

Article

The Effect of Proprioceptive Training on Directional Dynamic Stabilisation

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1 The Effect of Proprioceptive Training on Directional Dynamic Stabilisation

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Key words: proprioception, training, dynamic stability, soccer, injury risk

37 **Abstract**

38

39 **Objectives:** Significant loss of playing time and the impact of treatment costs due to lower
40 limb injury in football demonstrates a need for improved protocols for injury risk reduction.
41 The aim of the present study is to assess the effect of a proprioceptive training programme on
42 the lower limb dynamic stability of elite footballers.

43

44 **Methods:** Sixteen elite premier league footballers were randomly allocated by matched pair
45 design to an 8-week proprioception training group (group A, n = 8) or non-training group
46 (group B, n = 8), to determine the effect of this training over a 16-week period. Group A
47 completed 8 weeks of bilateral proprioceptive training, 5 times per week for 10 minutes.
48 Biodex Dynamic Stability (BSS) measures of Overall Stability Index (OSI), Anterior-Posterior
49 (A-P), Medial-Lateral Stability (M-L) at levels 8-6-4-1 were taken for both groups at baseline,
50 4, 8 and 16 weeks. Main effects of time, level of stability and direction of stability were
51 determined, with comparisons of effect made between the two groups.

52

53 **Results:** The training group displayed significant differences for multi directional stability at
54 week 8 ($P \leq 0.05$). A-P stability within the training group displayed significant differences
55 between baseline measures and 16 weeks ($P > 0.05$), with significant increases in scores
56 displayed for M-L and A-P stability between weeks 8 and 16 ($P \leq 0.05$), representing a
57 detraining effect. No significant differences were detected at any time point for the non-
58 training group ($P > 0.05$).

59

60 **Conclusions:** Proprioceptive training over 8 weeks has a positive effect on all directions of
61 stability. Greater declines in A-P stability were evident at 16 weeks when compared to M-L
62 and OSI. Consideration must be given to the increased stability scores presented pre testing
63 for A-P when compared to M-L. Findings of this work present implications for training design.

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71 **Introduction**

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73 The sport of football, being the most popular in the world continues to increase in participation,
74 subsequently so does the risk and frequency of sustaining injury [1, 2]. The resultant, costs of
75 treatment and loss of playing time still demonstrates a need for improved injury risk reduction
76 protocols, with Ekstrand et al, 2019 [3] reporting average time losses of 4 weeks due to injury
77 in professional football. Evolving epidemiological information provides an understanding of
78 injury incidence, recently highlighted injury incidence rates for matches and training was 11.5
79 per 1000 match-hours monitored over 6-season of profession level football [4]. Football places
80 both physical and physiological demands on players, which becomes more evident at higher
81 levels of competition. Considerable injury-risk associated with significant economic burden
82 and subsequent impact to the success of competitive play in football at professional levels is
83 reported [5].

84

85 One of the most serious injuries in modern professional football is rupture of the Anterior
86 Cruciate Ligament (ACL) with an occurrence rate of 0.066 per 1000hrs of exposure and a
87 median timescale of 7.4months to return to match play following reconstruction [6]. The study
88 also found match ACL injury rate was 20 times higher than the training injury rate 0.340 vs
89 0.017 per 1000 hrs. Ankle injury accounts for 10-18% of all injuries in high-level football [7-
90 9). More than 75% of the ankle sprains in these studies affect the lateral ligaments as a result
91 of inversion of the ankle joint. Following musculoskeletal injury, empirical investigations
92 indicate that athletes are prone to enter a vicious succession known as the continuum of
93 disability [10]. Reductions in sensorimotor control postulated to emerge from known damage
94 structurally to mechanoreceptors of the affected ligament and associated tissues [4]. Examples
95 such as chronic ankle instability following repeated ankle sprains in football demonstrates
96 evidence to support this continuum [11]. Previous injury and inadequate rehabilitation are
97 important intrinsic factors for future injury [12], due to mechanical and functional instability
98 predisposing athletes to repetitive injury.

99

100 Dynamic stabilisation is heavily reliant on an efficient neuromuscular pathway [13] with
101 evidence highlighting the positive effect of 3-5 stability-training sessions per week [14, 15].
102 Within each of the aforementioned studies the balance training was completed on a variety of
103 surfaces including foam pads and wooden discs, both acknowledging the effectiveness of
104 differentiated surfaces to challenge the neuromuscular response of the athlete. Although,

105 previous findings are conclusive with regards frequency of training and effect, limitations are
106 evident. These include the influence of training on the level of stability tested, influence of
107 training on directional stability and the longer-term effects of a proprioceptive training period.
108 Ligamentous ankle injury leads to proprioceptive deficits, and reductions in joint position sense
109 (JPS) relating to the athlete's perception of the position of a joint with their vision occluded
110 and minimal feedback given [16]. Trauma to mechanoreceptors within tissue can result in
111 partial de-afferentiation leading to proprioceptive deficits [17]. Therefore, it is imperative for
112 optimum rehabilitation programmes designed specifically to include proprioceptive
113 components to promote healing and minimise risk of re-injury [18]. Mechanical loading of a
114 joint stimulates reflex muscular stabilisation through spinal reflexes; this can be achieved
115 through various proprioceptive training methods reported in current literature [19]. Increasing
116 the knowledge of the duration required for an optimal training effect on directional stability,
117 could potentially optimise rehabilitation/ injury prevention strategies. Measurement of
118 stability in previous research has been ascertained via multiple outcome measures, which can
119 include; goniometers, Y-Balance, Star Excursion Balance Test, isokinetic dynamometers,
120 postural sway via force plate, surface electromyography, stability systems [20, 21, 22]. The
121 Biodex stability system (BSS) commonly utilised in sport assesses the ability of the athlete to
122 maintain balance and postural control in multi directional planes [23], with conclusions
123 supporting reliability of this tool to quantify dynamic stability [24].

124

125 Proprioceptive deficits resulting from lower limb injury in football requires proprioceptive
126 training over a period of weeks, through balance and coordination exercises, in order to restore
127 stabilometry [14, 15]. Due to the multi directional nature of football, it is important to consider
128 the mechanism of injury associated with specific lower limb injury when considering a player's
129 rehabilitation or training plan. Therefore, the aim of the present study is to assess the effect of
130 an 8-week proprioceptive training program on multi directional stability, observing effect on
131 multi directional dynamic stability over a 16-week period.

132

133 **Methods**

134

135 *Participants*

136

137 From an available squad of twenty-three, sixteen elite premier league footballers were available
138 to volunteer for the study and took part in a sixteen-week proprioception intervention

139 programme (age 17.60 ± 0.85 years, height 176.83 ± 9.8 cm and body mass 69.7 ± 12.9 kg).
140 A minimum sample size was based on sixteen players who met the inclusion / exclusion criteria
141 of; no history of previous lower limb injury in the last 6 months and highlighted by the clubs
142 medical team as having no mechanical or functional instability in the knee or ankle at time of
143 testing. Players included were also free from systemic or vestibular disorders known to impair
144 cutaneous sensation of balance [15]. In total, seven players were excluded from partaking in
145 the study due to: injury (n=3), playing position (goalkeepers' n=2), unavailable due to being
146 on loan to another club (n=2). All participants taking part in the study provided written and
147 informed consent, with study approval provided by the Ethics Committee of the host university.
148 The authors hypothesised that a positive training effect in the group exposed to proprioceptive
149 training would occur for all directions of stability.

150

151 *Experimental Design*

152

153 Participants were randomly allocated to one of two groups (Randomisation.com), being
154 intervention (Group A, n = 8) and non-training group (Group B, n = 8). Group A undertook an
155 eight-week ankle proprioceptive training programme (Table 1) in addition to their normal
156 football training and competitive fixture demands. Group B underwent their normal football
157 training and competitive fixture demands, with no additional proprioceptive training.
158 Dynamic stability measures were completed for both groups at weeks 4, 8 and 16. All testing
159 and training interventions were completed at the host club, an elite premier league football
160 club, in an ambient temperature-controlled environment.

161

162 Examination of the effects of an 8-week ankle proprioceptive training programme in
163 professional footballers measured through the BSS (Biodex Medical Systems, Shirley, NY),
164 determined a score output at baseline, then again at 4, 8 and 16 weeks. All measures were
165 taken between 13:00 and 17:00 hrs at all-time points to account for the effects of circadian
166 rhythm [25, 26] and in accordance with regular training and competition times. The BSS
167 (Biodex Medical Systems, Shirley, NY) is an unstable platform that can tilt up to 20° in any
168 direction, with the stability of the platform determined by the level by which it is set ranging
169 from 1 (most unstable) to 12 (most stable) [27]. Each limb tested individually at levels 8-6-4-
170 1 of stability on the BSS (Level 8 = more stable / Level 1 = less stable). All testing on the BSS
171 was completed barefoot due to the effect footwear can have on kinematics of the foot and
172 muscle activity in the lower limb [28].

173 Participants undertook a familiarisation test trial, performed on each limb at all levels prior to
174 testing 7 days prior to testing beginning. The participants completed 3 trials of 20 seconds on
175 stability level 1, once completed measures were calculated based on the amount of tilt in
176 degrees for OSI, A-P and M-L. A low index score indicated high stability and high score a low
177 level of stability. Players were asked to repeat trials if it was judged they required further
178 familiarisation with the testing equipment. The BSS was setup in accordance with previous
179 literature [29].

180

181 The BSS platform was set at a maximum of 20 degrees surface tilt. Subjects instructed to stand
182 on the platform tried to balance and hold the platform level for a period. The subjects' ability
183 to control the angle of tilt quantified as variance from neutral position. Before testing on the
184 BSS began the subjects were asked to remove all footwear and socks. They then stood on the
185 platform in full extension with their dominant limb with their foot in the centre of the platform.
186 The feedback screen was set at eye level and the participants were asked to observe the screen,
187 this was set as such to avoid any unwanted head movement and avoid vestibular distraction.
188 Subjects were then asked to adjust their standing foot to a comfortable position, while the
189 marker on the feedback screen maintained a central position. Once this was completed and the
190 participant reported to be in a comfortable position the platform was locked into a stable
191 position and the players' foot position was recorded. Once recorded the foot position remained
192 consistent through each trial throughout the testing period. In between each trial players were
193 told to weight-bear through the contralateral limb to minimise the effect of fatigue when testing.
194 In cases where subjects lost their balance, they were told to use the contralateral limb to
195 stabilise themselves by placing it at the back corner of the BSS and were only encouraged to
196 use the handrails if they completely lost balance. The same assessor followed the same exact
197 testing protocol throughout, applying individual configurations for each participant. The
198 assessor was blinded as to which group each participant was allocated to for testing to avoid
199 testing bias and improve validity of the results. Figure 1 provides a representation of the testing
200 set-up. Testing protocol consisted of a single-leg hold for 20-seconds at levels 8-6-4-1. Each
201 subject performed the assessment on alternate limbs for each level with a 1-minute period of
202 rest in between each level.

203

204

Insert Figure 1 here

205

206

207 *Eight-Week Intervention Protocol*

208

209 Prior to completion of any proprioceptive training participants completed a warm up on a cycle
210 ergometer. Participants were asked to maintain a speed of 70-watts and completed at this
211 moderate intensity for a period of ten minutes. Post completion of the warm up on the cycle
212 ergometer participants were supervised through a series of dynamic stretches, which included
213 the hamstrings, quadriceps, adductors, abductors and gastrocnemius. The stretches were
214 completed as four sets of three with each set lasting 30-second period and this was consistent
215 for all participants [30]. The training programme supervised by the same Sports Scientist at
216 the club, was carried out in a performance gymnasium environment. The training programme
217 performed by Group A, was applied five times per week at 9:45am, prior to football training
218 schedules, accounting for the effects of circadian rhythm [25. 26]. All participants in the
219 training programme group were barefoot and performed exercises for 10-minutes on five pieces
220 of equipment (x1 Trampet, x1 Wobble Board, x1 Sissal Pad, x1 Foam Pad and x1 Gymnastic
221 Beam). Within those 10-minutes, on each piece of equipment subjects spent 1-minute
222 balancing on the right limb, followed by 1-minute balanced on the left limb, then instructed to
223 repeat. Participants were timed by the Sports Scientist using a stopwatch for standardisation
224 of time spent on each piece of equipment. Each piece of equipment and testing was performed
225 within the performance gymnasium on a hard floor surface. For each exercise on each piece of
226 equipment, the subject placed their arms across their chest with eyes open. All exercises,
227 varying surfaces/equipment, timings and frequency of training were modelled on previous
228 literature displaying positive effects on overall stability index scores [14, 15].

229

230 *Statistical Analysis*

231

232 A univariate repeated measures general linear model quantified main effects for training, time,
233 level and direction of stability. Interaction effects were also quantified, and significant main
234 effects of training were explored using post hoc pairwise comparisons with a Bonferonni
235 correction factor. The assumptions associated with the statistical model were assessed to ensure
236 model adequacy. To assess residual normality for each dependant variable, q-q plots were
237 generated using stacked standardised residuals. Scatterplots of the stacked unstandardized and
238 standardised residuals were also utilised to assess the error of variance associated with the
239 residuals. Mauchly's test of sphericity was also completed for all dependent variables, with a
240 Greenhouse Geisser correction applied if the test was significant. Partial eta squared (η^2) values

241 were calculated to estimate effect sizes for all significant main effects and interactions. As
242 recommended by Cohen (1988) [31], partial eta squared was classified as small (0.01–0.059),
243 moderate (0.06-0.137), and large (>0.138). All statistical analysis was completed using PASW
244 Statistics Editor 22.0 for windows (SPSS Inc, Chicago, USA). Statistical significance was set
245 at $P \leq 0.05$, and all data are presented as mean \pm standard deviation.

246

247 **Results**

248

249 Table 1 summarises the training effect on stability scores of OSI, A-P and M-L, illustrating
250 percentage differences at each time point when compared to pre training levels.

251

252 ****Insert table 1 here****

253

254

255 Analysis of the overall data set (inclusive of both the the training and non-training group)
256 identified a significant effect for time ($F = 13.22, P < 0.001, \eta^2 = 0.056$), level of stability test
257 ($F = 37.24, P < 0.001, \eta^2 = 0.143$), direction of stability ($F = 132.6, P < 0.001, \eta^2 = 0.283$)
258 and group ($F = 78.3, P < 0.001, \eta^2 = 0.104$). Significant interactions were displayed for time
259 x level ($F = 4.84, P < 0.001, \eta^2 = 0.061$), time x direction interaction ($F = 9.03, P < 0.001, \eta^2$
260 $= 0.08$) and time x group ($F = 2.8, P < 0.05, \eta^2 = 0.01$).

261

262 On separation of the data sets in to the training and non-training group significant effects for
263 time ($F = 10.66, P < 0.001, \eta^2 = 0.087; F = 5.58, P = 0.001, \eta^2 = 0.047$), level of stability test
264 ($F = 12.86, P < 0.001, \eta^2 = 0.103; F = 25.78, P \leq 0.001, \eta^2 = 0.187$), direction of stability
265 ($F = 53.77, P < 0.001, \eta^2 = 0.242; F = 80.13, P \leq 0.001, \eta^2 = 0.323$) and group ($F = 78.29,$
266 $P < 0.001, \eta^2 = 0.242; F = 80.13, P \leq 0.001, \eta^2 = 0.323$) were found.

267

268 No significant differences were identified between any time points within the non-training
269 group, when compared to pre testing levels ($P > 0.05$). A time x level ($F = 3.35, P = 0.001,$
270 $\eta^2 = 0.082$) and time x direction interaction ($F = 7.34, P \leq 0.001, \eta^2 = 0.12$) was identified.
271 Conversely, the training groups week 8 values were significantly lower when compared to
272 baseline measures post completion of the training protocol ($P < 0.008$), with no significance
273 differences displayed at week 4 and 16 ($P > 0.05$). A time x level ($F = 2.06, P \leq 0.05, \eta^2 =$
274 0.052) and time x direction interaction ($F = 2.96, P = 0.008, \eta^2 = 0.50$) was also found.

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With the data set collapsed for the training group to consider each direction of stability, all directions displayed a significant effect of time (OSI: $F = 5.46$; $P = 0.002$, $\eta^2 = 0.128$; A-P: $F = 3.89$; $P = 0.01$, $\eta^2 = 0.10$; M-L: $F = 7.96$; $P \leq 0.001$, $\eta^2 = 0.18$). Significant reductions in A-P stability scores were displayed at 4 and 8-weeks post training when compared to pre training levels ($P \leq 0.05$), with M-L and OSI stability displaying positive significant training effects at week 8. Significant increases in stability scores were displayed for A-P stability at 16 weeks ($P \leq 0.05$), representing a detraining effect post training. Contrastingly, OSI and M-L identified significant decreases compared to pre training levels ($P \leq 0.05$). It was also noted that a significant training effect was observed between week 4 and 16 and for A-P stability ($P \leq 0.05$). Significant differences were also displayed between week 8 and 16 in both A-P and M-L stability displaying a de-training effect within the training group ($P \leq 0.05$) (Mean Scores Range: Week 8: A-P: 1.11 – 1.49; M-L: 0.94 – 1.32; Week 16: A-P 1.13 – 1.71; M-L: 0.99 – 1.54). A significant main effect was also displayed for level of stability within the training group (OSI: $F = 3.92$, $P = 0.01$, $\eta^2 = 0.10$; A-P: $F = 4.06$, $P = 0.001$, $\eta^2 = 0.128$; M-L: $F = 5.49$, $P = 0.001$, $\eta^2 = 0.13$), with significant differences only displayed between level 1 and 8 ($P = 0.007$).

Analysis of the collapsed data considering each direction of stability for the non-training group identified no significant effect of time in any direction (OSI: $F = 0.52$, $P = 0.67$, $\eta^2 = 0.1$; A-P: $F = 10.12$, $P = 0.14$, $\eta^2 = 0.05$; M-L: $F = 9.91$, $P \geq 0.05$, $\eta^2 = 0.42$). A significant main effect was displayed for level of stability (OSI: $P < 0.001$, $\eta^2 = 0.16$; A-P: $P \leq 0.001$, $\eta^2 = 0.21$; M-L: $P \leq 0.001$, $\eta^2 = 0.21$), with significant differences displayed between level 1 and 6 ($P \leq 0.001$) and level 1 and 8 ($P \leq 0.001$), in all directions.

insert Figure 2 here

insert Figure 3 here

insert Figure 4 here

insert Figure 5 here

309 **Discussion**

310

311 The aim of the present study was to investigate the effects of an eight-week proprioception
312 training protocol over a 16-week period on multi directional dynamic stability. Previous
313 research has highlighted the positive training response elicited post a period of proprioceptive
314 training consisting of 3 - 5 training sessions per week. The training periods within literature
315 have varied between 4 - 8 weeks, and the current work observes a longer-term effect, post
316 completion of the 8-week training period. Present literature is also limited in relation to
317 directional stability, although methods have been utilised that would quantify directional
318 stability, they have not been analysed in isolation [14, 15].

319

320 Main findings within this body of work indicate significant proprioceptive training effects for
321 all directions of stability at week 8 at all levels, with A-P and M-L displaying significant
322 differences in stability scores at week 8 and 16. Indicating, that cessation of training post 8
323 weeks had a decreased impact on stability scores within these directions. It was also identified
324 that significant improvements of A-P stability were identified at 4 weeks post the initiation of
325 training. No significant differences were detected at any time point for the non-training group.
326 Thus, highlighting the importance of continued training to improve multi directional dynamic
327 stabilisation.

328

329 Observation of the training groups directional stability mean scores and percentage changes
330 across each time point for all levels shows a reduction within the period of training, indicating
331 an improvement up to 8 weeks. Post 8 weeks, a detraining effect can be seen where mean
332 scores move back towards baseline levels, with the exception of levels 6 and 8. Further analysis
333 of the mean scores and percentage changes indicate that improvements in stability scores are
334 evident at levels 6 and 8 in both the training and non-training group. In addition, the training
335 group highlight improvements at levels 1 and 4 within the training period, with reductions in
336 stability performance at week 16. Conversely, the non-training group display reductions in
337 directional stability performance throughout the 16-week period. Thus, supporting current
338 research that more unstable platforms within BSS testing are more appropriate for elite level
339 athletes [24].

340

341 Analysis of the mean scores for OSI, A-P and M-L stability display higher stability scores for
342 OSI across all levels compared to A-P and M-L, which is unsurprising considering that OSI is

343 a combination of A-P and M-L stability. These findings highlight the limitations that exist
344 within present literature which analyse training effects on dynamic stability [14, 15]. Further,
345 observation of mean stability scores indicates higher values of stability for A-P from baseline
346 to week 16 when compared to M-L, suggesting that the A-P stability is weaker in this
347 population. Potentially, suggesting increased potential for injury risk within this plane when
348 associating it with common mechanisms of sustaining ACL injury in footballers.

349
350 Previous research in the area has identified that integration in to the training schedule of 3 - 5
351 proprioceptive sessions per week for 4 – 10 minutes per session in elite footballers, has a
352 positive impact on proprioceptive output [14]. The current study followed a training schedule
353 of 5 sessions per week for 10 minutes per session collected at the same time each week.
354 Previous literature has not accounted for circadian rhythm [25, 26]. Applying this in practice
355 can be challenging due to coach demands, time restriction and fixture congested periods [32]
356 and further work is required around maintenance of proprioceptive levels. This would add to
357 the current body of work and allow practitioners to periodise training appropriately to
358 accommodate these demands. It is important to note that literature has identified minimal time
359 investment and the integration of such practices within warm ups have been shown to reduce
360 injury risk [33]. Thus, identifying the importance of educating players and coaches for the
361 need of such training, but also highlighting key windows for practitioners to integrate these
362 methods with minimal disruption to the training schedule. Caution must be taken with the
363 interpretation of the results of the current study due to small participant numbers; future work
364 should consider a larger sample.

365
366 Common injuries sustained by footballers are often associated with the knee and ankle, with
367 mechanisms of sustaining these injuries often not singularly associated with one plane of
368 movement [34, 35]. Examples of this exist when observing the ankle inversion sprain and ACL
369 injuries, thus emphasising the importance of multi directional stability. Findings from the
370 present study indicate a positive training effect over an 8-week training period for all directions
371 of stability when compared to the non-training group. Time \times direction interactions were
372 observed in both the training and non-training groups. Indicating a difference between
373 directions of stability over time. Thus, highlighting that the changes in direction over time
374 were different depending on the direction of stability observed.

375

376 Interestingly collapsed data assessing individual directional differences indicated a training
377 effect observed within all directions of stability at 8 weeks, with A-P stability displaying a
378 significant positive training effect at week 4 when compared to baseline. Leaving the
379 assumption that 4 weeks of proprioceptive training is adequate to improve A-P stability. In
380 addition, it is important to note that A-P stability identifies a significant improvement in
381 stability scores between training weeks 4 and 8. A significant increase in A-P and M-L stability
382 between weeks 8 and 16 when training stopped, was also identified. Thus, suggesting a decline
383 in A-P and M-L stability when training was stopped. Observation of mean scores indicated
384 this decline was highlighted in testing levels 1 and 4, where mean scores increased representing
385 a decline in stability performance Mean Scores Range: Week 8: A-P: 1.11 – 1.49; M-L: 0.94 –
386 1.32; Week 16: A-P 1.13 – 1.71; M-L: 0.99 – 1.54. Reasons for this are unclear.

387

388 Performance of anterior stability would result in an increased anterior shearing force placed on
389 the lower limb, stimulating a neuromuscular response to engage the hamstring muscles to
390 provide stability to the joint [36, 37]. Literature is contradictory as to the number of
391 mechanoreceptors detected in the ACL compared with other stabilising structures in the knee
392 [38, 39, 40]. It is important to note the higher mean scores displayed pre training in the training
393 exposure group, when compared to M-L stability scores. Potentially, the reduced number of
394 mechanoreceptors detected within the ACL could provide one possible explanation for this.
395 Although not quantified in the current study, it is important to consider current findings and
396 previous evidence highlighting that proprioceptive training improves the efficiency of the
397 neuromuscular response, not the composition or number of mechanoreceptors [38]. Within the
398 present study it is evident that 4 weeks of proprioceptive training improves A-P stability and
399 these improvements can be attributed to increased neuromuscular efficiency within this plane,
400 despite mechanoreceptor number. This could also potentially provide an explanation for the
401 greater decline in mean scores post the cessation of training in A-P stability. Findings
402 emphasise the importance of continued proprioceptive training to minimise injury risk in all
403 directions of stability, but emphasise a greater effect on A-P stability. Further research should
404 consider analysis of changes in the electromyography of the muscles in relation to directional
405 stability, to determine efficiency in the muscular response to the unstable surface.

406

407 Utilisation of a variety of levels to assess elite footballer's stability on the BSS has been
408 questioned, with level 1 being the most appropriate level of assessment for this population [24].
409 Interestingly a time \times level interaction was observed for the data within both the training and

410 non-training groups. Suggesting that over time significant differences were found between the
411 levels, potentially supporting earlier findings. When collapsing the data however, the present
412 study highlights no significant differences between level 1 and 4 directional stability scores.
413 Potentially advocating the use of level 4 directional stability assessment in elite footballers,
414 particularly those that are recovering from injury. Note that caution should be taken in the
415 interpretation of these findings due to the number of participants utilised and further research
416 is required.

417

418 Recent studies have indicated the positive effects of proprioceptive training on dynamic
419 stability [14, 15]. Directional stability has been identified as a key aetiological factor
420 associated with sustaining many non-contact lower limb musculoskeletal injuries [13].
421 Consideration of the mechanisms associated with common joint injuries sustained at the knee
422 and ankle, indicate that injuries sustained at these joints can often be associated with multi
423 planar movement patterns [33, 34]. The findings of the current research highlight varying
424 training effects on directional stability (OSI, A-P and M-L), identifying differences within the
425 training response of OSI, M-L and A-P stability. It is suggested from current findings that OSI,
426 M-L and A-P stability all display improvements as a result of an 8-week training protocol
427 completed for 10 minutes, five times a week. However, A-P stability shows greater declines
428 if training is stopped and this potentially has implications for injury risk.

429

430 **Conclusions**

431

432 Proprioceptive training was shown to have a positive effect on dynamic stability scores in elite
433 footballers, across all levels of stability tested on the BSS. Consideration should be given to
434 the level of testing on the BSS, with no significant differences reported between levels 1 and 4
435 for stability scores achieved by elite footballers. When observing the long-term effect of an 8-
436 week training period on OSI, A-P and M-L stability it was evident that post 8 weeks of training
437 stability performance had been improved, with A-P stability showing improvements post 4
438 weeks. Interestingly, observations of stability performance at 16 weeks, saw greater declines
439 in A-P stability compared to OSI and M-L. Providing key considerations for practitioners
440 when periodising proprioceptive training as part of their injury risk reduction strategies.
441 Careful consideration must also be given to the implications of these findings and their
442 association with the MOI of common lower limb injuries sustained in football. Injury risk
443 reduction strategies or rehabilitation of the athlete post injury would need to carefully consider

444 specific directional training and period completed within their training design, to minimise
445 injury risk.

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575 Table 1. Training and Non-Training Group Data with % difference for OSI, A-P and M-L Stability, from Pre
 576 to 4, 8 and 16-Week Time Points.

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| | | Training Group | | | | Non Training Group | | | |
|------------|-----------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| Time Point | Direction | Level | | | | Level | | | |
| | | Level 1 | Level 4 | Level 6 | Level 8 | Level 1 | Level 4 | Level 6 | Level 8 |
| Pre | OSI | 2.12±0.7 5 | 1.80±0.3 5 | 1.98±0.4 5 | 1.96±0.5 9 | 2.20±0.60 | 1.91±0.54 | 2.00±0.52 | 2.24±0.4 4 |
| | A-P | 1.69±0.6 7 | 1.44±0.2 9 | 1.56±0.4 7 | 1.64±0.5 2 | 1.83±0.45 | 1.53±0.34 | 1.66±0.40 | 1.80±0.3 6 |
| | M-L | 1.52±0.4 1 | 1.45±0.2 7 | 1.28±0.2 8 | 1.23±0.4 0 | 1.31±0.36 | 1.09±0.32 | 1.29±0.35 | 1.48±0.3 1 |
| 4 Weeks | OSI | 1.92±0.4 7 (10%) | 1.79±0.4 0 (1%) | 1.80±0.4 4 (9%) | 1.71±0.2 6 (13%) | 2.29±0.37 (+4%) | 2.13±0.43 (+10%) | 1.95±0.41 (2%) | 1.91±0.2 7 (15%) |
| | A-P | 1.42±0.3 4 (16%) | 1.34±0.2 7 (7%) | 1.26±0.3 0 (19%) | 1.21±0.2 7 (26%) | 1.82±0.32 (1%) | 1.62±0.27 (+6%) | 1.42±0.24 (14%) | 1.31±0.2 5 (27%) |
| | M-L | 1.44±0.3 7 (5%) | 1.29±0.2 7 (11%) | 1.44±0.3 4 (11%) | 1.47±0.3 2 (16%) | 2.06±0.36 (+28%) | 1.89±0.36 (+32%) | 1.59±0.18 (+19%) | 1.61±0.2 2 (28%) |
| 8 Weeks | OSI | 1.81±0.4 8 (15%) | 1.61±0.3 2 (11%) | 1.52±0.2 5 (22%) | 1.34±0.1 8 (32%) | 2.36±0.60 (+7%) | 2.04±0.42 (+6%) | 1.77±0.42 (11%) | 1.72±0.3 1 (23%) |
| | A-P | 1.49±0.4 1 (12%) | 1.41±0.2 7 (2%) | 1.29±0.2 1 (17%) | 1.11±0.1 6 (32%) | 2.03±0.46 (+10%) | 1.83±0.39 (+16%) | 1.52±0.39 (8%) | 1.47±0.3 1 (18%) |
| | M-L | 1.32±0.3 5 (13%) | 1.09±0.3 2 (15%) | 1.03±0.1 9 (20%) | 0.94±0.1 2 (24%) | 1.49±0.45 (+12%) | 1.29±0.33 (+16%) | 1.03±0.19 (20%) | 0.94±0.1 2 (34%) |
| 16 Weeks | OSI | 1.95±0.3 1 (8%) | 1.76±0.2 7 (2%) | 1.51±0.2 0 (24%) | 1.36±0.1 6 (31%) | 2.46±0.45 (+11%) | 2.16±0.40 (+12%) | 1.80±0.27 (10%) | 1.70±0.2 0 (24%) |
| | A-P | 1.71±0.2 7 (+1%) | 1.53±0.2 3 (+6%) | 1.31±0.1 9 (16%) | 1.13±0.1 7 (31%) | 2.11±0.35 (+13%) | 1.82±0.30 (+16%) | 1.53±0.21 (8%) | 1.45±0.1 7 (19%) |
| | M-L | 1.54±0.2 5 (1%) | 1.39±0.2 1 (4%) | 1.14±0.1 8 (11%) | 0.99±0.1 0 (20%) | 1.89±0.31 (+21%) | 1.56±0.19 (+17%) | 1.37±0.22 (+6%) | 1.22±0.1 9 (18%) |

OSI = Overall Stability Index; A-P = Anterior-Posterior Stability; M-L = Medial-Lateral Stability.

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580 Figure 1. Experimental Set-Up for Biodex Stabilometry Testing.

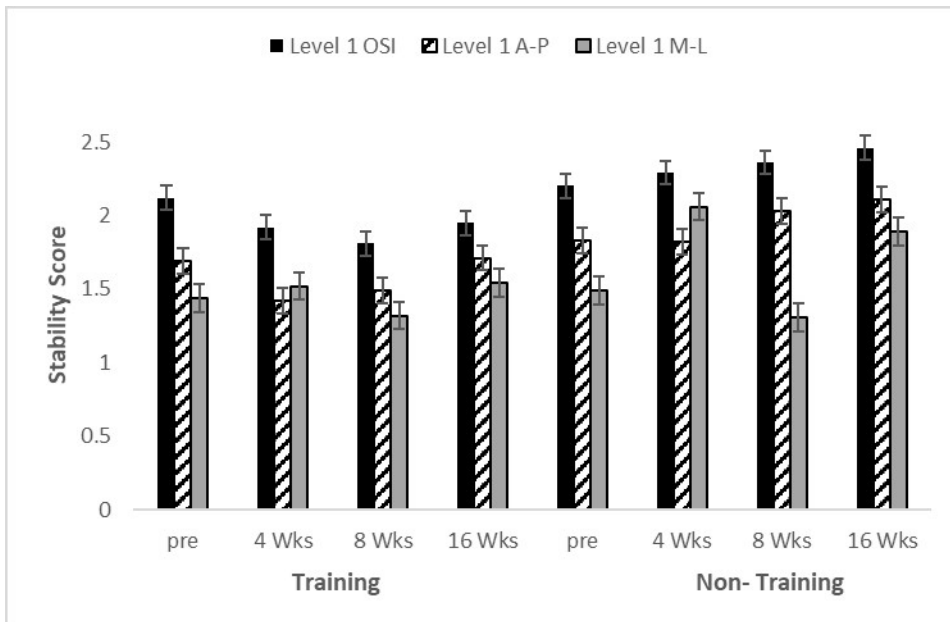
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584 Figure 2: Training v's Non Training Group Stability Scores (Level 1 BSS).



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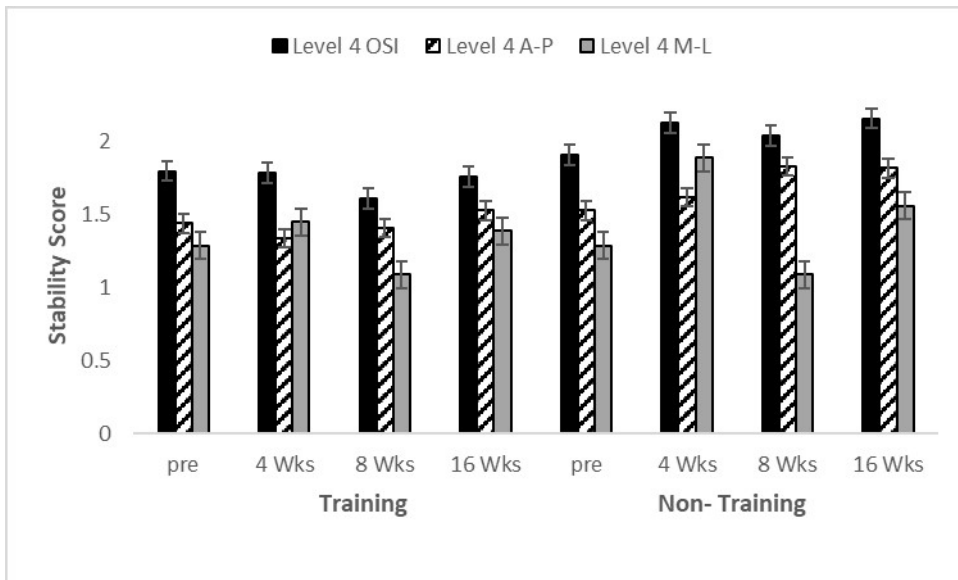
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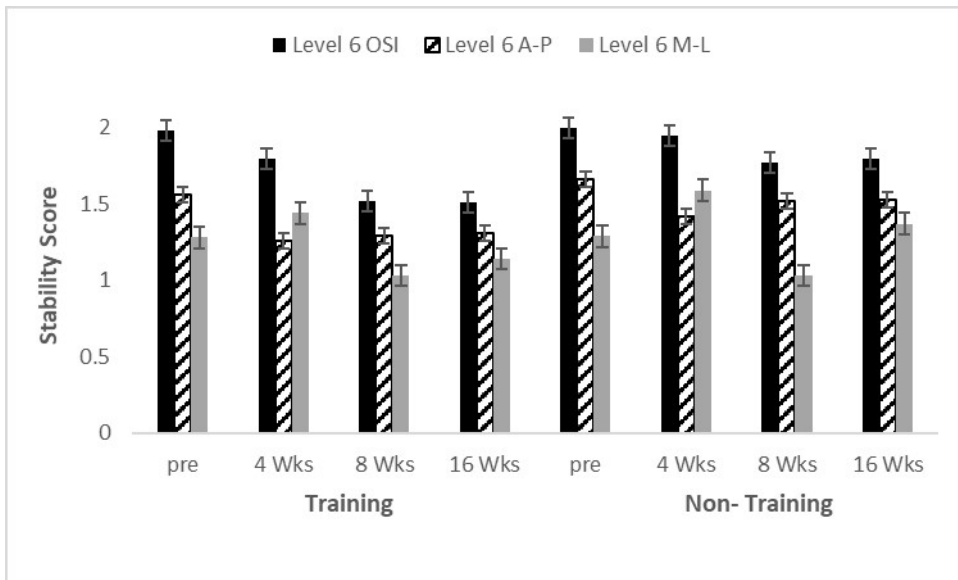
605 Figure 3: Training v's Non Training Group Stability Scores (Level 4 BSS).



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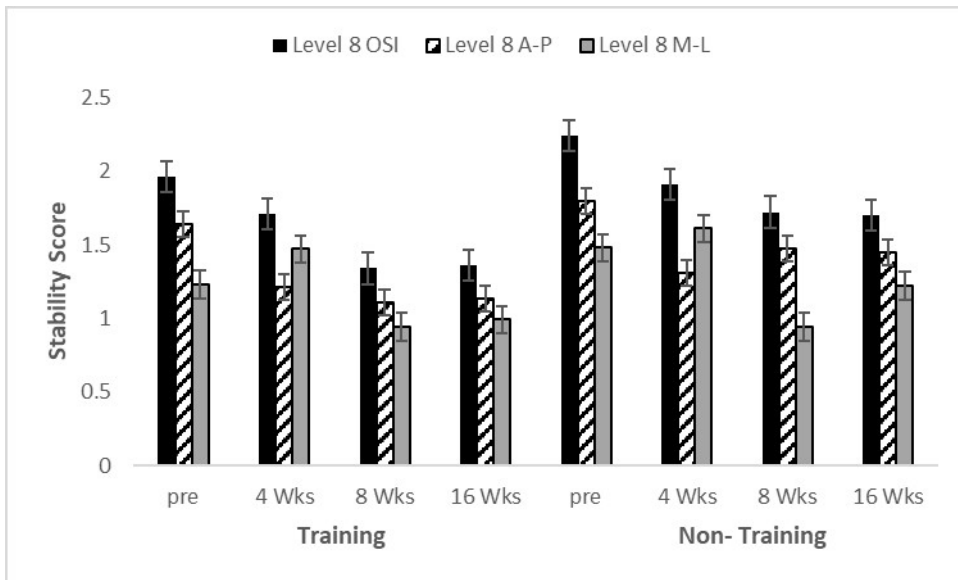
627 Figure 4: Training v's Non Training Group Stability Scores (Level 6 BSS).



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649 Figure 5: Training v's Non Training Group Stability Scores (Level 8 BSS).



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