

Relph, Nicola and Small, Katie (2019) The influence of 9 marathons completed in 9 days on injury incidence and selected musculoskeletal tests. *International Journal of Athletic Therapy and Training*, 24 (3). pp. 115-121.

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1     **The Influence of 9-marathons completed in 9 days on injury incidence and selected**  
2                                 **musculoskeletal tests**

3

4     **Key Points:**

- 5             • Flexibility, proprioception and balance performance progressively decrease during a  
6             multi-day running event.
- 7             • Athletic trainers should design recovery and injury prevention strategies to be used  
8             with-in competition based on with-in event data collection.
- 9             • Future studies should adopt this novel with-in competition data collection method to  
10            appreciate the dynamic nature of musculoskeletal physiology.

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12     **Key words:** Multi-day running; athletic therapy; musculoskeletal testing.

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## 21 **Abstract**

22 Multi-day running events are increasingly popular however, research in these events is lacking  
23 and fails to consider the dynamic nature of musculoskeletal physiology. Twenty-three athletes  
24 completing a ten-day marathon event participated in the study. Proprioception, dynamic  
25 balance, knee valgus and flexibility were assessed the day before the event and after one, five  
26 and nine consecutive marathons. There were significant reductions in these measurements  
27 across the event and reductions were more apparent in the non-dominant side. Each runner  
28 suffered on average 4.2 injuries. Runners performed significantly worse in musculoskeletal  
29 measurements, particularly on the non-dominant side, as the competition progresses.  
30 Therefore, athletic trainers should design appropriate between-day recovery strategies during  
31 events based on with-in event data collection.

## 33 **Introduction**

34 Ultra-distance running events continue to increase in popularity<sup>1</sup>. The distance of these events  
35 is greater than 26.2 miles with total running times typically over six hours, occurring over  
36 multiple days<sup>2</sup>. It is perhaps not surprising that there are higher injury rates in these events  
37 relative to shorter running distances<sup>3</sup>, running of this nature may cause repeated stresses on  
38 tissues in a fatigued state<sup>4</sup>. Indeed, injuries occurred in between 60% and 100% of all  
39 competitors in previous research on ultra-distance events<sup>5-7</sup>. Furthermore, in a 7-day running  
40 event 84.8% of 396 runners required medical attention, which was equivalent to 3.8 injuries  
41 per runner or 7.2 injuries per 1000 hours<sup>3</sup>. However, there is a lack of research investigating  
42 musculoskeletal physiology changes that may inform athletic practice during multi-day  
43 running events.

44 It is important for practitioners to know how the musculoskeletal system changes to design  
45 effective with-in event treatments<sup>8</sup>. A dynamic approach to injury prevention has been  
46 developed in a model of etiology in sport injury<sup>9</sup>. Importantly, this incorporates repeated  
47 exposure to events that may lead to musculoskeletal adaptations<sup>9</sup>. This cyclical approach is one  
48 that is often missed in literature with clinical measurements being taken only once, before the  
49 race occurs; for example, static measures of alignment<sup>10</sup>. However, it is important to consider  
50 how the body may adapt across a performance taking the dynamic nature of injury occurrence  
51 into consideration.

52 There is very little research on the changes in musculoskeletal physiology during a multi-day  
53 running event<sup>5</sup>. One important measurement is neuromuscular control which has been linked  
54 to efficient running technique<sup>11</sup>. Poor proprioceptive ability (the ability to perceive position,  
55 movement and force of the limbs during running<sup>12</sup>) may be linked to changes in running  
56 performance as the central nervous system may not receive effective afferent information  
57 (feedback mechanisms) and hence prepare the correct muscle activity for impending  
58 perturbations (feed-forward mechanisms)<sup>12</sup>. Dynamic balance relies on good neuromuscular  
59 control and poor ability is possibly linked to running injuries due to excessive knee valgus  
60 positions from poor hip adductor strength during running<sup>13-15</sup>. An increased or decreased range  
61 of motion has previously been cited as a potential risk of injury<sup>16-17</sup> due to a potential increase  
62 in compressive and tensile stress on lower-limb joints<sup>18</sup>. Therefore, it is important these  
63 measures are monitored across a multi-day event to identify when musculoskeletal physiology  
64 changes and if athletic therapy is required.

65 The lower-extremity is the most common location for running injuries in multi-day events<sup>19</sup>.  
66 Therefore, the current study considered knee joint position sense (JPS), lower-limb dynamic  
67 balance, knee neuromuscular control during single-leg landing and hip and ankle flexibility

68 adaptations during a multi-day event. The aim of this study was to evaluate the effect of running  
69 one, five and nine consecutive marathons on musculoskeletal physiology using in-competition  
70 data collection methods.

## 71 **Methods**

### 72 *Participants*

73 A total of 23 athletes (age  $44.7 \pm 7.59$  years, mass  $75.1 \pm 12.99$  kg, self-reported weekly mileage  
74  $43.3 \pm 12.67$  miles) participated in this prospective cohort study. The event involved completing  
75 10 marathons in 10 consecutive days on the same course, however data was collected after day  
76 zero (D0), marathon one (M1), five (M5) and nine (M9). Table 1 describes participant  
77 characteristics. All participants provided voluntary, written informed consent and the rights of  
78 the participants were protected. The study was ethically approved by the University Review  
79 Board (ref: DC/SB 15/19).

### 80 *Instrumentation*

81 Knee JPS was collected using a camera (Casio Exilim, EX-FC100, Casio Electronics Co., Ltd.  
82 London, UK) on a fixed, level tripod. Dynamic balance was collected using a “Y symbol” taped  
83 to the floor (see figure 1) and tape measure. Knee neuromuscular control data was collected  
84 using a camera (Casio Exilim, EX-FC100, Casio Electronics Co Ltd, London, UK) mounted  
85 on a fixed, level tripod. Flexibility was collected using a 30cm goniometer (Baseline®  
86 Evaluation Instruments, White Plains, NY) and tape measure.

### 87 *Tasks*

88 Reliability statistics for tasks are reported in Table 2.

### 89 *Knee JPS*

90 Markers were placed on a point on a line following the greater trochanter to the lateral femoral  
91 epicondyle, the lateral femoral epicondyle and the lateral malleolus on the dominant leg. The  
92 athlete was seated on the end of a treatment table and blindfolded. The leg was passively moved  
93 by the experimenter through 30°–60° of extension from a starting knee angle of 90° or 60°–  
94 90° of flexion from a starting angle of 0° at an approximate angular velocity of 10°/s (see figure  
95 2). The target angle was held by the athlete for 5s before the researcher returned the limb to the  
96 starting position. The athlete then replicated the target position. Knee positions were captured  
97 using photographs and digitising software (Kinovea, v0.8.15, Joan Chamant & Contrib, 2006-  
98 2011). The delta score between target and reposition angles was taken as the absolute error  
99 score in degrees and averaged across five trials. The protocol has been validated against an  
100 isokinetic dynamometer<sup>20</sup>.

### 101 *The Modified Star Excursion Balance Test (SEBT)*

102 Dynamic stability was measured using the modified SEBT. Briefly, this task involves single  
103 leg squats, with the non-weight bearing leg reaching maximally towards anterior, posterior-  
104 medial and posterior-lateral directions along a designated line and then returning to the start  
105 position of single leg stance. Further detail of this protocol can be found in Munro and  
106 Herrington<sup>22</sup>. Each runner completed four trials in each direction on both legs and results were  
107 normalised to leg length.

### 108 *Knee Neuromuscular Control*

109 Knee neuromuscular control was measured using maximum knee valgus angle during single-  
110 leg-landing. Markers were placed on the mid-point of the femoral condyles, the mid-point of  
111 the ankle malleoli and the anterior superior iliac spine on both legs. The athlete stepped forward

112 from a 30-cm height, dropping as vertically as possible landing in a single-leg stance and  
113 holding for 3s, completing three trials on each leg. A trial was void if the non-stepping leg  
114 touched either the step or the floor during the task. Knee valgus angles were measured as the  
115 greatest angle between the line from the ASIS to the patella and the patella to the ankle marker  
116 during the landing performance using digitising software (Kinovea, v0.8.15, Joan Chamant &  
117 Contrib, 2006-2011) and the average taken. This task is correlated to forward running  
118 technique<sup>25</sup>.

### 119 *Lower-Limb Flexibility*

120 Two experienced athletic trainers took flexibility measurements on both legs with consistent  
121 roles in each protocol. The pelvis was stabilised to avoid compensatory movements in hip  
122 measurements. The flexibility of the iliotibial band was collected using the Ober's protocol<sup>26</sup>.  
123 Hip adductor flexibility measurements were taken in a supine position, the goniometer arms  
124 placed in-line with the contralateral anterior-superior iliac spine and the anterior mid-line of  
125 the ipsilateral femur. The runner actively performed maximal hip abduction and the value on  
126 the goniometer was recorded. Ankle dorsiflexion flexibility was measured using the knee to  
127 wall protocol detailed in Powden, Hoch and Hoch<sup>28</sup>. The runner completed the test in a tandem  
128 stance, with the tibia progressing over the talus and the heel remaining fully on the ground until  
129 the knee touches the wall. Internal and external rotation of the hip was measured following the  
130 Bullock-Saxton and Bullock protocol<sup>29</sup>. The runner was in prone and the knee passively flexed  
131 by the first examiner to 90°. The stationary arm of the goniometer was positioned parallel to  
132 the testing surface and the moving arm was placed along the tibia. The additional examiner  
133 then palpated the opposite posterior-superior iliac spine and the original examiner passively  
134 externally or internally rotated the limb. The measurement was taken at the point before the  
135 pelvis began rotating.



### 136 *Procedures*

137 Data was collected in a sports clinic between May 2015 and June 2016. The number of injuries  
138 per athlete was recorded by two athletic trainers three times daily (further details of injury data  
139 is reported elsewhere<sup>30</sup>). An injury was defined as a specific musculoskeletal abnormality that  
140 the runner perceived to affect performance<sup>5</sup>.

### 141 *Statistical Analysis*

142 Normality was checked using the Shapiro-Wilk test, if confirmed, the means and standard  
143 deviations of parametric measures were calculated. One-way repeated measures ANOVAs  
144 were used to explore the main effect of time and then post-hoc Bonferroni comparisons were  
145 utilised when required to complete multiple (six) comparisons. Non-normal data was presented  
146 as medians and interquartile ranges and analysed using Friedman's ANOVA and Wilcoxon  
147 Signed Rank tests. The significance level was accepted at  $p \leq 0.05$ .

### 148 **Results**

149 In total 73%, 50%, 69% and 70% of the sample completed all knee JPS, SEBT, knee valgus  
150 and flexibility testing respectively (see Table 3). Post-hoc analysis revealed no significant  
151 differences between completers and drop-outs for baseline measures of each tests. Non-  
152 parametric data (medians) and parametric data (means) is presented in Table 4.

### 153 *Knee JPS*

154 There were no effects of time on knee JPS into extension but was into flexion. JPS ability  
155 improved from D0 to M1 by  $2.4^\circ$  and reduced from M0 to M5 by  $1.3^\circ$ . On one or more  
156 occasions in the event 85% of runners demonstrated JPS difference scores above the SDD into  
157 flexion.

158 *Dynamic Balance*

159 Results of the modified SEBT did not alter during the competition on the dominant leg for  
160 anterior and posterior-lateral reach directions. However, posterior-medial reach distances  
161 reduced from D0 to M5 by 15% of leg length and from D0 to M9 by 19% of leg length (both  
162 above the SDD) and 80% of participants produced results above the SDD.

163 Anterior reach distance, posterior-medial reach distance and posterior-lateral reach distance all  
164 reduced on the non-dominant side. The anterior reach distances reduced by 9% of leg length  
165 from D0 to M9 (above the SDD). The posterior-medial reach distance reduced by 5% of leg  
166 length from D0 to M1 (below the SDD) and by 13% of leg length from D0 to M9 (above the  
167 SDD). The posterior-lateral reach distances reduced by 12% of leg length from D0 to M9  
168 (above the SDD). 70% of runners produced differences greater than the SDD for anterior reach,  
169 90% for posterior-medial reach data and 80% for posterior-lateral reach data.

170 *Knee Neuromuscular Control*

171 Knee neuromuscular control did not significantly change during the event for either the  
172 dominant or non-dominant side, indeed 77% of runners did not demonstrate difference values  
173 over the reported SDD.

174 *Lower-Limb Flexibility*

175 Adductor flexibility and ankle dorsiflexion flexibility on the dominant side of the body  
176 reduced. Adductor flexibility reduced from D0 to M5 by 5.6° and M9 by 10.8°. This flexibility  
177 also reduced from M1 to M9 by 11°. 91% of runners' data exceeded the reported SDD. Ankle  
178 dorsiflexion flexibility was reduced from D0 to M1 (by 1.41cm), M5 (by 2.65cm) and M9 (by  
179 3.40cm). There was also a significant reduction in this flexibility between M1 and M9 (by

180 2.00cm). 87% of runners had differences above the SDD during the event. The remaining  
181 flexibility measurements on the dominant side did not change.

182 All flexibility measures on the non-dominant side significantly reduced. ITB flexibility reduced  
183 from D0 to M9 (by 0.98cm) and from M1 to M9 (by 0.50cm). Flexibility of the adductor  
184 muscles again reduced from D0 to M9 (difference 9.1°) and M5 (difference 8.2°). This  
185 flexibility also significantly decreased when comparing M1 to M5 (difference 7.4°) and M9  
186 (difference 8.3°). 87% of runners' data was above the reported SDD. A similar pattern was  
187 evident in ankle dorsiflexion flexibility, there were differences between D0 and M5 (difference  
188 2.72cm) and M9 (difference 4.6cm). Ankle dorsiflexion flexibility was also worse after M9  
189 compared to M1 (difference 3.6cm) and marathon five (difference 1.8cm). For this  
190 measurement 83% of runners displayed differences above the SDD. Internal hip rotation on the  
191 non-dominant side significantly increased between D0 and M9 (difference 6.0°). External hip  
192 rotation also significantly reduced over time from D0 to M5 by 7.6° and M9 by 10.5°. 78% of  
193 runners displayed differences greater than the SDD for hip rotation measures.

194 There were 4.2 injuries per runner; 89% of injuries involved the lower extremity; 24.1% in the  
195 foot, 18.5% the hip/buttock, 16.7% the ankle and 16.7% in the lower leg.

## 196 **Discussion**

197 The aim of this study was to measure the effects of a multi-day running event on knee  
198 proprioception, dynamic balance, knee neuromuscular control and flexibility. The results  
199 suggest these measures, particularly on the non-dominant side, decrease in performance from  
200 D0 to M5 and again to M9 during the event.

### 201 *Knee Proprioception*

202 There was an initial improvement in knee JPS into flexion from D0 to M1, but this difference  
203 was below SDD values<sup>21</sup>. However, knee JPS into flexion reduced from D0 to M5 and this  
204 difference was above SDD values<sup>21</sup>. This suggests knee JPS may not reduce after running one  
205 marathon but could be impaired after five marathons. To our knowledge this is the first paper  
206 to consider JPS ability during a multi-stage running competition. However, previous research  
207 has reported a reduction in JPS ability following treadmill running to fatigue<sup>31-32</sup>. Three  
208 theories have been proposed to explain the mechanisms behind this finding; impaired excitation  
209 of motor units<sup>33</sup>, increase in knee laxity<sup>34</sup> and increase in pain<sup>33</sup>. All explanations suggest the  
210 afferent signalling used by the CNS to process JPS information is disrupted with fatigue,  
211 therefore making this process unstable and increasing errors<sup>35</sup>. Knee flexion occurs in running  
212 from initial touch down to mid-swing phases<sup>36</sup>. If the runner is unable to correctly perceive the  
213 position of their knee this could lead to errors in efferent signalling used for movement  
214 preparation. The results of the current study suggest knee JPS ability into flexion reduces after  
215 completion of five marathons. Therefore, athletic trainers may incorporate proprioceptive  
216 exercises after five days of running.

### 217 *Dynamic Balance*

218 Dynamic balance significantly reduced in all reach directions on the non-dominant limb and  
219 the posterior-lateral direction on the dominant limb from D0 to M9 and all average differences  
220 were above SDD values<sup>22</sup>. Again, to the author's knowledge, this is the first study to measure  
221 dynamic balance ability during a multi-day running event. However, the findings from the  
222 current study support previous literature that reported a decrease in balance performance  
223 following shorter running activities; for example, Steib<sup>37</sup> reported a decrease in SEBT  
224 performance following treadmill running to exhaustion. Other authors used different methods  
225 of balance measurement to present a reduction in ability with fatigue<sup>38-39</sup>. A reduction in

226 dynamic balance has been suggested to potentially increase the risk of running injuries due to  
227 a loss in neuromuscular control in lower extremity joints<sup>31, 40</sup>. The results of dynamic balance  
228 in the non-dominant leg got progressively worse across the event with the biggest performance  
229 decrease from D0 to M9. This has important implications for the timing of prevention and  
230 treatment strategies during an ultra-endurance event, athletic trainers should introduce dynamic  
231 balance exercises with-in ultra-running events.

### 232 *Knee Neuromuscular Control*

233 There were no significant changes to knee neuromuscular control on either leg. This is an  
234 unexpected finding however, Munro<sup>24</sup> stated the SDD as 7.54°-7.90° for the task and the  
235 greatest differences in this study were below the SDD. Therefore, 2D manual digitisation may  
236 not be sensitive enough to identify changes in knee valgus angle.

### 237 *Lower Limb Flexibility*

238 Increased flexibility may be desirable for optimal running performance<sup>41</sup>. The flexibility of the  
239 adductor muscles and ankle dorsi-flexors significantly reduced on both the dominant and non-  
240 dominant sides during the event. All adductor differences were above the reported SDDs apart  
241 from dominant leg, D0 to M5. Poor hip adductor flexibility has been linked to reduced stability  
242 at the hip and knee joint during gait and increased risk of ITB syndrome<sup>42</sup>. The flexibility of  
243 the adductor ankle dorsi-flexors also significantly reduced on both legs and differences were  
244 above the SDD except between D0 and M1 on the dominant leg. A reduction in ankle dorsi-  
245 flexion may change running mechanics at the ankle, specifically in preparation for foot strike;  
246 if the ankle is less flexed, this can modify foot strike patterns and lower-limb absorption  
247 mechanics and hence increase ground reaction forces<sup>43</sup>. Reduced ankle dorsi-flexion has been

248 linked to injuries to the knee<sup>44</sup> and foot<sup>45</sup> due to an increase in force transmitted along the  
249 kinetic chain.

250 The non-dominant limb also had reduced flexibility in the remaining measurements. Hip  
251 internal rotation increased, and external rotation decreased in flexibility across the competition  
252 and all differences were above the SDD. A modification in hip internal movement has been  
253 associated with modified knee kinematics that may possibly be linked to injury<sup>46</sup>. Poor hip  
254 control can lead to reduced neuromuscular control lower in the kinetic chain and potentially an  
255 increased risk of injury<sup>46</sup>. Furthermore, a reduction in ITB flexibility may potentially cause  
256 patello-femoral pain<sup>47</sup> and ITB syndrome<sup>48</sup>. These results suggest athletic trainers should  
257 consider flexibility recovery strategies after each day of a multi-day running event, particularly  
258 on the non-dominant side.

### 259 *Limitations*

260 Fatigue was not measured objectively, however, previous research has demonstrated fatigue  
261 will be present during ultra-marathon events<sup>49</sup>. Reliability estimates were taken from prior  
262 studies. However, knee JPS measures were taken by the same assessor from the reliability  
263 study. Also, there is over a decade's worth of reliability literature on both flexibility and SEBT  
264 measurements. The dropout levels should also be acknowledged; however, appropriate  
265 statistical analysis was used based on the assumption of normality.

266

### 267 *Clinical Implications*

268 The results of this study suggest musculoskeletal physiology performance worsens after five  
269 days of marathon running and by nine days this may be significant. Athletic trainers should  
270 design individual interventions based on in-event testing that runners can perform both before  
271 and during events that target flexibility, knee neuromuscular control and dynamic balance.

272

273 *Future Research*

274 The Meeuwisse model<sup>11</sup> of injury prevention states risk of injury is cyclical, hence is event  
275 and time dependent, therefore, it is recommended that the in-event data collection design  
276 should be utilised in further work with larger sample sizes.

277

278 *Conclusion*

279 Multi-day running events can cause over four injuries per runner and musculoskeletal  
280 physiology measures worsen progressively across competitions. Athletes should be aware of  
281 the potential changes that will occur and prepare appropriately. Importantly, these  
282 modifications became more apparent during the competition; these findings would not have  
283 been identified if traditional research designs that do not take measurements within competition  
284 had been used. Hence athletic trainers should consider in-event measurement with a view to  
285 prescribe recovery strategies that incorporate this knowledge (i.e. balance and flexibility  
286 recovery methods) in competition.

287 *Acknowledgements*

288 The authors would like to thank Brathay Trust for their assistance in recruiting runners to  
289 participate in this research study and to all the runners themselves for their commitment to the  
290 study.

291

292 **References**

293 1. van der Worp MP, ten Haaf DSM, de Wijer A et al. Injuries in runners; A systematic review  
294 on risk factors and sex differences. PLoS ONE 2015;10:e0114937.

- 295 2. Knechtle B, Duff B, Schulze I et al. Anthropometry and pre-race experience of finishers and  
296 nonfinishers in a multistage ultra-endurance run – Deutschlandlauf 2007. *Percept Mot Skills*  
297 2009;109:105-118.
- 298 3. Krabak BJ, Waite B & Schiff MA. Study of injury and illness rates in multiday ultramarathon  
299 runners. *Med Sci Sports Exerc* 2011;43:2314-2320.
- 300 4. Hreljac A. Impact and overuse injuries in runners. *Med Sci Sports Exerc* 2004; 36:845-849.
- 301 5. Bishop GW & Fallon KE. Musculoskeletal injuries in a six-day track race: Ultramarathoner's  
302 ankle. *Clin J Sport Med* 1999;9:216-220.
- 303 6. Fallon KE. Musculoskeletal injuries in the ultra-marathon: the 1990 Westfield Sydney to  
304 Melbourne run. *Br J Sports Med* 1996;30:319-323.
- 305 7. Graham SM, McKinley M, Connaboy CC et al. Injury occurrence and mood states during a  
306 desert ultramarathon. *Clin J Sport Med* 2012; 22:462-466.
- 307 8. Borland ML, Rogers IR. Injury and illness in a wilderness multisport endurance event.  
308 *Wilderness Environ Med.* 1997;8(2):82–88
- 309 9. Clansey A, Hanlon M, Wallace E, et al. Effects of Fatigue on Running Mechanics Associated  
310 with Tibial Stress Fracture Risk. *Med Sci Sports Exerc* 2012;44:1917-1923.
- 311 8. Bahr R, Krosshaug T. Understanding injury mechanisms: a key component of preventing  
312 injuries in sport. *Br J Sports Med* 2005;39:324-329.
- 313 9. Meeuwisse WH, Tyreman H, Hagel B et al. A dynamic model of etiology in sport injury:  
314 The recursive nature of risk and causation. *Clin J Sport Med* 2007; 17:215-219.



- 315 10. Hespanhol Junior LC, De Carvalho ACA, Costa LOP et al. Lower limb static alignment  
316 characteristics are not associated with running injuries in runners: Prospective cohort study.  
317 Eur J Sport Sci 2016;16:1137-1144.
- 318 11. Glofcheskie GO & Brown SHM. Athletic background is related to superior trunk  
319 proprioceptive ability, postural control, and neuromuscular response to sudden perturbations.  
320 Hum Mov Sci 2017;52:74-83.
- 321 12. Switlick T, Kernozek TW & Meardon S. Difference in joint-position sense and vibratory  
322 threshold in runners with and without a history of overuse injury. J Sport Rehabil 2015;24:6-  
323 12.
- 324 13. Baltich J, Emery CA, Stefanyshyn D et al. The effects of isolated ankle strengthening and  
325 functional balance training on strength, running mechanics, postural control and injury  
326 prevention in novice runners: design of a randomized controlled trial. BMC Musculoskelet  
327 Disord 2014;15:407-418.
- 328 14. Francis, P., Gray, K. and Perrem, N. The Relationship Between Concentric Hip Abductor  
329 Strength and the Performance of the Y-Balance Test (YBT). International Journal of Athletic  
330 Therapy and Training. 2018;23:42-47.
- 331 15. Munro A, Herrington L. & Comfort P. The Relationship Between 2-Dimensional Knee-  
332 Valgus Angles During Single-Leg Squat, Single-Leg-Land, and Drop-Jump Screening Tests. J  
333 Sport Rehabil. 2017;26(1):72-77.
- 334 16. Shanley E, Kissenberth MJ, Thigpen CA, Bailey LB, Hawkins RJ, Michener LA, Tokish  
335 JM, Rauh MJ. Preseason shoulder range of motion screening as a predictor of injury among  
336 youth and adolescent baseball pitchers. J Shoulder Elbow Surg. 2015 Jul;24(7):1005-13

- 337 17. Winkelmann ZK, Anderson D, Games KE, Eberman LEJ. Risk Factors for Medial Tibial  
338 Stress Syndrome in Active Individuals: An Evidence-Based Review. *Athl Train*. 2016  
339 Dec;51(12):1049-1052.
- 340 18. Mann KJ, Edwards S, Drinkwater EJ, Bird S. A Lower Limb Assessment Tool for Athletes  
341 at Risk of Developing Patellar Tendinopathy. *Medicine & Science in Sports & Exercise* 2013;  
342 45(3):527-533.
- 343 19. Scheer BV & Murray A. Al Andalus ultra trail: An observation of medical interventions  
344 during a 219-km, 5-day ultramarathon stage race. *Clin J Sport Med* 2011;21:444-446.
- 345 20. Relph N & Herrington L. Criterion-related validity of knee joint-position-sense  
346 measurement using image capture and isokinetic dynamometry. *J Sport Rehabil*  
347 2015:Technical Notes(10).
- 348 21. Relph N & Herrington L. Interexaminer, intraexaminer, and test-retest reliability of  
349 clinical knee joint-position-sense measurements using an image-capture technique. *J Sport*  
350 *Rehabil* 2015;Technical Notes(12).
- 351 22. Munro AG & Herrington LC. Between-session reliability of the star excursion balance test.  
352 *Phys Ther Sport* 2010;11:128-132.
- 353 23. Gribble PA, Hertel J & Plisky P. Using the star excursion balance test to assess dynamic  
354 postural-control deficits and outcomes in lower extremity injury: A literature and systematic  
355 review. *J Athl Train* 2012;47:339-357.
- 356 24. Munro A, Herrington L, Carolan M. Reliability of 2-dimensional video assessment of  
357 frontal-plane dynamic knee valgus during common athletic screening tasks. *J Sport Rehabil*.  
358 2012;21(1):7-11

- 359 25. Atkin K, Herrington L, Alenezi F, Jones P & Jones R. The Relationship Between 2d Knee  
360 Valgus Angle During Single Leg Squat (SLS), Single Leg Landing (SLL), And Forward  
361 Running. *Br J Sports Med* 2014 48: 563.
- 362 26. Gajdosik RL, Sandler MM, & Marr, HL. (2003). Influence of knee positions and gender on  
363 the ober test for length of the iliotibial band. *Clin Biomech* 2003;18:77–79.
- 364 27. Cejudo A, Ayala F, De Baranda PS & Santonja F. Reliability of Two Methods of Clinical  
365 Examination of the Flexibility of the Hip Adductor Muscles. *Int J Sports Phys Ther.* 2015;  
366 10(7): 976–983.
- 367 28. Powden CJ, Hoch JM & Hoch MC. Reliability and minimal detectable change of the  
368 weight-bearing lunge test: A systematic review. *Man Ther.* 2015;20(4):524-32
- 369 29. Bullock-Saxton JE & Bullock MI. Repeatability of Muscle Length Measures around the  
370 Hip. *Physiotherapy Canada* 1994; 46(2): 105-109.
- 371 30. Small K & Relph N. Musculoskeletal Injury Rates in Multiday Marathon Runners  
372 Performing Ten Consecutive Marathons on a Repeat Course. *Journal of Athletic Enhancement*  
373 2017; 6 (5).
- 374 31. Baharlue J & Khayambashi K. The effect of sub-maximal and maximal running on knee  
375 joint position senses and static balance in healthy young male athletes. *World Journal of Sport*  
376 *Sciences* 2012;6:242-246.
- 377 32. McMullen KL, Cosby NL, Hertel J. et al. Lower Extremity Neuromuscular Control  
378 Immediately After Fatiguing Hip-Abduction Exercise. *J Athl Train* 2011;46:607-14.

- 379 33. Miura K, Ishibashi Y, Tsuda E, et al. The effect of local and general fatigue on knee  
380 proprioception. *Arthroscopy* 2004;20:414-418.
- 381 34. Hutton RS & Nelson DL. Stretch sensitivity of Golgi tendon organs in fatigued  
382 gastrocnemius muscle. *Med Sci Sports Exerc* 1986;18:69-74.
- 383 35. Fortier S & Basset FA. The effects of exercise on limb proprioceptive signals. *J*  
384 *Electromyogr Kinesiol* 2012;22:795-802.
- 385 36. Dugan, S. A., & Bhat, K. P. Biomechanics and analysis of running gait. *Physical medicine*  
386 *and rehabilitation clinics of North America*, 2005;16(3):603-621.
- 387 37. Steib S, Zech A, Hentschke C et al. Fatigue-induced alterations of static and dynamic  
388 postural control in athletes with a history of ankle sprain. *J Athl Train* 2013;48:203-208.
- 389 38. Burdet C & Rougier P, Effects of utmost fatigue on undisturbed upright stance control. *Sci*  
390 *Sports* 2004;19:308-316.
- 391 39. Lepers R, Bigard AX, Diard JP et al. Posture control after prolonged exercise *Eur J Appl*  
392 *Physiol Occup Physiol*. 1997;76:55-61.
- 393 40. Wright KE, Lyons TS & Navalta JW. Effects of exercise-induced fatigue on postural  
394 balance: a comparison of treadmill versus cycle fatiguing protocols. *Eur J Appl Physiol*  
395 2013;113:1303.
- 396 41. Overmoyer GV, Reiser RF 2nd. Relationships between lower-extremity flexibility,  
397 asymmetries, and the Y balance test. *J Strength Cond Res*. 2015;29(5):1240-7.

- 398 42. Louw M, Deary C. The biomechanical variables involved in the aetiology of iliotibial band  
399 syndrome in distance runners - A systematic review of the literature. *Phys Ther Sport*.  
400 2014;15(1):64-75
- 401 43. Carter J & Greenwood M. Does Flexibility Exercise Affect Running Economy? A Brief  
402 Review. *Strength and Conditioning Journal* 2015 37(3):12-21
- 403 44. Malliaras P, Cook JL, Kent P. Reduced ankle dorsiflexion range may increase the risk of  
404 patellar tendon injury among volleyball players. *J Sci Med Sport*. 2006;9(4):304-9.
- 405 45. Wearing SC, Smeathers JE, Urry SR, Hennig EM, Hills AP. The pathomechanics of plantar  
406 fasciitis. *Sports Med*. 2006;36(7):585-611.
- 407 46. Bedi A, Warren RF, Wojtys EM, Oh YK, Ashton-Miller JA, Oltean H, Kelly BT.  
408 Restriction in hip internal rotation is associated with an increased risk of ACL injury. *Knee*  
409 *Surg Sports Traumatol Arthrosc*. 2016;24(6):2024-31.
- 410 47. Hudson Z, Darthuy E. Iliotibial band tightness and patellofemoral pain syndrome: a case-  
411 control study. *Man Ther*. 2009;14(2):147-51
- 412 48. Noehren B, Schmitz A, Hempel R, Westlake C, Black W. Assessment of strength,  
413 flexibility, and running mechanics in men with iliotibial band syndrome. *J Orthop Sports Phys*  
414 *Ther*. 2014;44(3):217-22.
- 415 49. Millet GY. Can Neuromuscular Fatigue Explain Running Strategies and Performance in  
416 Ultra-Marathons?: The Flush Model. *Sports Med* 2011;41:489-506.

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For Peer Review

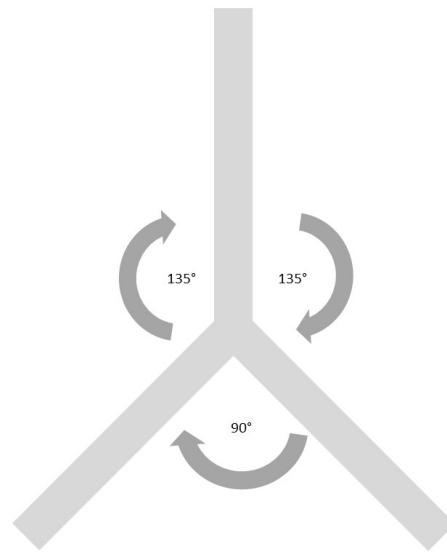


Figure 1. Modified Star Excursion Balance Test (SEBT) set-up  
215x279mm (150 x 150 DPI)

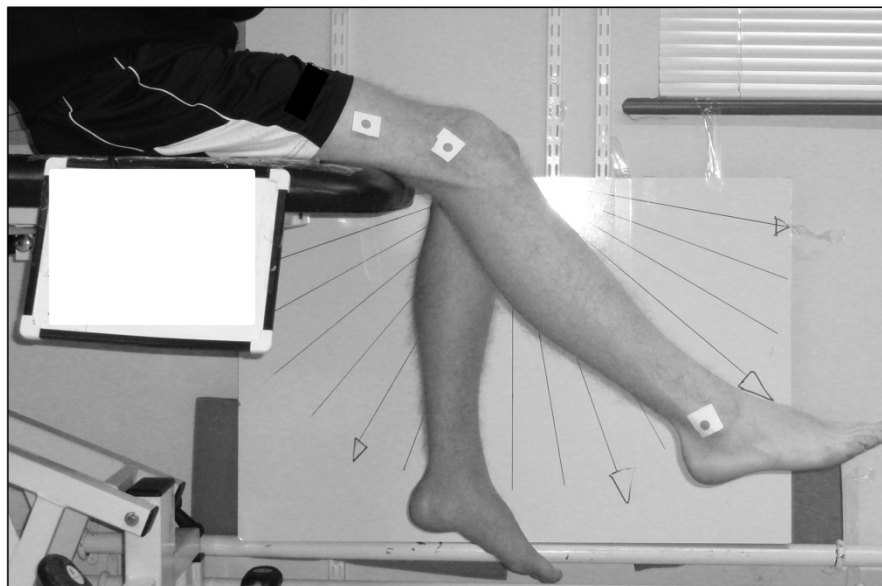


Figure 2. Example of Knee Joint Position Sense (JPS) data collection set-up  
665x563mm (144 x 144 DPI)



**Table 1.** Participant Characteristics (mean±SD unless stated).

Flexibility Testing (n=23)	
Age (years)	44.7±7.59
Mass (kg)	75.1±12.99
Gender (males/females)	16/7 (number)
Knee JPS and Neuromuscular Control (n=13)	
Age (years)	46.8±5.03
Mass (kg)	72.3±13.02
Gender (males/females)	9/4
Dynamic Balance (n=10)	
Age (years)	42.0±9.61
Mass (kg)	78.8±12.66
Gender (males/females)	7/3 (number)

**Table 2.** Reliability statistics

Protocol	Test-retest reliability (ICC)	Smallest Detectable Difference (SDD)
Knee Joint Position Sense <sup>21</sup>	Knee Flexion 0.92 Knee Extension 0.86	Knee Flexion 1.10° Knee Extension 1.67°
Star Excursion Balance Test <sup>22-23</sup>	0.84-0.92	Anterior reach 6.87% leg length Posterior-medial reach 8.15% leg length Posterior-lateral reach 7.11% leg length
Knee Neuromuscular Control <sup>24</sup>	Men 0.80 Women 0.82	Men 7.54° Women 7.90°
Ober's Protocol <sup>26</sup>	0.82-0.92	Not available
Hip Adductor Flexibility <sup>27</sup>	0.92-0.99	5.1° - 7.6°
Ankle Dorsiflexion Flexibility <sup>28</sup>	0.99	1.57cm
Internal Hip Rotation <sup>29</sup>	0.98	4.29°
External Hip Rotation <sup>29</sup>	0.99	6.11°

**Table 3.** Drop out data (absolute number of runners at each time phase).

<b>Risk Factor</b>	<b>Day zero</b>	<b>Marathon 1</b>	<b>Marathon 5</b>	<b>Marathon 9</b>	<b>Completion</b>
Flexibility	23	23	18	16	70%
Knee JPS	13	12	11	8	73%
Knee Neuromuscular Control	13	12	10	9	69%
SEBT	10	10	6	5	50%

**Table 4.** Mean±SD measurements for parametric data and Median [IQR] measurements for nonparametric data at day zero (D0), marathon one (M1), five (M5) and nine (M9) for parametric data. SEBT = Star Excursion Balance Tests. \* $p \leq 0.05$ , \*\* $p \leq 0.01$ , \*\*\* $p \leq 0.001$ .

Variable	D0	M1	M5	M9	Main Effect p-value	Significant Post-hoc analysis
Knee Joint Position Sense Extension (°)	3.6±1.9	3.7±1.8	3.3±2.3	2.8±1.2	0.65	N/A
Knee Joint Position Sense Flexion (°)	4.7 [3.3]	2.9 [2.2]	3.3 [2.9]	3.3 [3.4]	0.03	D0 v M1** M1 v M5*
Dominant Leg SEBT Anterior (% of leg length)	85±8.3	85±5.0	80±11.5	75±6.6	0.15	N/A
Dominant Leg SEBT Posterior Medial (% of leg length)	101 [18.0]	90 [11.2]	86 [13.6]	82 [17.6]	0.01	D0 v M5* D0 v M9*
Dominant Leg SEBT Posterior Lateral (% of leg length)	86±10.7	84±14.5	80±14.2	79±11.4	0.42	N/A
Non-Dominant Leg SEBT Anterior (% of leg length)	86 [12.4]	83 [11.6]	80 [8.7]	77 [6.4]	0.05	D0 v M9*
Non-Dominant Leg SEBT Posterior Medial (% of leg length)	96±8.6	91±10.4	84±10.9	83±7.4	0.004	D0 v M* D0 v M9*
Non-Dominant Leg SEBT Posterior Lateral (% of leg length)	86 [15.4]	85 [12.7]	82 [19.1]	74 [118.6]	0.02	D0 v M9*
Dominant Leg Knee Valgus (°)	5.8±2.0	5.5±3.1	6.5±5.4	6.9±5.1	0.57	N/A
Non-Dominant Leg Knee Valgus (°)	7.6±4.9	8.6±3.5	5.9±4.7	7.8±3.7	0.85	N/A
Dominant Leg Iliotibial Band Flexibility (cm)	14.9±1.7	14.8±1.8	15.3±1.8	15.6±2.0	0.21	N/A
Non-Dominant Leg Iliotibial Band Flexibility (cm)	14.6±1.9	15.1±1.7	15.6±1.8	16.8±2.0	0.001	D0 v M9** M1 v M9*

Dominant Leg Ankle Dorsiflexion Flexibility (cm)	11.0±3.1	9.6±3.3	8.4±3.3	7.6±2.9	0.001	D0 v M1** D0 v M5 *** D0 v M9 *** M1 v M9*
Non-Dominant Leg Ankle Dorsiflexion Flexibility (cm)	10.5±3.0	9.6±3.7	7.8±2.8	5.9±2.5	0.001	D0 v M5*** D0 v M9*** M1 v M9** M5 v M9**
Dominant Leg Internal Hip Rotation (°)	31.8±9.5	35.3±9.7	34.7±9.4	34.1±5.4	0.32	N/A
Dominant Leg External Hip Rotation (°)	29.8±11.4	30.5±13.5	30.4±9.6	29.1±8.5	0.24	N/A
Non-Dominant Leg Internal Hip Rotation (°)	31.1±9.9	32.9±10.6	34.3±7.4	37.1±6.5	0.01	D0 v M9**
Non-Dominant Leg External Hip Rotation (°)	34.7±11.6	31.8±12.3	27.2±8.0	24.2±6.9	0.001	D0 v M5* D0 v M9*