82 this type of functional test is important because it challenges athletes in a way which
83 reflects the forces and directions of movement that are integral to sport. ¹⁸

84 Although this test has been reported to have very good inter-tester reliability (ICC
85 values 0.70-0.92), ¹⁸ intra-rater reliability was shown to be lacking. ¹⁰ Closer inspection
86 of the intra-rater reliability reveals that this lack of reliability only refers to the balance
87 scores which significantly differed between tests; no significant difference was
88 observed with the landing scores. ¹⁰ Further, this study ¹⁸ assessed three test sessions,
89 each 48 hours apart; a different scenario to the current intra-rater reliability study in
90 which the testing was completed in one session.

91 A further consideration for any balance study involving athletes with a lower limb
92 injury is the influence of lower limb dominance. In football, a players' dominant
93 (preferred kicking leg) has been shown to be significantly stronger than their non-
94 dominant leg in terms of hip adductor strength, ¹⁹ and hip flexor strength, ²⁰ but not in

95 all muscle groups.¹⁹ It has been suggested that any rehabilitation of injury needs to take
96 leg dominance into consideration.¹⁹ As a strength deficit may potentially contribute to
97 poor balance, it is important that a study considers the role of limb dominance, and
98 examines how this may influence the reliability of the balance measure used.

99

100 The purpose of this study was to assess the intra-rater reliability of a dynamic balance
101 test, the multiple single-leg hop-stabilization test (MSLHST) on the dominant and non-
102 dominant legs.

103 A secondary purpose was to explore whether relationships exist between the MSLHST
104 scores and leg dominance, age, and time spent engaging in exercise (training).

105

106 **METHODS**

107

108 **Design**

109 An intra-rater reliability study was undertaken. All of the testing was undertaken by a
110 single investigator, using portable equipment; the test was scored in “real time” while
111 the balance measure was being performed.

112

113 **Participants**

114 A convenience sample of volunteers was recruited from Plymouth University staff and
115 students, and from local sports clubs. To maximise recruitment the study was conducted
116 at the University (Human Movement Laboratory) to accommodate the staff and student
117 participants. Ethical approval was gained from a local University Ethics Committee
118 (Plymouth University).

119

120 **Eligibility Criteria**

121 To be included, subjects had to be over the age of 18, and able to give informed
122 consent, be self-declared as healthy, and have sustained no lower limb musculoskeletal
123 injuries in the prior three months. Subjects were excluded if they were pregnant, had a
124 current illness / unresolved condition , or had any neurological, musculoskeletal or
125 cardiorespiratory impairment.

126

127 **Sample Size**

128 Reliability coefficients greater than 0.7 are deemed to be acceptable for most clinical
129 trials.²¹ A power calculation indicated that 15 people were needed to be recruited in
130 order to demonstrate an ICC of >0.7 (power = 0.88; α = 0.05). This is in keeping with
131 the work of Fleiss²² and their discussion of the numbers required for a reliability study
132 involving quantitative measures.

133

134 **Participant Characteristics**

135 Participant demographics (age, gender, height, weight), their leg dominance (as defined
136 by which side they would kick a ball), and the average number of hours spent training /
137 performing sports in a week were recorded.

138

139 **Measurement of the MSLHST**

140 Testing was undertaken in standard sports attire (shorts, t shirt and athletic shoes) and
141 conducted in the same undisturbed environment, in order to minimise external
142 influences and allow for standardization. Standardized written instructions were given
143 to all participants prior to testing; this included photographs of stances. Participants also

144 received verbal instructions from the researcher while viewing the MSLHST set up, and
145 before completing their practice attempts.

146 The distances between each of the boxes (Table 1) were standardised according to the
147 participants' height. Diagonal distances represented 45% of the participants' height
148 (wearing athletic shoes), and Pythagoras Theorem used to calculate the distances in the
149 frontal plane, for the adjacent boxes. The mat was labelled according to the height
150 related distances prior to testing to ensure that during testing, there was minimal delay
151 in setting up the mat. This was achieved using hook and loop combinations of numbered
152 Velcro® squares.

153

154 **Table 1.** *Hop distances according to height*²³

Height in Centimetres (cm)	Diagonal Distance (cm)	Adjacent Distance (cm)
150-159.9	70	49
160-169.9	74	53
170-179.9	79	58
180-189.9	83	59
190-199.9	88	62
200-209.9	92	66

155

156

157 One practice attempt on each leg was undertaken for familiarization of the procedure
158 while avoiding fatigue. Both the dominant leg (as defined as the leg that people would
159 prefer to kick a ball with) and the non-dominant leg were tested in a randomized order
160 (randomization was undertaken using the Microsoft Excel 2010 randomization

161 function). After a 10 minute rest, participants were asked to complete the MSLHST
162 again on both legs, in the same order.

163 The starting position was standardised with the participants standing on one leg with
164 both hands on their iliac crests and eyes facing forwards. Participants were asked to hop
165 to a series of numbered boxes; each with an area of 2.5cm² (Figures 1a, 1b). Arm
166 position was standardized throughout the test, with participants asked to keep their
167 hands on their iliac crests. The task was paced by a metronome (with an auditory cue
168 every one second). On landing on each box, participants were asked to maintain their
169 position for five seconds (counted aloud by the investigator). The balance period was
170 defined as the period prior to undertaking each jump and the period one to five seconds
171 after landing and stabilizing the position. The landing period was defined as the one
172 second period immediately after landing, when the participant attempted to stabilize
173 their position.

174 Previous work¹⁸ has described how any error in either a landing or balance phase was
175 counted as a failure.¹⁸ Errors were scored according to the period in the test in which
176 they were committed i.e. 3 points for an error in a balance period, and 10 points for a
177 landing period error. Testing did not stop following an error; participants continued with
178 the test and all errors were scored. The final test score was the sum of the balance and
179 landing error scores. The MSLHST scoring was defined as:

180

181 *Balance score.* 3 error marks were given for participants committing the following in
182 any balance period:

- 183 • Touching the floor with the non-weight bearing limb;
- 184 • Removing hands from iliac crests;
- 185 • Non-weight bearing limb touching the weight bearing limb;
- 186 • Non-weight bearing limb moving into excessive flexion, extension or abduction

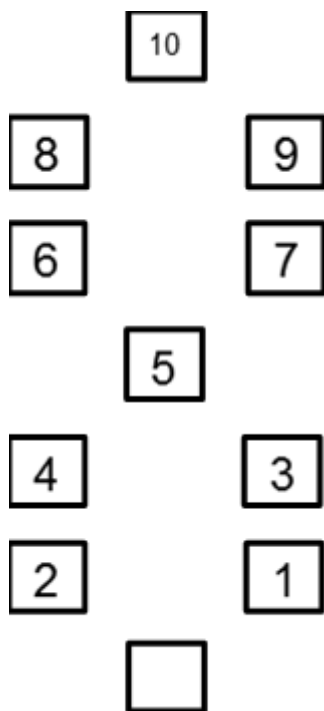
187 (this was defined as movement beyond the predetermined stance (>30 degrees of
188 movement); displayed to the participants in a photographic format).

189

190 *Landing score.* 10 error marks were given for participants committing the following in
191 any landing period:

- 192 • Removing hands from iliac crests;
- 193 • Foot not covering the numbered square;
- 194 • Stumbling on landing;
- 195 • Landing foot not facing forwards with 10 degrees of inversion or eversion.

196 Therefore potential test scores could range from 0 -130 (0-100 for the landing
197 component, and, 0-30 for the balance element).



198

199

200 **Figure 1a.** *A representation of the boxes marked out for the multiple single-leg hop-*
201 *stabilisation test*

202



203

204 **Figure 1b.** *A photograph of the testing mat being prepared for variable distances*

205

206 **Statistical Analyses**

207 Statistical analyses were performed using SPSS 20 for Windows (IBM). Two-way
208 random absolute agreement intra-class correlation (ICC_{2,1}) and 95% confidence
209 intervals were used to assess the intra-rater reliability.²⁴

210 Bland Altman plots were presented to show a visual representation of intra-rater
211 reliability. Using more than one measure of reliability has been advised as no one
212 measure is suitable for all reliability studies.²⁵ ICCs give a relative view of reliability,
213 therefore it has been advised not to draw conclusions before using methods of
214 examining the absolute reliability.²⁶

215 A paired t-test was used to ascertain if there was a significant difference between the
216 balance ability of the dominant and non-dominant leg ($p = <0.05$). Regression analyses
217 were undertaken to explore possible relationships between balance ability on the
218 dominant and non-dominant leg, age and time spent training each week. The strength of

219 the correlation coefficients were interpreted as: 0 = zero, 0.1-0.3 = weak, 0.4-0.6 =
220 moderate, 0.7-0.9 = strong and 1 = perfect. ²⁷

221 The time spent training each week was further explored using t tests to determine the
222 possibility of predicting test performance according to the amount of training
223 undertaken (< or > five hours per week). Such a relationship has been observed in
224 previous work, showing that lifelong football trained men demonstrated significantly
225 superior balance to age matched untrained men. ²⁸

226

227 **RESULTS**

228

229 Fifteen participants (males = 8), aged 22-57 participated in the study. The
230 demographics of the tested population are presented in Table 2.

231

232 **Table 2.** *Demographical data*

	Age (yrs)	Weight (kg)	Height (cm)	Gender	Dominant Leg	Average Weekly Training Hours
Mean	32.8	71.4	174.2	Female = 7 Male = 8	Left = 2 Right = 13	5.5
SD	9.2	9.5	7.5			4.3
Range	22-57	53.8-88	162.5-184.5			0.3-14

233

234

235 Table 3 presents the MSLHST score inter-rater reliability ICCs for the dominant and
 236 non-dominant leg, along with the 95% CI's. ICCs for both legs = 0.85.
 237 Tables 4 and 5 present the ICCs for the balance and landing scores on each leg. For the
 238 non-dominant leg, balance and landing score ICCs were 0.87 and 0.78 respectively. For
 239 the dominant leg, ICCs were 0.88 for the balance score, and 0.72 for the landing score.
 240

241 **Table 3.** *Intra-rater reliability results. ICC (2,1)*

		95% Confidence Intervals	
	Intraclass Correlation Coefficient	Lower Bounds	Upper Bounds
Dominant Leg	0.85	0.62	0.95
Non-Dominant Leg	0.85	0.61	0.95

242

243

244 **Table 4.** *Intra-rater reliability results for the non-dominant leg balance and landing*
 245 *scores. ICC (2,1)*

Non-Dominant Leg		95% Confidence Intervals	
	Intraclass Correlation Coefficient	Lower Bounds	Upper Bounds
Landing Score	0.78	0.47	0.92
Balance Score	0.87	0.64	0.95

246

247

248 **Table 5.** *Intra-rater reliability results for the dominant leg balance and landing scores.*

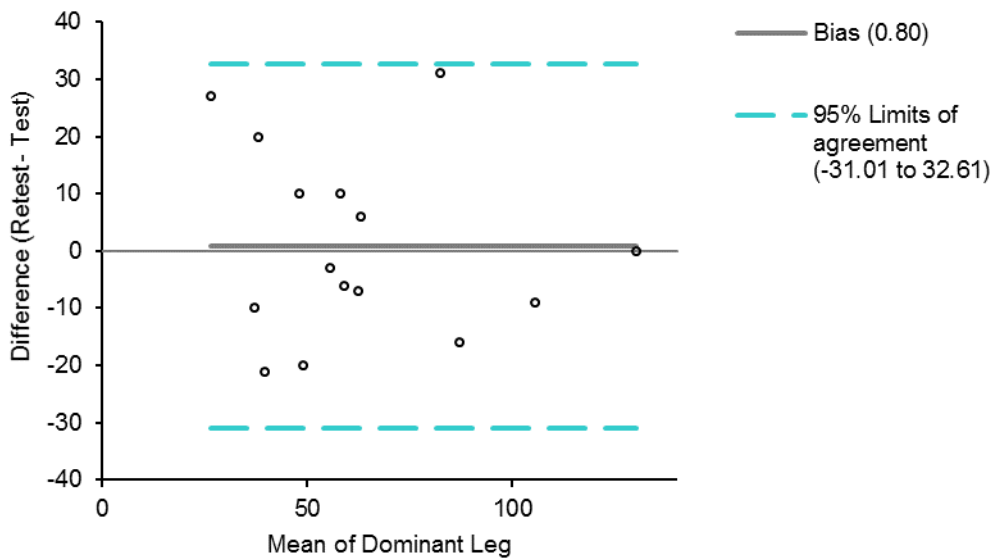
249 *ICC (2.1)*

Dominant Leg	Intraclass Correlation Coefficient	95% Confidence Intervals	
		Lower Bounds	Upper Bounds
Landing Score	0.72	0.34	0.90
Balance Score	0.88	0.83	0.96

250

251 Figures 2 and 3 present visual representations of the intra-rater differences in scores for

252 the dominant and non-dominant legs. Offer a summary statement here too.

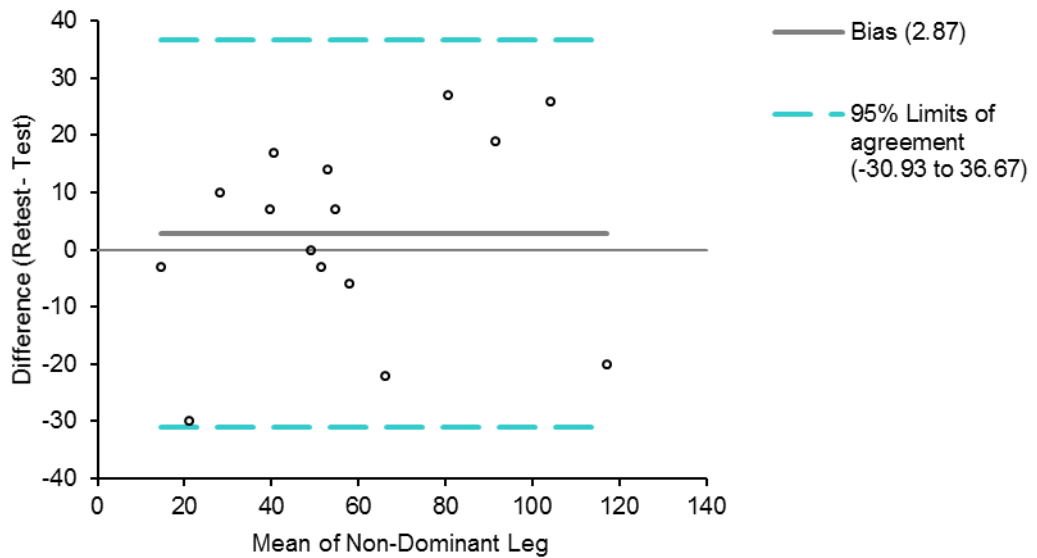


253

254 **Figure 2.** *Bland Altman plot of the intra-rater differences when the MSLHST is*

255 *performed on the dominant leg*

256

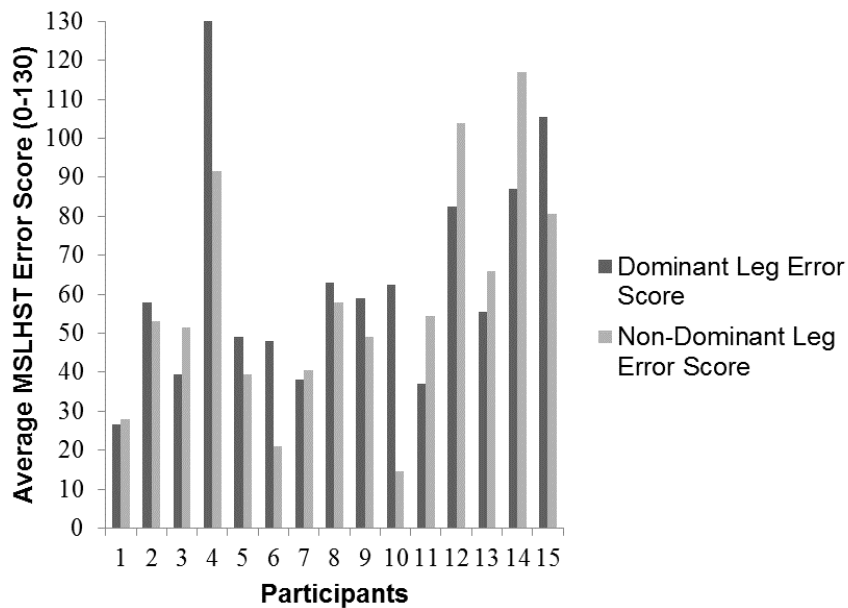


257

258 **Figure 3.** Bland Altman plot of the intra-rater differences when the MSLHST is
 259 performed on the non-dominant leg

260

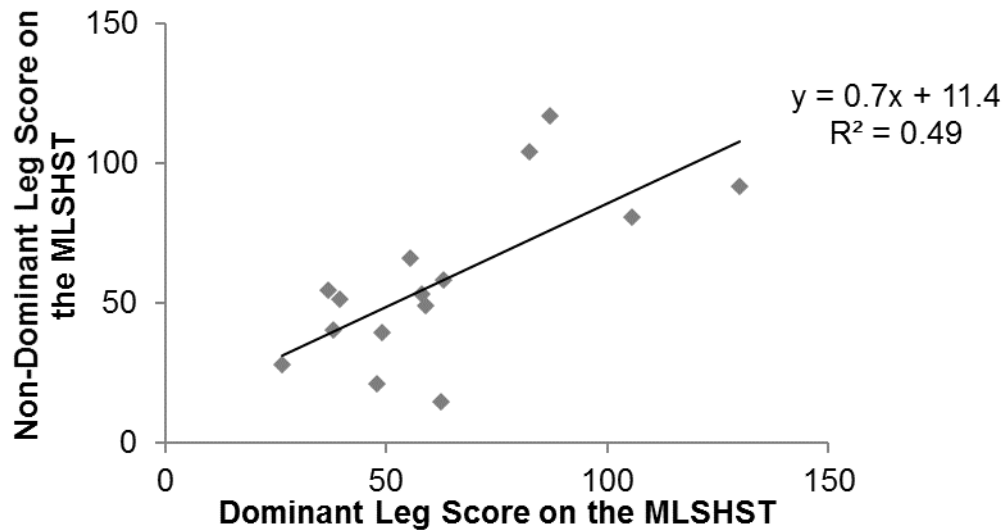
261 Paired t-tests revealed no significant differences between performance of the dominant
 262 and non-dominant legs in the first or second performance of the test ($p = >0.05$),
 263 therefore the scores for the dominant and non-dominant legs were averaged across the
 264 two tests (Figure 4).



265

266 **Figure 4.** Mean error scores for the dominant and non-dominant leg

267 There was a significant positive and strong relationship ²⁹ between the scores obtained
268 on the dominant and non-dominant legs; higher scores on one leg were associated with
269 higher scores on the other leg ($R^2=0.49$ $P<0.05$; Figure 5).



270

271 **Figure 5.** A scatterplot showing the linear relationship between the average dominant
272 and non-dominant leg scores on the multiple single-leg hop-stabilization test

273

274 There was a significant positive and moderate relationship ²⁹ between the scores
275 obtained on both the dominant / non-dominant legs and the age of the participant.

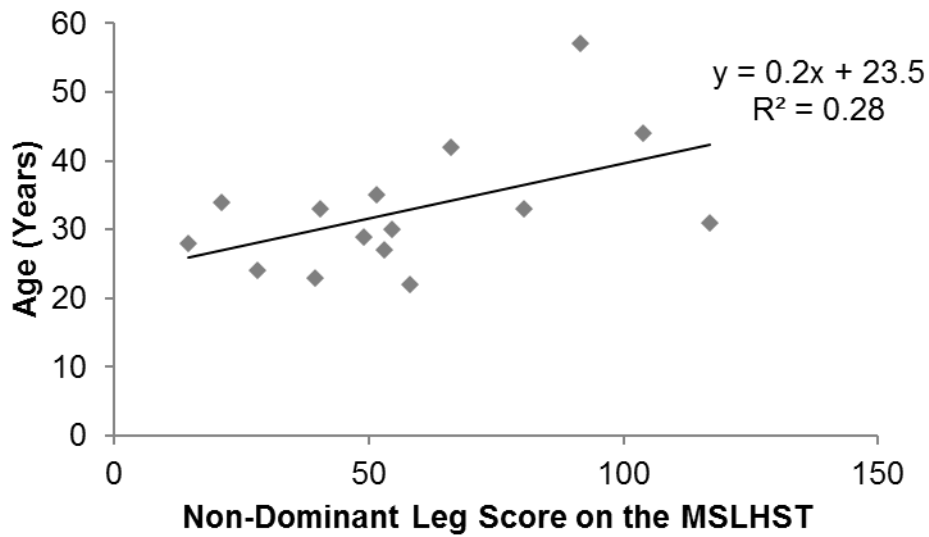
276 Higher scores (indicating more errors) were associated with advancing age The

277 relationship was stronger on the dominant leg (non-dominant leg $R^2 = 0.28$, $p<0.05$,

278 Figure 6; dominant leg $R^2=0.39$, $p<0.05$, Figure 7).

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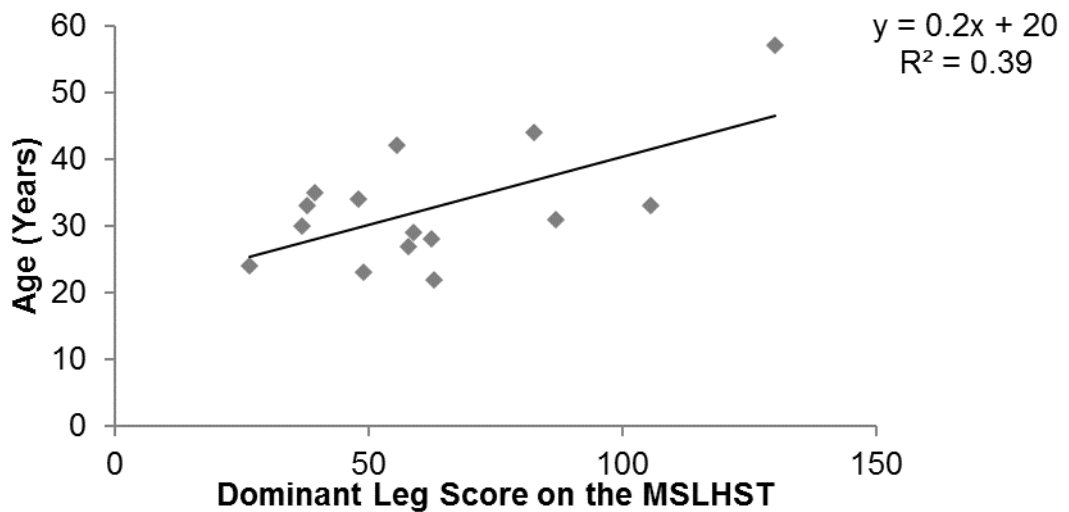
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281

282

283 **Figure 6.** A scatterplot showing the linear relationship between the average non-
 284 dominant leg scores on the multiple single-leg hop-stabilisation test and age



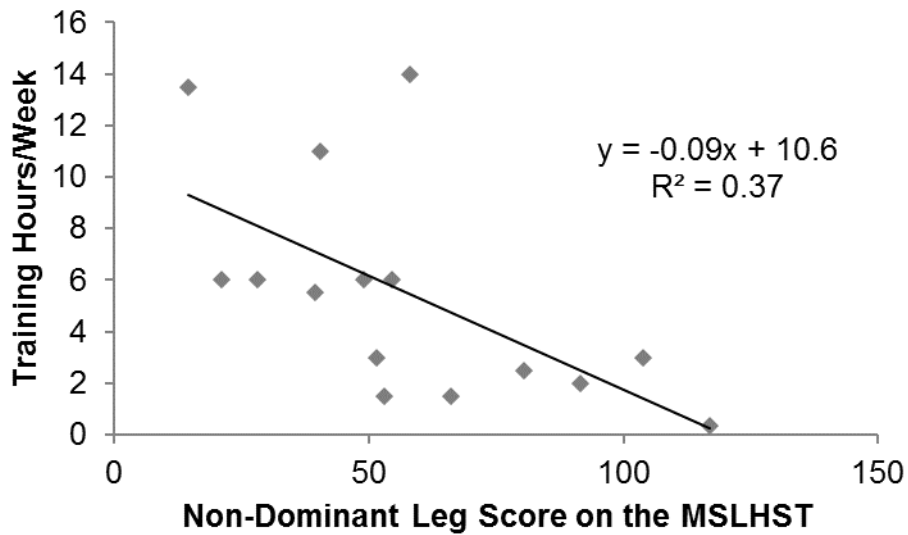
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286

287 **Figure 7.** A scatterplot showing the linear relationship between the average dominant
 288 leg scores on the multiple single-leg hop-stabilisation test and age

289

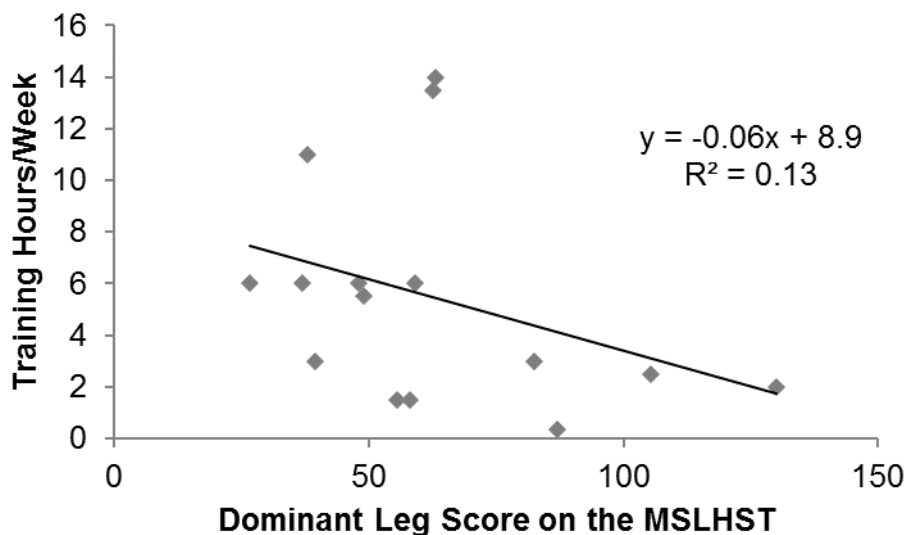
290 Greater number of training hours per week were associated with lower scores on the
291 MSLHST. This relationship, which was of moderate strength,²⁹ was significant for the
292 non-dominant leg only ($R^2=0.37$ $p<0.05$).



293

294 **Figure 8.** A scatterplot showing the linear relationship between the average non-
295 dominant leg scores on the and weekly multiple single-leg hop-stabilisation test
296 training hours

297



298

299 **Figure 9.** A scatterplot showing the linear relationship between the average dominant
300 leg scores on the MSLHST and weekly training hours

301 Further analysis using t-tests showed a significant difference ($p = <0.05$) in overall
302 scores between those training more and those training less than five hours per week.
303 This was seen for both the average dominant and non-dominant leg scores.

304

305 **DISCUSSION**

306

307 ICC values can be interpreted as follows; 0.75 and above indicates excellent reliability,
308 0.4-0.75 is fair to good reliability and <0.4 is seen as poor reliability.²² The ICC results
309 for both the dominant and non-dominant leg both demonstrate a mean value of 0.85.
310 Whereas this may be considered as demonstrating excellent intra-rater reliability,²²
311 examination of the 95% CI urges more caution. The intervals ranging from 0.62-0.95
312 for the dominant leg, and, 0.61-0.95 for the non-dominant leg, should be interpreted as
313 showing that the MSLHST demonstrates good to excellent intra-rater reliability in a
314 healthy, exercising population.

315 The varying degrees of reliability shown in Tables 4 and 5 allows a comparison with
316 previous findings on the differences in the landing and balance score reliability.¹⁸ The
317 current findings show that ICCs range from 0.72-0.88; indicating good to excellent
318 reliability.²² The finding that reliability is greater with the balance scores than landing
319 is in contrast to prior work.¹⁸ While this may reflect the difference in the prescribed
320 scores given for landing and balance errors, for the purpose of this work the focus upon
321 intra-rater reliability is with the overall MSLHST score which is derived by totalling the
322 balance and landing scores.

323 While ICCs were examined to provide a quantitative assessment of reliability in terms
324 of consistency of agreement; Bland Altman plots were examined as a qualitative
325 method of assessing reliability and determining degree of absolute agreement³⁰.

326 Inspection of these plots (Figures 2 and 3) show that the MSLHST intra-rater scores all
327 lay within the 2 standard deviation limits. Considering these findings together with
328 those of previous research,¹⁸ it appears that the MSLHST could be a reliable functional
329 outcome measure, and may be considered for inclusion in future clinical trials in a
330 similar population.

331 Thorborg et al¹⁹ suggested that one may expect to see a difference in balance ability
332 between the dominant/ non-dominant legs. However, paired t-tests used to examine the
333 current data demonstrated that there was no significant difference between the dominant
334 and non-dominant limbs ($p > 0.05$). Furthermore a significant strong, positive
335 correlation was observed between the MSLHST scores of the dominant and non-
336 dominant leg. Those making less errors completing the test on their dominant leg, tend
337 to perform similarly on their non-dominant leg. This finding has also been observed in
338 the sedentary population,³¹ although future work is warranted to explore this in athletes.

339 A moderate and significant positive relationship was demonstrated between balance
340 scores and age; higher error scores (indicative of worsening balance) occurred with
341 increasing age when both the dominant and non-dominant legs were assessed. A
342 deterioration of balance with age has been reported previously.³² Changes include an
343 increased amplitude and speed of postural sway, reduced dynamic balance and greater
344 instability when sensory inputs controlling balance are perturbed or reduced.³³ Many of
345 these studies compared balance ability in younger (<30 years) and older (>60 years) age
346 groups.^{32,33} It is of note that this measure of dynamic balance appeared able to detect
347 variations in performance with age even within the relatively narrow age band of the
348 current sample (22-57 years).

349 People who trained for longer periods each week had lower scores on the MSLHST
350 (indicating better balance ability). This was only significant on the non-dominant leg.
351 Interestingly, the task used to define the dominant leg was kicking a ball in which the

352 opposite non-dominant leg is balancing, supporting the body weight. The moderate
353 relationship seen between the hours spent training and better performance on the non-
354 dominant leg balance scores might be because this leg is used more frequently for
355 balancing activities; especially during asymmetric activities like football that involve
356 phasic movements of the dominant leg.

357 Predicting performance scores through other variables can be useful in forecasting
358 future performance outcomes. Led by the findings of earlier research ²⁸ the number of
359 training hours undertaken each week was explored as a predictor of subjects MSLHST
360 scores; a significant difference ($p = <0.05$) was shown between participants when
361 grouped in terms of the time spent engaged in exercise activities each week. More
362 specifically the results show that it is possible to predict how well a participant will do
363 on the MSLHST by looking at the number of hours that they spend training each week;
364 more than five hours of training per week is a strong indicator that a participant will
365 have a lower error score (indicative of better balance). This is supported by literature in
366 other populations where engagement in sport and physical activities has been shown to
367 be associated with better balance and postural control. ³⁴

368

369 **CONCLUSION**

370

371 The results of the current study demonstrate that the MSLHST demonstrates good to
372 excellent intra-rater reliability in a healthy, active population. Furthermore simple
373 regression analyses may suggest that predictions may be made as to participants'
374 MSLHST error scores, based on known factors such as their age and training hours. The
375 latter showing a significant difference (<0.05) in performance between those training

376 more and less than five hours per week. However further work is required to confirm
377 these findings.

378 In conclusion and concurring with previous work,¹⁸ it appears that this test could be an
379 appropriate functional measure of athletic balance to use in a future study with a young,
380 healthy, active population.

381

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