

1 **Title**

2 The temporal pattern of recovery in directional dynamic stability post-football specific fatigue.

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20 There are no conflicts of interests to report.

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38 **Abstract**

39

40 **Background:** Rising injury rates within football require further understanding of aetiological risk
41 factors associated with lower limb injury.

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43 **Aim:** The aim of the present study was to examine the temporal pattern of recovery of **directional**
44 dynamic stability measures post-football specific fatigue.

45

46 **Methods:** Eighteen male elite footballers completed baseline assessments of directional dynamic
47 stability measures (Overall Stability Index (OSI); Anterior-Posterior stability (A-P); Medial-Lateral
48 Stability (M-L) on level 1 of the Biodex Stability System (BSS). Post SAFT⁹⁰ measures were repeated
49 immediately, +24hrs, +48hrs and +72hrs. Main effects for recovery time and direction of stability were
50 supplemented by regression modelling to describe the temporal pattern of recovery.

51

52 **Results:** Significant main effects for time were identified for all directions of stability (OSI, A-P and
53 M-L) up to +48 hrs post exercise ($p \leq 0.05$). The quadratic pattern to temporal recovery highlights a
54 minima of 37.55 - 38.67hrs and maxima of 75.09 – 77.33hrs. Additionally, a main effect for direction
55 of stability was observed, with significant differences identified between A-P and M-L stability at all
56 timepoints ($p \leq 0.001$).

57

58 **Conclusions:** Reductions in directional dynamic stability +48hrs post fatigue highlight implications for
59 training design, recovery strategies and injury management for performance practitioners. Interestingly,
60 A-P stability has been highlighted as being significantly reduced compared to M-L stability at all time
61 points, regardless of the fatigue exposure. Practitioners should consider the reduction of stability in this
62 plane in relation to common mechanisms of injury in the knee to inform injury risk reduction strategies.

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64 **Keywords:** Performance; Recovery; Stability; Soccer; Screening.

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75 **INTRODUCTION**

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77 Evidence highlights proprioception and fatigue as two key aetiological risk factors associated with
78 lower limb injury.^{1,2,3} The operational definition of proprioception is the body's ability to sense
79 movements within joints and to have a knowledge of where these joints are in relation to space.⁴
80 Interpretation and quantification can cause confusion amongst applied practitioners, as measures, tests
81 and exercise prescription relate to the effected output and do not quantify the physiological process.^{5,6}
82 Although it is accepted that the effected output relates to how efficient this neuromuscular process is,
83 future evidence requires clarity on what is being measured to inform injury risk reduction strategies.
84 Debate exists with regards to the effect of fatigue on proprioceptive ability with contrasting views of
85 whether it has any effect at all.⁷ Within this **present body of work** the extent of fatigue and type of
86 training is not well described. Furthermore, variation of the quantification of proprioceptive output
87 exists between studies in terms of joint position sense, balance or dynamic stabilisation.^{2,7,8} Thus,
88 drawing varying conclusions in response to a fatigue exposure and reasons reduction in performance.
89 Arguably, when relating these findings to injury risk, the effected output is often the focus, relating
90 strongly to dynamic stability responses.

91

92 Dynamic stability can be quantified through various subjective or objective means, such as single leg
93 landing, single leg-hop and hold, Y-balance, single leg stand; to name a few.^{3,1,4,9} Commonly when
94 objectively quantifying dynamic stability, literature has focussed on determining an overall stability
95 index (OSI) and refrained from deeper discussion surrounding directional stability.^{7,10} Further
96 understanding of directional dynamic stability response (DDS) may provide practitioners with further
97 insight for conditioning and injury risk reduction strategies. Dynamic stabilisation of the lower limb is
98 affected by muscle response, and as such, poor muscle response may increase injury risk.¹¹ Movement
99 patterns performed in football are multi-planar and it is not unreasonable to suggest directional output
100 is important to observe and quantify.

101

102 Eccentric loading experienced during game play during such movements is reported to be the most
103 damaging type of muscle contraction that an athlete can be exposed to, resulting in potential detrimental
104 effects on strength.^{12,13,14} Consequently, exposure to exhaustive eccentric loading may result in
105 reductions in dynamic stability performance,^{2,3} demonstrating the influence of muscle response on
106 dynamic stabilisation.¹⁵ Conclusions drawn from the literature suggest that the fatiguing nature of
107 eccentric loading results in an inhibition of the intrafusal fibres of the muscle spindles and **golgi tendon**
108 **organs (GTO)**.^{16,17} This inhibition of the neuromuscular pathway may affect strength response or result
109 in an electromechanical delay (EMD) in the neuromuscular pathway, thus impeding dynamic stability
110 output.¹⁸ Either response would result in increased injury risk, due to exposure of the joint to increased
111 loading or abnormal movement patterns. Several studies acknowledge the effect of fatigue on eccentric

112 strength of the **hamstrings**, with the consensus that eccentric strength reduces significantly.^{12,13,14} It is
113 suggested that the implications of this are wider. During functional performance the hamstring is a key
114 muscle in stabilisation of the knee, most notably anterior translation and rotation.^{19,20} Consequently,
115 these two movement patterns, through differing planes, are largely associated **with anterior cruciate**
116 **ligament (ACL) injury**.^{6,21,22} Consequently, implications may also be observed inferiorly to the knee,
117 potentially affecting the ankle joint control mechanisms. Failure to identify the effect of fatigue on
118 directional dynamic stability does not provide the practitioner with enough detail to inform injury risk
119 reduction strategies in the lower limb.

120

121 **Reduced dynamic stability has been associated with common lower limb injuries often seen in elite**
122 **footballers, predominantly associated with the ankle (lateral ankle sprains) and knee (ACL).**^{21, 23}
123 Interestingly, current evidence has reported a large increase in the number of **ACL** injuries sustained
124 within elite male footballers and the detrimental effect these injuries can have on a player's career.^{19,22,23}
125 Both lateral ankle sprains and knee injuries are associated with multi-planar movements when the injury
126 is sustained.^{22,23,24} Analysis of an athlete's functional directional dynamic stability is essential for
127 determining injury risk.⁹ Evidence surrounding the fatigue effect on dynamic stabilisation focusses
128 primarily on an immediate response^{1,5} and falls short of successfully analysing the resultant temporal
129 pattern. This approach fails to consider the context of contemporary elite football, where demand is
130 placed on frequency and subsequent congestion of fixtures and training. Literature clearly highlights
131 the detrimental effect of fixture congestion on injury^{25,26}. Subsequently further identification of the
132 temporal pattern of directional dynamic stabilisation post-football specific fatigue, would inform
133 training design and injury risk reduction strategies. Therefore, the aim of the present study is to quantify
134 the temporal pattern of recovery in directional dynamic stabilisation of elite footballers for 72 hrs post
135 a simulated specific fatigue protocol.

136

137 **METHODS**

138

139 *Participants*

140

141 From an available squad of twenty-four, eighteen elite male football players took part (age: 22.94±4.57
142 years, height: 185.3±4.2 cm; body mass: 75.91±6.38 kg). A minimum sample size was based on
143 sixteen players who met the inclusion / exclusion criteria of; no history of previous lower limb
144 injury in the last 6 months and highlighted by the clubs medical team as having no mechanical
145 or functional instability in the knee or ankle at time of testing.⁹ Players included were also free
146 from systemic or vestibular disorders known to impair cutaneous sensation of balance.⁷ In
147 total, eight players were excluded from partaking in the study due to: injury (n=2), playing

148 position (goalkeepers' n=3), unavailable due to being on loan to another club (n=3). All players
149 provided written informed consent in accordance with Department and Faculty Research Ethics
150 committees at the host University (SPA-REC-2014-334), and in accordance with the Declaration of
151 Helsinki (2013).

152

153 *Experimental Design*

154

155 Players completed a familiarisation trial 7 days prior to testing to negate potential learning effects,²⁷
156 which included the football Aerobic Field Test (SAFT⁹⁰) protocol²⁸ and the directional dynamic stability
157 (DDS) testing on the BSS (Medical Systems, Shirley, NY.) Subsequently, the testing session also
158 included elements of the SAFT⁹⁰ as part of the pre-exercise warm-up, and trial repetitions of the DDS
159 testing on the BSS. All testing was completed between 13:00 and 17:00 hrs to account for the effects
160 of circadian rhythm and in accordance with regular competition times.²⁹ All trials were completed on
161 the dominant lower limb, identified by their favoured kicking foot, based on non-contact
162 musculoskeletal injury epidemiology.³⁰

163

164 All testing was completed on the same BSS at testing level 1. The BSS (Biodex Medical Systems,
165 Shirley, NY) is an unstable platform that can tilt up to 20° in any direction, with the stability of the
166 platform determined by the level by which it is set ranging from 1 (most unstable) to 12 (most stable).³¹
167 Research has shown that the most appropriate level for an elite footballer is level 1, with ICC
168 repeatability scores indicated to be 0.85.^{8,32} Players were asked to complete 10 minutes of the SAFT⁹⁰
169 protocol as a warm up followed by directed dynamic stretching focussed on the quadriceps, hamstrings,
170 gluteal muscles and gastrocnemius. The SAFT⁹⁰ was utilised within the study as it is a free running
171 protocol that replicates the physiological and mechanical demands experienced during game play.²⁸
172 Over a 20m distance, players move through a series of cones and poles, alternating between side steps,
173 backwards running, accelerations and decelerations with varying intensities, which are prompted by
174 audio cues. The 15-min activity profile is repeated six times to formulate the 90 mins, with players
175 having a 15-min half time break, where they are directed to sit, as they would in normal game play.
176 The activity profile is performed in a randomised and intermittent fashion and incorporates 1269
177 changes in speed and 1350 changes in direction over a 90-min period.¹³

178

179 Pre-exercise, all players completed the BSS testing, which comprised of 3 trials of 20-seconds
180 completed on stability level 1. **Once completed metrics of Overall Stability Index (OSI), Anterior-
181 Posterior (A-P) and Medial-Lateral (M-L) were observed and noted. These metrics were calculated by
182 the BSS software and based on the amount of tilt in degrees of the foot platform during the trial.** A low
183 index score indicated high stability and high score a low level of stability. All testing on the BSS was

184 completed barefoot, due to the effect footwear can have on kinematics of the foot and muscle activity
185 in the lower limb.³³ The BSS was setup in accordance with previous literature.⁸ They then stood on the
186 platform in full extension with their dominant limb with their foot in the centre of the platform. The
187 feedback screen was set at eye level and the players were asked to look at the screen, this was set as
188 such to avoid any unwanted head movement and avoid vestibular distraction.⁸ Once set the players
189 were then asked to adjust their standing foot to a comfortable position, while the marker on the feedback
190 screen maintained a central position, once done and comfortable 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 entire 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. In
194 cases where players lost their balance, they were told to use the contralateral limb to stabilise themselves
195 by placing it at the back corner of the BSS and were only encouraged to use the handrails if they
196 completely lost balance. Figure 1 provides a representation of the testing set-up.

197

198

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

199

200 Following completion of the SAFT⁹⁰ the standardised BSS testing was completed immediately. Further
201 trials were completed following the same protocol at +24hrs, +48hrs and +72hrs post SAFT⁹⁰ in order
202 to monitor the temporal pattern of recovery in DDS performance.¹⁴ Between trials players were
203 reminded to refrain from exercise and to maintain a normal diet.

204

205 **Statistical Analysis**

206

207 The directional stability output was analysed for each 20-second trial and an average score across the
208 three trials was taken for analysis. Directional stability scores were identified for OSI, anterior-posterior
209 stability (A-P) and medial-lateral stability (M-L). Each directional stability variable was determined
210 pre-exercise, immediately post-exercise, and then at +24-, +48- and +72-hrs after exercise.

211

212 A univariate repeated measures general linear model was used to quantify main effects for recovery
213 duration post-exercise and DDS. Interaction effects were quantified, and significant main effects in
214 recovery duration were explored using post-hoc pairwise comparisons with a Bonferonni correction.
215 The assumptions associated with the statistical model were assessed to ensure model adequacy. To
216 assess residual normality for each dependant variable, q-q plots were generated using stacked
217 standardised residuals. Scatterplots of the stacked unstandardised and standardised residuals were
218 utilised to assess the error of variance associated with the residuals. Mauchly's test of sphericity was
219 completed for all dependent variables, with a Greenhouse Geisser correction applied if the test was
220 significant. Partial eta squared (η^2) values were calculated to estimate effect sizes for all significant

221 main effects and interactions. As recommended in literature³⁴, partial eta squared was classified as
222 small (0.01–0.059), moderate (0.06-0.137), and large (>0.138).

223

224 The temporal pattern of changes in each directional dynamic stability variables over the 72hr data
225 collection period was examined using a regression analysis. Linear and quadratic polynomial models
226 were applied, with the optimum fit determined by the strength of the correlation coefficient (r). Where
227 a quadratic regression analysis represented the best fit, the regression equation was differentiated with
228 respect to time to elicit the time (post-exercise) at which the data reached maxima (or minima). All
229 statistical analysis was completed using PASW Statistics Editor 26.0 for windows (SPSS Inc, Chicago,
230 USA). Statistical significance was set at $P \leq 0.05$, and all data are presented as mean \pm standard deviation.

231

232 RESULTS

233

234 Figure 2 summarises the effects of the exercise protocol and the temporal pattern of recovery on
235 directional dynamic stability, for OSI, A-P and M-L. There was a significant main effect of direction
236 ($F = 34.20, p < 0.001, \eta^2 = 0.21$) and time ($F = 10.54, p < 0.001, \eta^2 = 0.14$). Significant differences
237 were displayed between all directions of stability represented as $p \leq 0.05$. Pre-exercise directional
238 stability values were significantly lower (pre to post: $p \leq 0.05$; pre to +24hrs and pre to +48hrs $p \leq$
239 0.001), no significant difference was indicated pre to +72hrs ($p > 0.05$). There was no direction \times time
240 interaction ($F = 0.49, p = 0.38, \eta^2 = 0.12$).

241

242 ***insert figure 2 here***

243

244 With the data set collapsed to consider the temporal pattern of recovery for each direction of stability,
245 all directions displayed a significant effect of time (OSI: $F = 3.98; p = 0.005, \eta^2 = 0.16$; A-P: $F = 2.81;$
246 $p = 0.03, \eta^2 = 0.12$; M-L: $F = 5.19; p = 0.001, \eta^2 = 0.20$). OSI and M-L directional stability displayed
247 significant increases in stability scores up to +48hrs when compared to pre exercise scores ($p \leq 0.05$).
248 A-P stability displayed no significant difference between pre and immediately post exercise stability (p
249 > 0.05). Although displayed significant increases in stability values pre to +24 hrs and pre to +48hrs
250 post exercise ($p \leq 0.05$). Each direction of stability also indicated significant reductions in stability
251 scores from +24hrs to +72hrs ($p \leq 0.05$). Significant differences in stability scores were also found
252 between each directional measure ($p \leq 0.001$). It was found that OSI stability scores were significantly
253 higher than A-P and M-L ($p \leq 0.001$) and A-P was significantly higher than M-L ($p \leq 0.001$). Mean
254 stability scores also highlighted that A-P stability scores at each time point were higher than M-L
255 stability scores (14 – 25%).

256

257

insert table 1 here

258

259 The relationship between directional dynamic stability and post-exercise recovery duration was best
260 represented as a quadratic polynomial function ($r = \geq 0.86$). The differentiated regression equations
261 yielded a minima between 37.55 – 38.00hrs (OSI: 37.55hrs ($y = -0.0011x^2 + 0.0826x + 2.5303$); A-P:
262 38hrs ($y = -0.0007x^2 + 0.0532x + 1.9633$); M-L: 38.67hrs ($y = -0.0006x^2 + 0.0464x + 1.5125$)) and
263 maxima between 75.09 – 77.33hrs (OSI: 75.09hrs; A-P: 76hrs; M-L: 77.33hrs). This would result in a
264 predicted return to baseline values of up to 77.33hrs.

265

266 **DISCUSSION**

267

268 The aim of the present study was to investigate the temporal pattern of recovery in directional dynamic
269 stability in elite male footballers for up to 72-hrs post a simulated football specific fatigue protocol.
270 Research in this area is limited, as it predominantly focuses on the immediate acute effect of fatigue
271 and does not differentiate measures based on the direction of stability.^{1,2,3,32} It was observed that
272 completion of the fatigue protocol induced an average 22% - 30% reduction in directional dynamic
273 stability scores (OSI, A-P and M-L) when compared to pre-fatigue measures. These findings are
274 consistent with previous research that analysed the effects of fatigue on eccentric hamstring
275 strength.^{12,13,14} Current findings, in agreement with previous studies report positive correlations
276 between hamstring function and directional dynamic stability.⁹ Main findings within this body of work
277 indicate significant differences between pre exercise measures and +48hrs for all directions of stability,
278 with no differences observed at 72hr+. Interestingly, no significant differences were observed for A-P
279 stability when compared to pre fatigue measures, despite a 22% average increase in scores. Significant
280 reductions in stability scores for all directions were observed between 24hr+ and 72hr+, highlighting a
281 period of recovery. This said, a 14–19% increase in stability scores still existed at 72hr+ when
282 compared to pre-fatigue values. Further analysis via polynomial regression indicated that mean stability
283 values took up to 77.33hrs to return to pre-exercise levels, with variations of recovery within specific
284 directions of stability metrics. The present findings are based on a cohort of elite footballers, where
285 group averages are observed. In practice it is important to consider individual responses to fatigue and
286 their temporal pattern, as these will differ between players. Future research should consider these
287 factors to bridge the gap between academia and applied practice.

288

289 Controversy exists within recent evidence indicating that sustaining knee injuries, such as anterior
290 cruciate ligament (ACL), **may not be related** to fatigue.³⁵ This contradicts previous evidence, where
291 fatigue has been highlighted as a key aetiological factor to sustaining these injuries.³⁶ It is important to
292 note that the research by Doyle et al., (2019) only observes the stage of the season and period of the
293 game when the injuries were sustained. Concluding that there were no specific periods of the season
294 or difference between halves of the game when these injuries were sustained, thus discounting a fatigue

295 effect. Although, this may discount the acute fatigue responses (in game), there is no indication within
296 the study of the players readiness to play. Prompting the question of whether sustaining this injury was
297 a result of accumulative fatigue during a fixture congested period or an increased training load
298 exposure.^{12,14} Understanding of the temporal pattern of fatigue in relation to directional dynamic
299 stability provides further insight into the recovery patterns of footballers in relation to key aetiological
300 factors associated with injury. Particularly useful in the current modern game where COVID-19 has
301 impacted on recovery time due to condensed fixture schedules, reduced preparation and training. It is
302 important to note that injury risk is multi factorial and this is only one piece of the injury risk paradigm.
303 **Present findings fail to consider a multifactorial model and future research should consider multiple**
304 **outcome measures utilised in the field to quantify fatigue effect. They should carefully relate to**
305 **biomechanical, physiological and psychological measures.**

306
307 ACL injuries sustained in footballers are commonly associated with an increased anterior shearing
308 force. **Resulting** in excessive load being exerted through the ACL.^{19,20} It is suggested that decreased
309 functional strength of the hamstrings may have an impact on directional dynamic stability performance,⁹
310 and with the addition of acute fatigue exposure or insufficient recovery this risk could be heightened.
311 Combined with the additional rotational load, potentially creating further damage to major joint
312 structures, these injuries can result in significant time loss for the athlete.^{19,22,23} The hamstrings are a
313 key muscle group providing support to the knee joint through these movement patterns, best explained
314 by understanding its functional anatomical role in performance.²⁰ **Future work should consider**
315 **quantifying muscle activity in relation to dynamic stability output, with the use of electromyography.**
316 The present study identifies significantly elevated A-P stability scores throughout all time points
317 compared to M-L (14-25%), which potentially indicates the vulnerability of the ACL to increased
318 anterior load exposure during performance. This further acknowledges the vulnerability of the structure
319 and recent evidence to suggest that injury occurrence may not solely be attributed to fatigue.³⁵ Further
320 research is required and should consider the effect of training load, accumulated fatigue or readiness to
321 play when analysing injury incidence in game play or within periods of high occurrences of ACL
322 involvement.

323
324 It is important to note that the post-exercise response displayed in the present study highlighted an
325 increase in directional dynamic stability scores up to a predicted 77hrs post exercise (Figure 2),
326 potentially increasing injury risk. This is accompanied by increases in M-L stability. Providing support
327 to suggest that eccentric loading experienced during football specific activity can result in an inhibition
328 of the intrafusal fibres of the muscle spindles **and GTO.**^{16,17} Thus, reducing muscle response to provide
329 dynamic stabilisation. The reduction in stabilisation experienced, potentially as a result of reduced
330 eccentric hamstring function, may have implications to other joints within the lower limb. It is
331 important to note the reduced function of the hamstrings as discussed may not be the only contributory

332 factor to reductions in dynamic stabilisation. These links are suggestive based on previous findings,
333 consideration of the functional anatomy and results reported within the present study. Further research
334 should consider the effect and influence of other muscle groups within the lower limb and their
335 influence on lower limb dynamic stability. Consideration should also be given to the electromyographic
336 response of varying muscle groups within the lower limb in response to fatigue and directional dynamic
337 stability.

338

339 Literature has indicated the acute detrimental effect of fatigue on dynamic stability^{1,2,3,32} with directional
340 stability being identified as a key aetiological factor associated with common non-contact lower limb
341 musculoskeletal injuries.^{6,21,22} **It is important to contextualise the meaning of OSI, A-P and M-L**
342 **stability. Previous research has heavily focussed on only OSI scores when quantifying dynamic**
343 **stability.^{7,10} It is suggested however that further insight into function to inform injury risk may be gained**
344 **from observing the planar outputs of A-P and M-L directional stability. These specific movement**
345 **patterns can be related to the injury mechanism during functional performance.** Consideration of the
346 mechanisms associated with common joint injuries sustained at the knee and ankle indicate that injuries
347 sustained at these joints may be associated with multi planar movement patterns.^{22,23} The findings of
348 the present study highlight the differing temporal pattern of recovery of directional dynamic stability
349 (OSI, A-P and M-L) post-football specific fatigue, displaying a return to baseline at 77.33hrs. In
350 addition, this identifies the differential response of A-P to M-L dynamic stability when quantified on
351 the BSS. Interestingly the detrimental effect of exercise continues for 38.67hrs post-football specific
352 fatigue. Consequently, these findings provide considerations for training design, player monitoring and
353 injury risk reduction strategies in elite football settings.

354

355 **Conclusions**

356

357 Directional dynamic stability of OSI, A-P and M-L were shown to significantly deteriorate up to 48 hrs,
358 as a result of football specific fatigue. Quadratic polynomial regression modelling suggest that mean
359 scores only truly returned to baseline at 77.33 hrs and continued to decline post fatigue exposure up to
360 38.67 hrs. Regardless of time points, A-P stability measures were shown to be significantly elevated
361 compared to M-L, indicating poorer stability performance through this plane. These findings provide
362 important considerations for sports performance practitioners with regards injury risk reduction,
363 recovery interventions and training design. Careful consideration must be given to the implications of
364 these findings and their association with the mechanism of common lower limb injuries sustained in
365 football. Injury risk reduction strategies, conditioning or rehabilitation of the athlete post injury should
366 consider specific directional stability training when the athlete is fatigued.

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478 **Table 1:** Mean Directional Dynamic Stability Measures and Temporal Pattern Changes over a 72-hour
 479 Data Collection Period.

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Dynamic Stability Measures	Time Point				
	Pre	Post	+ 24 hrs	+48 hrs	+72 hrs
OSI	2.42 ± 1.07	3.38 ± 1.42	4.22 ± 1.58	3.69 ± 1.62	3.00 ± 1.48
A-P	1.89 ± 1.01	2.42 ± 1.07	3.06 ± 1.06	2.68 ± 1.49	2.24 ± 1.29
M-L	1.46 ± 0.49 (23%)	2.07 ± 0.69 (14%)	2.44 ± 0.94 (20%)	2.14 ± 0.85 (20%)	1.69 ± 0.52 (25%)
Note: +24 hrs - 24 hours post fatigue; +48 hrs - 48 hours post fatigue; +72 hrs - 72 hours post fatigue. % indicates difference between A-P and M-L Stability Scores. Data is presented as mean ± SD.					

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505 **Figure Legends**

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507 **Figure 1.** Experimental set-up for Stabilometry testing.

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509 **Figure 2.** The temporal pattern of recovery of OSI, A-P and M-L directional stability.