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1 **The relationship between concentric hip abductor strength and the performance of the**  
2 **Y-balance test (YBT)**

3

4 **Key Points**

5 • Hip abductor strength is moderately associated with single leg dynamic balance as  
6 measured by the YBT.

7 • The association between hip strength and single leg dynamic balance is strongest  
8 during the posterior reaches of the YBT.

9 • The requirement for greater hip flexion, during the posterior reaches may impose  
10 greater demands on the hip extensors and abductors to control the movement.

11 • Targeting the hip abductor muscles as part of multi-level intervention is warranted  
12 when attempting to improve dynamic single leg stability.

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14 **Key words:** single leg, dynamic postural stability, gluteus

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22 **Abstract**

23 Side lying hip abduction is an action used during manual muscle testing and is also  
24 prescribed as a rehabilitation exercise to improve dynamic single leg stability. Little is known  
25 about the functional cross-over of this activity. The aims of this study was to investigate the  
26 relationship between concentric hip abductor strength and performance of the Y-Balance test  
27 (YBT). Forty-five recreational gym users (27 male age 26.2 (8.4) years, 18 female age 27.4  
28 (7.5) years) had dynamic single leg stability and concentric hip abductor peak torque assessed  
29 in the non-dominant limb using a YBT and isokinetic dynamometry, respectively. All  
30 components of the YBT had a moderate association with concentric hip abductor torque  
31 which were greater in the posteromedial ( $r=0.574$ ,  $P<0.001$ ) and posterolateral ( $r=0.657$ ,  
32  $P<0.001$ ) directions compared to the anterior direction ( $r=0.402$ ,  $P=0.006$ ). Greater  
33 concentric hip abductor strength is associated with greater scores on components of the YBT,  
34 particularly the posterior reaches.

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## 44 **Introduction**

45 In static conditions, balance is defined as the ability to maintain the centre of gravity over a  
46 base of support.<sup>1</sup> Athletic activities such as running require the centre of gravity (position and  
47 velocity) to be maintained in the upright position despite a changing and moving base of  
48 support.<sup>2</sup> Hip abductor torque is thought to play an important role in stabilizing the trunk and  
49 pelvis. The hip abductors maintain lower limb alignment through reducing accelerations of  
50 the centre of mass in the sagittal and frontal plane in response to postural perturbations.<sup>3,4</sup>  
51 Compared to healthy controls, individuals with lower extremity injury such as chronic ankle  
52 instability (CAI),<sup>1</sup> anterior cruciate ligament (ACL) injury<sup>5</sup> and patellofemoral pain syndrome  
53 (PFPS)<sup>6,7</sup> have been reported to have reduced dynamic single leg stability. Hip abductor  
54 dysfunction is thought to contribute to poor lower extremity control by allowing knee valgus  
55 which occurs as a result of coupled adduction and internal rotation of the femur.<sup>8</sup> Greater  
56 knee valgus during dynamic tasks has been reported in those with acute (ACL)<sup>9</sup> and chronic  
57 (PFPS)<sup>10</sup> injury, compared to healthy controls. Furthermore, individuals with hip abductor  
58 dysfunction tend to lean towards the side of dysfunction to balance the centre of gravity on  
59 the hip joint centre,<sup>8</sup> further reducing the demand of the hip abductors on the stance leg. This  
60 position likely contributes to increased knee valgus, altering of the centre of pressure relative  
61 to the ankle joint and leading to increased demand on muscles of the lower leg.<sup>3</sup>

62 The hip abductors, most notably tensor fascia latae, gluteus minimus, medius and maximus,  
63 concentrically abduct the hip, isometrically stabilise the pelvis and eccentrically control hip  
64 adduction and internal rotation.<sup>11</sup> Increasing isometric hip abductor strength is associated  
65 with greater dynamic single leg stability. Previously, both Hubbard et al. and Lee et al. have  
66 demonstrated a moderate to strong association ( $r=0.49 - 0.72$ ;  $P<0.05$ ) between isometric hip  
67 abduction strength and performance of the posterior reaches of the Y-balance test (YBT).<sup>12,13</sup>

68 Open kinetic chain side lying hip abduction has been shown to elicit levels of muscle  
69 contraction (>70% of maximum voluntary contraction (MVC)) in line with that required to  
70 achieve strength gains.<sup>14,15</sup> However, to date, little is known about whether hip abductor  
71 strength whilst side-lying in a non-weight bearing position is associated with enhanced single  
72 leg stability in a weight-bearing position. Isokinetic dynamometry is a criterion method for  
73 the assessment of a MVC as it is subject to less confounding variables than that of handheld  
74 dynamometry such as examiner strength, the inability to correct for gravity and stabilisation  
75 techniques used.<sup>16</sup> Furthermore, peak torque from a voluntary muscle contraction can be  
76 measured within a coefficient of variance of 5%.<sup>17</sup> Many studies have assessed hip abductor  
77 strength using handheld dynamometers,<sup>12,18-20</sup> comparatively few have used isokinetic  
78 dynamometry.<sup>6,21</sup> Furthermore, variance in participant positioning, protocol for assessment as  
79 well as the criteria for the acceptance of peak torque measured from a MVC has varied  
80 widely among researchers. The Star Excursion Balance Test (SEBT) has emerged as a time  
81 and cost effective method of quantifying single leg dynamic balance with established  
82 reliability.<sup>22</sup> An instrumented version of the modified SEBT is known as the Y-balance test  
83 (YBT) and has been shown to measure balance in the anterior and posterior reach  
84 directions.<sup>23</sup> Whilst Coughlan et al.<sup>24</sup> identified that participants could reach further in the  
85 anterior direction of the SEBT, no difference in posterior reaches was found when compared  
86 to the YBT, suggesting posterior reaches are comparable with existing literature.

87 To the authors knowledge there has yet to be a study which assesses the relationship between  
88 concentric hip abductor strength and single leg dynamic balance as measured by isokinetic  
89 dynamometry and the YBT test respectively. It is plausible that those with lower hip muscle  
90 strength will have a lower capability of performing the YBT, particularly the posterior reach  
91 directions, due to an inability to eccentrically control the required hip flexion.<sup>8</sup> The aim of  
92 this study was to assess whether there is an association between concentric hip abductor

93 strength and single leg dynamic balance in a convenience sample of healthy recreational gym  
94 users aged 18 – 35 years. We hypothesize that greater hip abductor torque will be associated  
95 with greater scores on the YBT, particularly in the posterior reach directions.

## 96 **Methods**

### 97 **Participants**

98 This study employed a cross-sectional study design in which participants reported to the  
99 laboratory for a single data collection session. A convenience sample of forty five  
100 participants (27 male, age 26.2 (8.4) years, height 173.3 (6.7) cm, weight 71.3 (9.9) kg and 18  
101 female, age 27.4 (7.5) years, height 169.3 (5.9) cm, weight 65.3 (9.9) kg) all of whom were  
102 recreationally active at a local health and wellbeing centre or the University sports centre  
103 were recruited to the study. The definition of a recreational gym user was anyone who took  
104 part in gym based or group exercise activities at least three times per week.<sup>25</sup> Participants  
105 were required to be free from lower extremity injury for at least 6 months prior to testing,  
106 have no history of hip, knee or ankle surgery and be free from illness, such as influenza.  
107 These factors may influence strength and balance assessments and were excluded as potential  
108 confounding variables. After receiving a complete explanation of the procedures, benefits and  
109 risks of the study, all participants gave their written informed consent. Participants were  
110 asked to refrain from strenuous exercise in the 24-hours before testing. All procedures were  
111 performed in accordance with the most recent version of the Declaration of Helsinki and  
112 approved by the Research Ethics Committee of the University of St. Mark and St. John.

113 **Instrumentation** Performance of the Y-balance test was conducted using a Y-Balance Test  
114 Kit (Functional Movement Systems, Virginia, USA) as illustrated in Figure 1. Peak torque of  
115 the non-dominant limb was determined from a MVC (30°/s) of the hip abductors using a  
116 commercially available dynamometer (Figure2; Humac Norm, CSMI, Massachusetts, USA).

117 **Task**

118 All participants reported to the University sports science laboratory for testing wearing shorts  
119 and a t-shirt. All measurements were recorded by the same clinician to avoid intertester  
120 variability. Warm up consisted of 5 minutes on a bicycle ergometer (Wattbike Cycle  
121 Ergometer, Wattbike Pro, Nottingham, UK) at a cadence of 60 RPM. Intensity was self-  
122 selected at what they felt was their normal warm up pace. Performance of the Y-balance test  
123 was conducted prior to isokinetic testing of hip abductor strength. The non-dominant limb  
124 (stance leg when kicking a ball) was used in both cases.

125 To perform the Y-balance test, participants were required to move each of the indicators in  
126 the anterior, posteromedial and posterolateral directions as far as possible, using the dominant  
127 foot. Isokinetic hip abductor strength was assessed in the side lying position (Figure 2).

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129 **Procedures**

130 Participants had their limb length measured from the anterior superior iliac spine to the distal  
131 tip of the medial malleolus using an anthropometric tape measure. The YBT was described as  
132 a test of balance to participants. A member of the research team demonstrated the test before  
133 instructing the participant. Participants were asked to place the foot of the non-dominant leg  
134 (support leg when kicking a ball; used for standardization) on the stance block with the hallux  
135 perpendicular to the red line and with the dominant leg in contact with the ground for support  
136 prior to testing. Participants were then asked to move each of the indicators in the anterior,  
137 posteromedial and posterolateral directions as far as possible, using the dominant foot and  
138 without losing contact with the indicators. Participants returned to the starting position prior  
139 to completing each movement. Any loss of balance or repetitive movement was excluded and  
140 a new trial performed. Four trial attempts were carried out, to exclude any learning effect,

141 prior to three test attempts as in Munro et al.<sup>22</sup>. The highest attempt in each direction was  
142 accepted as a value for anterior, postero-medial and posterolateral reach directions.  
143 Participants performed each trial when they were ready after the previous trial and without a  
144 defined rest period.

145 After completion of the YBT, participants had the non-dominant limb assessed for peak  
146 concentric torque of the hip abductors. The contraction speed (30°/s) was chosen due to the  
147 descending force associated with increasing speed of contraction.<sup>26</sup> Participants were side  
148 lying with a seat angle of 0°. The hip and knee of the dominant limb were flexed to 90°. The  
149 pelvis was in neutral to try to ensure the head of the femur of the non-dominant limb was  
150 aligned over that of the dominant limb. From this position and with the use of a goniometer  
151 the non-dominant hip (hip to be tested) was placed into 10° of extension in order to best  
152 isolate the hip abductors and limit torque generation from anterior muscles such as the  
153 quadriceps femoris muscle group, the iliopsoas and tensor fasciae latae.<sup>27</sup> This decision was  
154 made after it became noticeable during pilot testing that the hip of the leg being tested, when  
155 started in 0°, tended to move forwards. Beginning in 10° of hip extension meant the hip did  
156 not move past 0° during hip abduction. To secure this position, a velcro strap was fastened  
157 from either side of the seat above the iliac crest of the participant. As in Gordon et al.<sup>28</sup>, a  
158 circular cushion was inserted under and parallel to the non-dominant limb to allow the limb  
159 to rest between contractions and also to reduce potential for over-activity in the adductor  
160 muscles. The dynamometer rotational axis was aligned with the greater trochanter (hip joint  
161 axis of rotation). The pad, into which participants exerted force into was placed 5cm above  
162 the base of the patella along the iliotibial band as in De Marche Baldon et al.<sup>21</sup>. Once secured,  
163 the mass of the limb was weighed in order to perform a gravitational correction. After  
164 familiarization with procedures, participants were given three trial attempts in which they  
165 were asked to perform at 25%, 50% and 75% of their perceived maximum as in Lepley et



166 al.<sup>29</sup>. This was to ensure adequate warm up and reduce the potential for a learning effect<sup>17</sup> due  
167 to unfamiliarity with exerting force in a side lying position. A minimum of 3 and a maximum  
168 of 5 MVC's were undertaken by participants in order to ensure repeated measures within a  
169 coefficient of variance (CV) of 5%. If after 3 attempts there was not 2 contractions which  
170 satisfied the criteria (see below) for MVC and resided within a CV of 5%, a 4th trial was  
171 performed and if necessary a 5th. All participants generated repeated measures within 5 trials.  
172 Each contraction was separated by two minutes of stationary rest in order to ensure sufficient  
173 replenishment of the phosphor-creatine energy system.<sup>30</sup> The participant was instructed to  
174 consistently produce their maximal force rapidly, through their maximum range of motion  
175 (ROM) (as hard and as fast as possible in the frontal plane) and to maintain that force for 3-4  
176 seconds. Participants received a 5 second count down with a distinct emphasis on "Go". No  
177 overt verbal encouragement was provided due to the difficulty in standardizing it for all  
178 participants.<sup>31</sup> Attempts not sustained for MVC (identified by an impact spike), containing an  
179 initial countermovement (identified by a visible drop/rise in the torque signal) >5 N·m or with  
180 a non-linear time-torque trace (identified by a double movement) were disqualified and  
181 excluded from further analysis. The remaining measures, which met the above criteria for a  
182 MVC and had repeated measures of peak torque within a CV of 5%, were accepted for  
183 correlation analysis with those of the YBT.

#### 184 **Statistical Analyses**

185 Statistical analyses were performed using IBM SPSS statistics 22 for windows (SPSS, Inc.,  
186 Chicago, IL). YBT test scores normalised for leg length were calculated as: (reach distance  
187 (cm)/leg length (cm)) \*100. A Shapiro-wilk test was used to assess whether parameters for  
188 single leg dynamic balance and hip abductor strength were normally distributed. Mean,  
189 standard deviation (SD) and ranges are reported. The predictor variable (peak concentric

190 torque) and criterion variable (anterior, poster lateral and posteromedial reaches) were  
191 normally distributed and therefore a Pearson's correlation analysis was used to assess the  
192 strength of the associations. The strength of association and 95% confidence intervals were  
193 classified based on that most recently suggested by the British Medical Journal: 0-0.19 very  
194 weak, 0.2-0.39, weak, 0.40-0.59 moderate, 0.6-0.79 as strong and 0.8-1 very strong. Simple  
195 linear regression analysis was used to quantify the variance in reach distance (normalized for  
196 limb length) explained by concentric peak torque (normalized for body mass). YBT distance  
197 (anterior, posterior-lateral or posterior-medial) was entered as the criterion variable and  
198 concentric hip abductor torque was entered as the predictor variable. Significance (2-tailed)  
199 was set at  $P < 0.05$  for all analyses.

## 200 **Results**

201 Participant limb length, concentric peak torque and YBT reach distances are displayed in  
202 Table 1. Concentric hip abductor peak torque was moderately correlated with all reach  
203 distances ( $P < 0.05$ ; Table 2). The posterior reach scores (normalized for limb length) of the  
204 YBT had the greatest association with peak concentric torque of the hip abductors  
205 (normalized for body mass). The posterolateral direction had the strongest association  
206 ( $r = 0.657$ ,  $P < 0.001$ ) with concentric peak torque, followed by the posteromedial ( $r = 0.574$ ,  
207  $P < 0.001$ ) and anterior ( $r = 0.402$ ,  $P = 0.006$ ) direction respectively (Table 2). Hip abductor  
208 torque corrected for body mass explained 43% of the variance in posterolateral reach distance  
209 corrected for limb length (Table 2; Figure 3).

## 210 **Discussion**

211 This study sought to investigate the relationship between concentric hip strength torque and  
212 components (anterior, posteromedial, posterolateral) of the YBT. All balance components  
213 had a moderate association with concentric hip abductor strength and in accordance with our

214 hypothesis were greater in the posteromedial and posterolateral directions compared to the  
215 anterior direction. Compared to the anterior reach, performance of the posterior reaches  
216 require a greater degree of hip flexion on the side of the stance leg.<sup>32</sup> This movement pattern  
217 is accomplished to a large extent by an anterior movement of the pelvis, a motion which  
218 requires greater eccentric hip muscle torque.<sup>8</sup>

219 The anterior reach of the YBT tends to cause participants to assume a more erect trunk  
220 posture which requires less hip flexion, and subsequently less anterior movement of the  
221 pelvis.<sup>32</sup> It is possible that this alteration in movement strategy requires participants to rely  
222 more on knee extensor muscle performance to accomplish the anterior reach task. This may  
223 explain the weaker association between hip abductor strength and anterior reach performance  
224 relative to the posterior reaches in the current study. These differences are likely due to the  
225 test constraints which require the foot to be extended out in front of the body during the  
226 anterior reach. Without a more upright posture, as the leg moves further forward there is a  
227 greater risk of loss of balance due to the centre of mass moving further away from its base of  
228 support. If the aim of the test was not to reach as far forward as possible, then a single leg  
229 squat (with the leg out in front) may be performed with a similar contribution from the hip  
230 extensors and abductors. Hubbard et al.<sup>12</sup> reported similar associations between isometric hip  
231 abduction, as measured by handheld dynamometry and posteromedial ( $r=0.51$ ,  $P=0.004$ ) and  
232 posterolateral ( $r=0.49$ ,  $P=0.006$ ) reach distances in thirty participants with chronic ankle  
233 instability (CAI). The slightly stronger associations in our study are perhaps due to the use of  
234 participants without CAI. Dynamic single limb stability is reportedly lower in patients  
235 suffering with CAI.<sup>1</sup> As healthy active young adults were observed in this study, direct  
236 comparison of results between cohorts cannot be made. Furthermore, peak torque has been  
237 shown to be angle specific,<sup>26</sup> meaning isometric assessment may not identify maximum  
238 strength in all participants.<sup>33</sup> This study utilised a predefined criteria for accepting a MVC as

239 valid prior to accepting a measure of peak torque. Subsequently, only repeated measures  
240 which met this criteria and were within a CV of 5% were used for analysis. In addition, our  
241 protocol began with participants in 10° of hip extension to avoid the hip joint moving past 0°  
242 during side lying hip abduction which appeared to happen during pilot testing. These  
243 differences in protocol may give our measures greater criterion validity,<sup>27</sup> although as of yet,  
244 it is unknown whether there is a difference in torque output between test positions used in the  
245 literature.

246 The importance of the hip abductor muscles in facilitating single leg stability is perhaps  
247 underscored by the fact that concentric hip abductor strength explained 43% of the variance  
248 in the posterolateral reach direction. It may be that a semi-static balance test in which the  
249 base of support is fixed depends more on absolute strength than more dynamic balance tasks  
250 in which neuromuscular control may play a greater role. Furthermore, the moment arm of the  
251 proximal gluteal muscles is longer than the other distal lower extremity muscles that act  
252 directly on the ankle joint and as such, may be better at controlling the centre of mass during  
253 the lowering phase of the YBT. This suggestion is supported by Miller and Bird<sup>34</sup> who  
254 reported fatigue of the muscles of the hip and knee to have greater negative impact on single  
255 leg stability relative to fatigue of distal lower extremity muscles. More recently, Gribble and  
256 Hertel<sup>35,36</sup> demonstrated greater postural control deficits when fatiguing the hip abductors and  
257 adductors compared to the ankle invertors and evertors. The muscles acting on the hip and  
258 knee have a greater cross-sectional area and therefore greater force output than those at the  
259 ankle. Conversely, larger muscles may have less ability to rapidly adjust to perturbations in  
260 comparison to the smaller muscles around the ankle. It may be that that slower movement  
261 strategy allowed in the YBT, in addition to the repeated practice trials undertaken before a  
262 measurement is taken, does not require rapid adjustment from the ankle musculature but  
263 instead depends on the torque of the muscles acting on the hip and knee.

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## 266 **Limitations**

267 Although the discussion of our data is plausible, it should be interpreted cognisant that  
268 although the association between hip strength and the posterior reaches is considered  
269 moderate to strong; the lower bound of the 95% confidence interval suggests the association  
270 may only be weak to moderate (Table 2). This study investigated a convenience sample of  
271 healthy active adults (18-35 years) and therefore sheds some light on the relationship between  
272 concentric hip strength and single leg stability but is not generalizable to all active  
273 populations. In addition, we did not control for previous history of concussion and cannot be  
274 sure that minor respiratory tract infections were not present which could affect the outcome  
275 of the balance tests.

## 276 **Clinical Implications**

277 Dynamic single leg stability is influenced by a multitude of factors including flexibility,  
278 neuromuscular control and strength. These data suggest that hip abductor strength may be an  
279 important contributor to single leg stability, particularly over a fixed base of support. Our  
280 findings, acknowledging the limitation of the cross-sectional study design, suggest that  
281 clinicians who wish to assess changes in single-leg balance, using the YBT, as a result of  
282 change in side-lying hip strength should focus on the posterior reaches.

## 283 **Future Research**

284 The authors implemented several measures to maximize the criterion validity of the hip  
285 abductor strength measures. However, this protocol of assessment can only be deemed more  
286 valid by a study design which compares muscle activity from this protocol to those in

287 existing literature. Furthermore, the authors in the present study decided to use concentric hip  
288 abduction, a movement used to assess hip abductor strength and prescribed as a rehabilitation  
289 exercise in clinical practice, when performance of the YBT depends primarily on isometric  
290 and eccentric control of the hip abductors. Future research should attempt to describe the  
291 association between eccentric hip abductor strength and performance of the YBT to add to  
292 those who have used isometric strength and the concentric measures described in this study.  
293 Future research should also aim to quantify muscle activation for each of the YBT reach  
294 directions to enable better understanding of the muscular demands of the test. Finally, future  
295 research should screen for previous history of concussion.

## 296 **Conclusion**

297 The data presented in this study suggest that concentric hip abductor strength is moderately  
298 associated with dynamic single leg stability when measured using the YBT. In contrast to the  
299 anterior reach, the associations between strength and balance are greater when using the  
300 posterior reaches of the YBT.

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