

1 **Title:**

2 The Relationship between Eccentric Hamstring Strength and Dynamic Stability in Elite Academy
3 Footballers.

4

5 **Authors:**

6 David Rhodes^a., Josh Jeffrey^b., Joe Maden-Wilkinson^b., Antony Reedy^c., Erin Morehead^a. John Kiely^a.,
7 Daniel Birdsall^a., Chris Carling^a., and Jill Alexander^a.

8

9 ^aUniversity of Central Lancashire, Preston, Lancashire, PR1 2HE, United Kingdom.

10 ^bEverton FC, Finch Farm, Merseyside, United Kingdom.

11 ^cBurnley FC, Gawthorpe Park, Padiham, United Kingdom.

12

13 **Corresponding Author:**

14 Dr David Rhodes

15 DRhodes2@uclan.ac.uk

16

17

18 **Word Count:**

19 3055

20

21 **Declarations of interest:**

22 None

23

24

25

26

27

28 **ABSTRACT**

29

30 **Objectives:** Previous research describes dynamic stability and functional strength as key aetiological
31 risk factors associated with lower limb non-contact musculoskeletal injury. Due to the multi factorial
32 nature of injury risk, relationships between the two factors will inform injury management and training
33 design.

34 **Methods:** Fifty-nine elite academy footballers from two English premier league category 1-status
35 academies completed the study. All players completed measures of eccentric hamstring strength and
36 dynamic stability. Relationships between directional stability (Anteroposterior (Ant), Posteromedial
37 (PM) and Posterolateral (PL)) and eccentric strength metrics (PkT, AvT, PkF, AvF and Θ) bilaterally
38 were identified for analysis.

39 **Results:** Significant correlations were identified bilaterally for functional hamstring strength metrics
40 and PM and PL stability ($P \leq 0.05$). No significant relationships were identified between anterior
41 stability and eccentric hamstring strength parameters ($P > 0.05$).

42 **Conclusions:** Eccentric hamstring strength has a positive influence on directional stability through two
43 planes, PM and PL. The lack of influence of eccentric hamstring strength on Ant directional stability
44 could be attributed to increased ACL risk. Careful consideration of the significance of the relationships
45 between eccentric hamstring strength and directional stability must be given when quantifying injury
46 risk in elite academy footballers.

47

48 **Keywords:** soccer, eccentric, dynamic stability, injury

49

50

51

52

53

54

55

56 **Introduction**

57

58 Epidemiological research within elite football highlights the incidence of muscular injury, citing that
59 they contributed to 31% of all injuries with injury most commonly occurring to the hamstrings¹. These
60 injuries alone in the English Premier League cost clubs in the region of £74.4 million in a single season
61 and £1 billion across the whole of English Football². Indications in the research literature illustrate that
62 hamstring injury incidence has increased^{1,3}, thus increasing the financial burden on placed on
63 professional football clubs. Coincidentally, research on the continent has reported rises in anterior
64 cruciate ligament injuries (ACL)^{4,5}. In addition literature also highlights the detrimental effect of ACL
65 rupture on subsequent levels of performance⁶ and the increased chance of re-rupture, with reductions of
66 eccentric hamstring strength highlighted as a key factor⁷.

67

68 Considering basic functional anatomy and the common mechanism of injury associated with ACL injury
69 in footballers, it seems logical to suggest that the functional strength of the hamstring would be a key
70 factor in maintaining stability within the knee, particularly through the anterior plane. Evidence
71 documents that athletes partaking in injury prevention programmes focussing on improving functional
72 hamstring strength parameters are at a reduced risk of sustaining knee injury⁸. Aetiological risk factors
73 associated with sustaining knee injuries include poor eccentric strength^{9,10} and dynamic stability¹¹. The
74 work of Booyesen et al., (2015)¹² examined the relationship between these two risk factors concluding
75 that no correlation exists. It is important to note that within this work dynamic stability was quantified
76 utilising an overall stability score when performing the 'Y' Balance Test (YBT). Consideration must
77 be given to the importance of establishing the relationship between functional strength of the hamstrings
78 and directional dynamic stabilisation, as this will inform injury risk reduction strategies employed by
79 sports medicine professionals. In functional performance the hamstrings play a vital role in
80 counteracting the stresses on the ACL when competing¹³. Thus, suggesting that poor eccentric control
81 may result in decreased directional dynamic stability within the knee, increasing the athlete's chance of
82 sustaining injury.

83 Although the consensus across literature appears clear for the hamstring, the effect of increased
84 functional hamstring strength on the stability of the knee is limited. Research highlights that players
85 who sustain an ACL rupture display significant reductions in hamstring function, post injury or surgical
86 intervention^{14,15}, increasing the risk of re-rupture. Previous injury is highlighted as a key aetiological
87 factor in the recurrence of ACL ruptures^{16,17}. This potentially highlights that returning an athlete post
88 injury with poor function compromises the stability of the knee and exposes the ACL to increased load¹⁸.
89 It is clear that poor function within the hamstring muscle group can contribute to non-contact
90 musculoskeletal injury sustained at the knee¹⁹. Aetiological contributions to sustaining such injuries are
91 well documented as being multi factorial, particularly literature surrounding the ACL²⁰. This said, the
92 global effect functional strength has on these aetiological factors is not well reported and further research
93 is required.

94

95 During functional performance, changes in muscle length or alterations in knee position initiate a
96 stabilisation response, due to the stimulation of mechanoreceptors within the joint or the muscle²¹. Key
97 receptors responsible for this afferent response include Muscle Spindles, Golgi Tendon Organs (GTO's),
98 Ruffini Endings, Ruffini Corpuscles and Pacinian Corpuscles^{11,22}. As to which receptors stimulate the
99 afferent signal however, is arguably irrelevant, as proprioceptive responses from the mechanoreceptors
100 within the joint and muscle are likely to occur at the same time. Reducing injury risk associated with
101 the hamstrings and the knee is reliant on the muscle's ability to generate the required effected functional
102 response⁹.

103

104 Research has focussed on eccentric hamstring strengthening interventions to decrease injury occurrence
105 in the hamstrings and the knee²³. This experimental paradigm fails to consider the effect of functional
106 training on other aetiological factors associated with injury, such as dynamic stability. It also fails to
107 contemplate the multi factorial nature of sustaining these injuries²⁴. The aim of the current study is
108 therefore to establish whether a relationship exists between eccentric strength and stability performance.
109 Establishing this relationship would inform the design of conditioning protocols implemented to reduce
110 injury risk in athletes. It was hypothesised that high eccentric strength measures would relate to low

111 dynamic stability scores. In consideration of the specific nature of the evidence base in regards to injury
112 epidemiology, a population of elite youth soccer players took part in the current study.

113

114 **Methods**

115

116 Fifty-nine elite academy male footballers from two English premier league category 1-status academies
117 completed the present study, age 17.98 ± 2.29 years; height 180.40 ± 7.93 cm and weight 73.65 ± 6.38 kg.

118 All players were in full training, free from injury and available for competitive selection. Any player
119 who had returned from injury within two months leading to the study were not included. All participants
120 provided written informed consent in accordance with department and faculty research ethics
121 committees (STEMH), and in accordance with the Helsinki Declaration.

122

123 Participants completed a familiarisation trial 7 days prior to testing to negate potential learning effects²⁵,
124 which included 3 repetitions of the Nordic Hamstring Curl on the NordBord and the YBT. Prior to any
125 testing all participants completed a standardised warm up (5 minutes cycling at submaximal intensity, a
126 combination of skipping, high knees and butt kicking drills, 10 forward lunges per leg and 2 Nordic
127 hamstring movements with low resistance²⁶. All testing was completed between 13:00 and 17:00 hrs to
128 account for the effect of circadian rhythm and in accordance with regular competition times²⁷.

129

130 All strength testing was completed on the NordBord (Vald Performance) to determine eccentric knee
131 flexor strength; with its reliability, being previously described²⁴. Players knelt on a padded board, with
132 the ankles secured immediately superior to the lateral malleolus by individual ankle braces that were
133 attached to custom made uniaxial load cells (Delphi Force Measurement, Gold Coast, Australia) with
134 wireless data acquisition capabilities (Mantracourt, Devon, UK). Post completion of the standardised
135 warm up previously described participants completed 1 set of 3 maximal repetitions of the bilateral
136 Nordic Hamstring exercises. Instructions to the players were to gradually lean forward at the slowest
137 possible speed while maximally resisting this movement with both limbs while holding the trunk and
138 hips in a neutral position throughout and the hands held across the chest. Participants were loudly

139 exhorted to provide maximal effort throughout each repetition. A trial was deemed acceptable when the
140 force output reached a distinct peak (indicative of maximal eccentric strength), followed by a rapid
141 decline in force when the participant was no longer able to resist the effects of gravity acting on the
142 segment above the knee joint²⁶. In synchronisation with the eccentric strength parameters quantified via
143 the Nordbord, joint kinematics were also measured during each repetition. Joint kinematics were
144 recorded from the sagittal plane using a Canon XA35 camera (Figure 1). The camera was placed on a
145 fixed stand set 3m away and 0.5m from the floor. Three reflective circular markers were attached to the
146 right greater trochanter, right lateral femoral condyle, and right lateral malleolus to calculate knee joint
147 kinematics. Minimal clothing was recommended to avoid movement of the markers. The Nordic
148 hamstring exercise completed on the NordBord was analysed using a variation of the motion analysis
149 protocol adopted from a previous study²⁸. Video clips were digitized and transformed into a two-
150 dimensional space using motion analysis application software (IOS Nordics Application). Each
151 participants' break point angle was calculated using the reflective markers placed on the landmarks
152 previously set.

153

154 *****insert figure 1 here*****

155

156 To ascertain dynamic stability measures for each athlete the YBT owing to its moderate-excellent
157 reliability²⁹ accompanied with its ease of use within a sporting environment. Participants were asked to
158 remove their shoes and socks and completed testing on both lower limbs. This was to eliminate stability
159 and balance provided by the footwear. Once stood single leg on the centre plate participants were asked
160 to push the reach indicator block with the contralateral limb in the anterior (Ant), posteromedial (PM)
161 and posterolateral (PL) directions. Each subject maintained a single leg stance with their hands on the
162 pelvis whilst pushing the reach indicator as far as possible in each of the directions listed. A trial was
163 classified as invalid if the participant did not return to the start position, failed to maintain a unipodal
164 stance on the platform, kicked the reach indicator block to gain more distance, stepped on top of the
165 reach indicator for support or removed their hands from their hips.

166

167 **Data Analysis**

168

169 Participants completed three repetitions on the YBT and the NordBord. YBT scores in each direction
170 (Ant, PM and PL) were normalised for lower limb length to calculate maximum distance (%MAXD)
171 utilising the following equation excursion distance/limb length x 100 = %MAXD. This accounted for
172 potential differences in leg lengths amongst individuals³⁰. Mean distance in each direction on the right
173 and left sides were utilised for data analysis. Eccentric strength data for both left and right limbs is
174 expressed as Newtons (N), Force (F), Peak Torque (PkT) and Average Torque (AvT) were identified
175 for each participant and utilised for analysis. In addition, break angle (Θ) for each of the repetitions
176 completed was taken and the mean (Θ) used for analysis.

177

178 **Statistical Analysis**

179

180 Pearson's correlation coefficients were calculated to quantify the linear relationship between YBT and
181 eccentric strength profiles. All statistical analysis was completed using PASW Statistics Editor 25.0 for
182 windows (SPSS Inc, Chicago, USA). Statistical significance was set at $P \leq 0.05$. Coefficient of
183 correlation (r) and respective level of significance (p value) describes total variance. The following
184 criteria quantified magnitude of the correlation <0.1, trivial; >0.1 to 0.3, small; >0.3 to 0.5, moderate;
185 >0.5 to 0.7, large; >0.7 to 0.9, very large; and >0 to 1.0, almost perfect.

186

187 **Results**

188

189 Table 1 summarises the mean and standard deviation scores achieved for all metrics observed within the
190 present study.

191

192

insert table 1 here

193

194 Correlations displayed between directional dynamic stability scores quantified with the YBT and
195 eccentric hamstring strength metrics ascertained through NordBord testing demonstrated statistically
196 significant correlation coefficients for all eccentric hamstring strength metrics against right (PkT (L): P
197 $= 0.04$, $r = 0.37$; PkT (R): $P = 0.04$, $r = 0.37$; AvF (L): $P = 0.03$, $r = 0.32$; AvF (R): $P = 0.003$, $r =$
198 0.39 ; AvT (L): $P = 0.005$, $r = 0.36$; AvT (R) $P = 0.04$, $r = 0.34$) and left posterior-medial stability (PkT
199 (L): $P \leq 0.001$, $r = 0.60$; PkT (R): $P \leq 0.001$, $r = 0.59$; AvF (L): $P = 0.01$, $r = 0.32$; AvF (R): $P = 0.03$,
200 $r = 0.31$; $P \leq 0.001$, $r = 0.62$; AvT (R) $P = 0.03$, $r = 0.38$). No significant correlation coefficients were
201 found between break angle and right and left posterior-medial stability ((R) PM: $P = 0.59$, $r = -0.07$;
202 (L) PM: $P = 0.58$, $r = 0.07$). The magnitude of the statistically significant correlations ranging from
203 small to moderate.

204

205 Right limb posterolateral stability displayed significant correlation coefficients against PkT (R) and (L)
206 (PkT (R): $P \leq 0.001$, $r = 0.42$; PkT (L): $P \leq 0.001$, $r = 0.41$); AvF (R) ($P = 0.05$, $r = 0.32$) and AvT (R)
207 ($P = 0.002$, $r = 0.40$). This was replicated for posterior-lateral (L) PkT (R): $P \leq 0.001$, $r = 0.42$; PkT
208 (L): $P = 0.002$, $r = 0.39$; AvF (L) $P = 0.003$, $r = 0.38$ and AvT (L) $P = 0.002$, $r = 0.39$. No significant
209 correlation coefficients were displayed for AvF (L), AvT (L) and Θ when compared to (R) and posterior-
210 lateral stability ($P > 0.05$). The opposite was identified for (L) posterior-lateral stability, where no
211 significant correlation coefficients were displayed for AvF (R), AvT (R) and Θ ($P > 0.05$). PM stability
212 displaying small significant correlations.

213

214 (R) and (L) Ant stability displayed no significant correlation coefficients against any eccentric hamstring
215 strength metrics ($P > 0.05$). See table 2 for a summary of stability parameters and eccentric hamstring
216 strength metrics for elite academy footballers.

217

218 ***insert table 2 here***

219

220

221

222

223 Discussion

224

225 The aim of the present study was to investigate the relationship between lower limb dynamic stability
226 and eccentric hamstring strength in elite academy footballers. Main findings from this body of work
227 highlight significant correlations between eccentric hamstring strength and PL/PM stability. However,
228 analysis of correlations between Ant stability and eccentric strength demonstrated no significant
229 relationships. Significant correlations were identified for PL and PM stability with the magnitude
230 ranging from small to moderate, with PkT and AvT displaying the highest range ($r = 0.36 - 0.62$),
231 compared to Force values ($r = 0.31 - 0.39$). This could potentially be explained by the relative nature
232 of force output to body mass²⁶. Break angle also displayed no significant correlations. This metric can
233 provide an interpretation of muscle architecture, but does not relate to the actual strength output of the
234 muscle. Observations of this metric were made to determine whether architecture of the muscle had any
235 influence on directional stability performance, due to changing demands in the varying directions of
236 movement tested within the YBT.

237

238 Previous work has often referred to dynamic stability, as proprioception¹¹. Proprioception has
239 consistently been highlighted as being, ‘the body’s ability to sense movements within joints and to have
240 a knowledge of where these joints are in relation to space’³¹. This operational definition within an
241 applied environment may cause some confusion, as measures, tests and exercises actually relate to an
242 effected output and not the physiological proprioceptive process. To measure proprioception as a whole
243 function is difficult and as practitioners in sport, we are more concerned about the effected output.
244 Consideration has been given to this in the present study and identification of the relationship between
245 eccentric hamstring strength and dynamic stability identified. The present study also considers the
246 directional nature of dynamic stability in relation to functional strength, something not reflected in
247 previous literature in this area¹². Quantification of dynamic stability within research is consistently
248 debated, with no gold standard functional test identified³². In the present study, the YBT was utilised to
249 determine stability measures. ACL injuries are commonly associated with high load anterior shearing
250 force, often accompanied with rotation¹⁶. Utilisation of the YBT provided an opportunity to analyse

251 directional stability, allowing association to be made between the anatomical function of the hamstring
252 and the stability score. Findings from the present study provide practitioners with an understanding of
253 the contribution of eccentric hamstring strength on knee function, informing conditioning, rehabilitation
254 and injury prevention protocols. However, small to moderate correlations support the acknowledgement
255 throughout literature that hamstring and knee injuries are multi factorial and may not be the only
256 consideration in injury risk reduction or rehabilitation protocols^{3,6}.

257

258 Previous research has focussed on quantifying proprioception/dynamic stability with an overall stability
259 score²¹, when examining the influence of eccentric strength. This limits interpretation of the relationship
260 between eccentric hamstring strength, knee function and its relevance to functional performance. In the
261 present study relationships were established between eccentric hamstring strength parameters and
262 directional stability (inclusive of; (R) and (L) Ant, PM and PL). Significant correlations were identified
263 for (R) and (L) PM stability, noted between all strength parameters of PkT, AvT and AvF (L) and (R).
264 Suggesting that increased eccentric hamstring strength in elite academy footballers, contributes to
265 greater stabilisation in this plane of movement. During the performance of the YBT the hamstrings act
266 as a dynamic stabiliser at the knee, reducing stress through the joint. The lunge position completed when
267 performing the YBT consists of flexion of the knee and increased rotational stress through the joint.
268 Consideration of the mechanism of injury associated with common knee injuries sustained in elite
269 football, are associated with this movement pattern¹⁶. Potentially indicating that sports medicine
270 practitioners should consider this in their choice of exercise prescription in the pursuit of decreasing
271 injury risk.

272

273 During functional movement patterns performed during football specific movements anterior
274 stabilisation is required to support key structures in the knee, such as the ACL. This movement pattern
275 provides the most contentious debate in the present findings. Consideration must be given to the position
276 of the athlete when performing this measure in the YBT, as the hamstring muscle is not contracting
277 eccentrically at reach position. However, to control further stress on the knee and reverse the movement
278 pattern the hamstrings will sustain eccentric load and if the functional strength of the athlete is not

279 apparent, there is potential to perform poorly on the stability test. Current findings indicate strength has
280 no influence on this. This potentially supports cardarvic research suggesting that reduced
281 mechanoreceptors detected in the ACL, may result in a delayed proprioceptive response when
282 performing functional tasks²². Previous research has identified the influence of decreased ankle
283 dorsiflexion, poor antagonistic function, and hip mobility, to name a few³³. These factors may explain
284 poor anterior or overall stability output, however; only provide limited explanation to why relationships
285 were found in other planes of movement. Consideration must also be given to limb dominance as this
286 may demonstrate further relationships between eccentric strength and dynamic stability³⁴. Future
287 research should investigate these considerations in order to establish the multi-factorial nature of injury.

288

289 Dynamic stability is the effected output generated through proprioceptive function. During completion
290 of this movement pattern, the knee and specifically the tibia are subjected to an anterior force, as it
291 would during functional performance when decelerating in an anterior plane. Cardarvic research
292 indicates that the ACL has fewer mechanoreceptors contained within it when compared to the
293 surrounding structures within the joint¹¹. Potentially, suggesting that there may be a delayed signal
294 within the proprioceptive pathway to generate the required output through this plane of movement. This
295 said other aetiological factors cannot be discounted such as antagonistic function, ankle dorsiflexion or
296 hip mobility³³.

297

298 It is well documented throughout literature that muscle architecture is key to reducing hamstring injury
299 risk²⁴. Findings within the present study showed no significant relationships between any stability
300 parameter and Θ . An explanation of this through observation of potential differences in position and
301 resultant muscle length when performing the two tests may be relevant. Consideration to the mechanism
302 of injury for hamstring and ACL provides a potential explanation as to why no relationship was found
303 in the current study. However, further research in this area would be required. Research indicates that
304 the ACL is the most commonly injured ligament in the knee³⁵, with increases in re-rupture and poor
305 return of the athlete to the same level pre-injury⁶. Common mechanisms associated with ACL are linear
306 motions from either a rapid acceleration or deceleration or excessive anterior force through the knee

307 joint¹⁶. The findings in the current research highlight relationships between higher eccentric strength
308 scores and lower dynamic stability scores, with the exception of AP stability and Θ . Consideration
309 therefore, that increased eccentric strength has a positive influence on stability of the knee is suggested.
310 Further research in this area should focus its attention on intervention training protocols to examine their
311 effect on key aetiological contributors to injury.

312

313 **Conclusion**

314 Eccentric hamstring strength metrics are positively associated with PM and PL directional stability
315 performance during the YBT, with no relationships existing between strength and anterior stability.
316 Caution must be applied when interpreting the significance of the findings due to the small to moderate
317 relationships identified. However, importantly interpretation of the findings suggest that despite
318 increases in functional hamstring strength, a main stabiliser of the knee during functional performance,
319 has no influence on the stability of the knee. Thus, implying that despite the intervention of eccentric
320 hamstring strengthening protocols within elite footballers, players can potentially still be at an increased
321 risk of sustaining ACL injury. Careful consideration must be given by key stakeholders within
322 performance departments to quantification of injury risk parameters of strength and stability,
323 interpretation of their results and application in conditioning and injury prevention protocols.

324

325 **Practical Implications**

- 326 • Relationships are evident between PM and PL directional stability and eccentric strength
327 metrics, which potentially indicates the need for practitioners to consider the inclusion of
328 eccentric strengthening programmes. However, further research is required in the format of a
329 training study to identify cause-effect relationships.
- 330 • Although relationships were identified between eccentric strength and PM/PL directional
331 stability, none were identified with AP stability. Sports medicine practitioners cannot
332 disregard other aetiological factors associated with poor stability performance and must not
333 discount these in injury risk reduction protocols.

- 334 • Increases in eccentric hamstring strength parameters may reduce muscle injury risk, but effect
335 on joint injury risk is not conclusive.

336 **References**

- 337 1. Ekstrand J, Hagglund M, Walden M. Injury Incidence and Injury Patterns in Professional
338 Football: The UEFA Injury Study. *Br J Sports Med* 2011; 45(7):553-558.
- 339 2. Woods C, Hawkins RD, Maltby S. The Football Association Medical Research Programme: an
340 audit of injuries in professional football. Analysis of Hamstring Injuries. *Br J Sports Med* 2004;
341 38(1):36-41.
- 342 3. Ekstrand J, Walden M, Hagglund M. Hamstring Injuries Have Increased by 4% Annually in
343 Men's Professional Football, Since 2001: A 13 Year Longitudinal Analysis on the UEFA Elite
344 Club Injury Study. *Br J Sports Med* 2016; 50(12):731-8.
- 345 4. Erickson BJ, Harris JD, Cvetanovich GL, et al. Performance and return to sport after anterior
346 cruciate ligament reconstruction in male Major League Soccer players. *Ort J Sports Med*; 2013;
347 11(1): 553-558.
- 348 5. Krutsch W, Zeman F, Zellner J, et al. Increase in ACL and PCL injuries after implementation
349 of a new professional football league. *Knee Surg Sports Traumatol Arthrosc* 2016; 24(7): 2271-
350 2279.
- 351 6. Walden M, Hagglund M, Magnusson H, et al. ACL Injuries in Men's Professional Football: A
352 15-Year Prospective Study on Time Trends and Return-to-Play Rates Reveals only 65% of
353 Players Still Play at the Top Level 3 Years after ACL Rupture. *Br J Sports Med* 2016; 50(12):1-
354 7.
- 355 7. Messer D, Bourne M, Timmins R, et al. Eccentric knee flexor strength and hamstring injury risk
356 in athletes with history of anterior cruciate ligament reconstruction. *Br J Sports Med*
357 2017;51:284-413.
- 358 8. Barengo NC, Meneses-Echavez JF, Robinson RV, et al. The Impact of the FIFA 11+ Training
359 Program on Injury Prevention in Football players: A Systematic Review. *Int J Environ Pub*
360 *Health* 2014; 11(11):11986-12000

- 361 9. Rhodes D, McNaughton L, Greig M. The Temporal Pattern of Recovery in Eccentric Hamstring
362 Strength Post Soccer Specific Fatigue. *Res Sports Med* 2018; 10(8):1-12.
- 363 10. Proske U and Morgan DL. Muscle Damage from Eccentric Exercise: Mechanism, Mechanical
364 Signs, Adaptation and Clinical Applications. *J Physiol* 2001; 537(pt2):333-345.
- 365 11. Changella PK, Selvamani K, Ramaprabhu. A Study to Evaluate the Effect of Fatigue on Knee
366 Joint Proprioception and Balance in Healthy Individuals. *Int J Sci Res Pub* 2012; 2(3):1851-
367 1857.
- 368 12. Booysen MJ, Gradidge PJ, Watson E. The relationships of eccentric strength and power with
369 dynamic balance in male footballers. *J Sports Sci* 2015; 33(20): 2157-2165.
- 370 13. Hyun-Jung K, Jin-Hyuck L, Sung-Eun A, et al. Influence of Anterior Cruciate Ligament Tear
371 on Thigh Muscle Strength and Hamstring-to-Quadricep Ratio: A Meta Analysis. *PLoS One*
372 2016; 11(1):1-11.
- 373 14. Arnason SM, Birnir B, Gudmundsson G, et al. Medial Hamstring Muscle Activation Patterns
374 are Affected 1-6 Years after ACL Reconstruction Using Hamstring Autograft. *Knee Surg*
375 *Sports Traumatol Arthrosc* 2014; 22(5):1024-1029.
- 376 15. Kim HJ, Lee J H, Ahn SE, et al. Influence of Anterior Cruciate Ligament Tear on Thigh Muscle
377 Strength and Hamstring-to-Quadriceps Ratio: A Meta Analysis *PLoS One* 2016; 11(1):1-11.
- 378 16. Alentorn-Geli E, Myer GD, Silvers HJ. Prevention of Non-Contact Anterior Cruciate Ligament
379 Injuries in Soccer Players. Part 1: Mechanisms of Injury and Underlying Risk Factors. *Knee*
380 *Surg Sport Traumatol Arthrosc* 2009; 17(7): 705-729.
- 381 17. Harput G, Kilinic E, Ozer H, et al. Quadriceps and Hamstring Strength Recovery During Early
382 Neuromuscular Rehabilitation After ACL Hamstring-Tendon Autograft Reconstruction. *J*
383 *Sports Rehab* 2015; 24(4):398-404.
- 384 18. Besier TF, Lloyd DG, Cochrane JL. External loading of the knee joint during running and
385 cutting manoeuvres. *Med Sci Sports Ex* 2001; 33(7):1168–1175.
- 386 19. Hewett TE, Di Stassi SL, Myer GD. Current Concepts for Injury Prevention in Athletes after
387 Anterior Cruciate Ligament Reconstruction. *Am J Sports Med* 2013; 41(1):216-224.

- 388 20. Bryant AL, Clark RA, Pua YH. Morphology of Hamstring Torque-Time Curves following ACL
389 Injury and Reconstruction: Mechanisms and Implications. *J Orthop Res* 2011; 29(6):907-914.
- 390 21. Melnyk M and Gollhofer A. Submaximal Fatigue of the Hamstrings Impairs Specific Reflex
391 Components and Knee Stability. *Knee Surg Sports Traumatol Arthrosc* 2007; 15(5):525-532.
- 392 22. Lee DH, Lee JH, Ahh SE. Effect of Time after Anterior Cruciate Ligament Tears on
393 Proprioception and Postural Stability. *PLoS One* 2015; 10(9):1-10.
- 394 23. Petersen J, Thorborg K, Nielsen BM, et al. Preventive effect of Eccentric Training on Acute
395 Hamstring Injuries in Men's Soccer: A Cluster-Randomized Control Trial. *Am J Sports Med*
396 2011; 39(11):2296-2303.
- 397 24. Opar DA, Piatkowski T, Williams MD, et al. A novel device using the Nordic hamstring
398 exercise to assess eccentric knee flexor strength: a reliability and retrospective injury study. *J*
399 *Orthop Sports Phys Ther* 2013; 43(9):636-640.
- 400 25. Hinman M. Factors Affecting Reliability of the Biodex Balance System: A summary of Four
401 Studies. *J Sport Rehabil* 2000; 9(3):240-252.
- 402 26. Buchheit M, Cholley Y, Nagel M, et al. The effect of body mass on eccentric knee-flexor
403 strength assessed with an instrumented Nordic hamstring device (NordBord) in football players.
404 *Int J Sports Physiol Perform* 2016; 11(6):721-726.
- 405 27. Sedliak M, Haverinen M, Hakkinen K. Muscle Strength, Resting Muscle Tone and EMG
406 Activation in Untrained Men: Interaction Effect of time of Day and Test Order-Related
407 Confounding Factors. *J Sports Med Phys Fit* 2011; 51:560 – 570.
- 408 28. Lee JWY, Mok K, Chan HCK, et al. Eccentric hamstring strength deficit and poor hamstring-
409 to-quadriceps ratio are risk factors for hamstring strain injury in football: A prospective study
410 of 146 professional players. *J Sci Med Sport* 2017; 21(8):789-793.
- 411 29. Smith LJ, Creps JR, Bean R, et al. Performance and Reliability of the Y Balance Test in High
412 School Athletes. *J Sports Med Phys Fit* 2017; 58(11):1671-1675.
- 413 30. Robinson R. and Gribble P. Kinematic predictors of performance on the star excursion balance
414 test. *J Sport Rehab* 2008; 17(4):347-357.

- 415 31. Han J, Waddington G, Adams R, et al. Assessing Proprioception: A Critical Review of
416 Methods. *J Sport Health Sci* 2015; 5(1):80-90.
- 417 32. Dawson N, Dzurino D, Karleskint M, et al. Examining the reliability, correlation and validity
418 of commonly used assessment tools to measure balance. *Health Sci Rep* 2018; 1(12): 1-8.
- 419 33. Kang MH, Kim GM, Kwon OY, et al. Relationship between the kinematics of the trunk and
420 lower extremity and performance on the Y-balance test. *PMR* 2015; 7(11): 1152-1158.
- 421 34. Brophy R, Silvers H J, Gonzales T, et al. Gender Influences: The Role of Leg
422 Dominance in ACL Injury Among Soccer Players. *Br J Sports Med* 2010; 44(10): 694–
423 69.
- 424 35. Silvers-Granelli HJ, Bizzini M, Arundale A, et al. Does the FIFA 11+ injury prevention
425 programme reduce the incidence of ACL injury in male soccer players? *Clin Orth Rel Res* 2017;
426 475(10):2447-2455.

427

428 **Tables Legends**

429 **Table 1:** Displaying Mean and Standard Deviation.

430

431 **Table 2:** Displaying Relationships between Stability Parameters and Eccentric Hamstring Strength
432 Metrics for Elite Academy Footballers.

433

434 **Figure Legends**

435 **Figure 1:** Image of the standardisation of the camera used in order to determine the break point angle
436 of the NHE.