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Effects of foot orthoses on dynamic balance and basketball free-throw accuracy before and after physical fatigue

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Abstract

While it is not uncommon for athletes to use foot orthoses to relieve pain and improve sports performance, little has been known about their effects on basketball performance. Free-throw basketball shooting is very important. However, fatigue deteriorates postural balance which might decrease free-throw shooting performance. This study investigated the effects of foot orthoses on dynamic balance and accuracy performance during free-throw shooting before and after physical fatigue was induced. Thirteen male recreational basketball players were tested with two foot orthoses (medial-arch support versus flat control) and fatigue conditions (before and after fatigue), when they performed standard free-throw shooting on a force platform. Results revealed that fatigue significantly increased coefficient of variance of medial-lateral center of pressure (CoP) excursion when participants worn flat control orthoses ($p < 0.05$). Meanwhile, foot orthoses improved dynamic balance during shooting as they significantly reduced total resultant and anterior-posterior sway excursions as well as resultant and anterior-posterior CoP velocities, and base of support area. Although this study found that fatigue and orthoses did not significantly affect the scores gained by free-throw shooting, the significant improvements in dynamic balance during shooting with the use of foot orthoses could have considerable impact on motor control during basketball shooting.

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10

11 **Abstract**

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25 resultant and anterior-posterior sway excursions as well as resultant and anterior-
26 posterior CoP velocities, and base of support area. Although this study found that
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28 shooting, the significant improvements in dynamic balance during shooting with
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31

32 Word Count: 197 (Abstract), 3432 (Main text)

33 **Keywords:** Insole, orthotic, postural stability, sports, shooting

34

35 **1. Introduction**

36 An estimated 450 million people participate in basketball worldwide (FIBA
37 2018). In a basketball game, 16-21% of the playing time is involved in high
38 intensity activities (Ben Abdelkrim et al., 2010), with execution of various jump,
39 cutting, and lateral movements (Ben Abdelkrim et al., 2007; Lopezosa-Reca et
40 al., 2017). Such intensity of activities can easily produce physical fatigues
41 causing reduced strength and coordination, which is associated with inferior
42 performances in jump, agility, passing and shooting accuracy (Lyons et al., 2006;
43 Padulo et al., 2015).

44 Free-throw shooting is extremely important, which directly influences the
45 team's success. Physical fatigue poses greatest challenge in shooting accuracy
46 (Padulo et al., 2015; Okazaki et al., 2015). It has been documented that physical
47 fatigue could deteriorate dynamic balance (Zemkova 2014), which in turn led to
48 lower rifle (Ball et al., 2003; Mononen et al., 2007) and archery (Mason and
49 Pelgrim, 1986) shooting accuracy. Similarly, basketball free-throw shooting also
50 requires players to maintain a stable position with very little sway while
51 simultaneously shooting the ball. A plausible strategy that can enhance dynamic
52 balance may potentially improve basketball free-throw shooting.

53 It is not uncommon for athletes to use foot orthoses to relieve pain
54 (Hirschmuller et al., 2011) and improved sport performance (Banwell et al.,
55 2014; Mills et al., 2010). More than 50% of basketball players were reported to
56 use foot orthoses in competition and training (Losito, 2010), as it can improve
57 balance, foot alignment, strain and load on soft tissues, and receptor sensory on
58 the foot plantar in various populations (Davidson, 2010; Ho et al., 2019; Lusardi
59 and Nielsen, 2007). Biomechanically, foot orthoses with medial arch-support

60 increase the foot-sole contact area and pressure at the medial longitudinal arch
61 of a foot, enhancing somatosensory inputs over the plantar foot. Previous studies
62 showed that they allow wearers to walk comfortably while enabling them to
63 maintain postural stability using a narrow base of support, which was considered
64 to be more challenging than a wider base of support (Hrysomallis, 2011;
65 Zemkova 2014).

66 Static and dynamic balance is the ability to maintain postural stability and
67 orientation with center of mass over the base of support and body at rest and in
68 motor task, respectively (Hrysomallis, 2011; Zemkova, 2014). Such postural
69 skills and stability can be developed through practice (Paillard 2014; Zemkova,
70 2014). Previous studies have found that poor shooters had inferior postural
71 stability than the good shooters (Zemkova, 2014) and that poor shooter
72 demonstrated higher center of mass velocity (76.5 m/s) compared to good (49.0
73 m/s) and elite (44.9 m/s) shooters (Verhoeven and Newell, 2016). However, the
74 relationship among shooting performance, dynamic stability and use of foot
75 orthoses in basketball free-throw is not yet established.

76 This study examined the effects of foot orthoses on the dynamic balance
77 during free-throw shooting and accuracy of shooting before and after physical
78 fatigue. We expected that fatigue would induce inferior postural stability and
79 shooting performance. We also expected that arch-support foot orthoses would
80 improve dynamic balance and shooting performance when participants were in
81 fatigue conditions. The information can be insightful for coaches and sport
82 scientists who consider to use foot orthoses in training and competitions.

83

84 **2. Methods**85 *2.1 Participants*

86 A priori power analysis was performed to determine the appropriate
87 sample size of 8 for this study, based on an alpha of 0.05 and 80% power with
88 medium effect size (Cohen's $d = 0.5$, Cohen 1988) calculated with pilot data to
89 detect postural stability between fatigue levels. Thirteen male basketball players
90 [mean age 21.4 ± 3.3 years; height 1.8 ± 0.06 m; mass 72.0 ± 7.1 kg] were recruited
91 for this study. Average competition experience was 4.5 ± 3.7 years. Only
92 participants having normal foot arches and foot lengths of US size 9 were
93 included. We used the pressure plate (Footscan 7, RSscan International,
94 Belgium) and Brannock foot measurement device (Brannock Device, Syracuse,
95 NY, USA) to confirm if the participants were normal foot arches. All participants
96 were right-handed basketball shooting and free of any inner ear infection, other
97 foot deformities, and lower extremity injuries for at least 6 months prior to the
98 start of the study. Ethical approval was granted by the Institutional Review Board
99 and written informed consent was obtained before data collection.

100

101 *2.2 Orthosis and shoe conditions*

102 To eliminate foot size and footwear as confounding factors, all of the
103 participants were tested with the identical high-top basketball shoes (Wade 6, Li
104 Ning, Beijing, China) with US size 9.0 were used with the two orthoses
105 conditions (medial-arch support versus flat control) for this study. The tested
106 orthoses were fabricated with the insole milling machines (CNC Milling

107 machine, Vulcan series, Sensor Medica, Italy) and the height of medial-arch
 108 support and forefoot/rearfoot thickness were based upon previous studies (Alavi-
 109 Mehr et al., 2018; Zhai et al., in press). The two orthoses were identical in terms
 110 of material, thickness and hardness, except for the inclusion of medial-arch
 111 support (see Fig. 1). The same orthotist quantified the hardness of the orthoses
 112 across forefoot, midfoot and rearfoot regions using a Type C shore durometer
 113 (1600 Asker SP-698 Rex Durometers, Rex Gauge Co., IL, USA) (Lam et al.,
 114 2017; Nin et al., 2015). Five measurements taken at each of the five dots from
 115 each respective regions were averaged and confirmed both orthoses have the
 116 same hardness across different regions.

117

118 *****Fig. 1 near here*****

119

120 *2.3 Equipment and laboratory setting*

121 All fatigue protocols and free-throw shooting were performed in our
 122 biomechanical laboratory. To replicate indoor basketball court, force plate and its
 123 surrounding surfaces were covered with standard basketball court surface and the
 124 free-throw distance and height of basketball rim were set according to the
 125 standard of International Basketball Federation (FIBA, 2018). Posturography
 126 data were collected by synchronised force platform (AMTI, Watertown, USA,
 127 sampling frequency of 1000 Hz) and motion analysis system of ten cameras
 128 (Oxford Metrics Ltd, Oxford, sampling frequency of 200 Hz) during basketball
 129 free-throw shooting. Six reflective markers were placed over the posterior (heel),
 130 anterior (toe), and lateral (fifth metatarsal) aspects of each of left and right shoes
 131 to define the area of base of support during free-throw trials (DiDomenico et al.,

2015). To prevent hindering the movements in test and fatigue-inducing protocol, no reflective markers were attached at any other body parts. Another high-speed camera (Casio EX-F1, Casio, Japan) at a sampling rate of 300 Hz was placed perpendicular to the shooting arm of the participant to determine the start and end points of each shooting trial. Both force plate and high speed camera were synchronised when determining the first basketball contact during a basketball dribbling on the two measuring systems.

139

2.4 Fatigue-inducing protocol

To induce physical fatigue, all participants were asked to perform both Yo-Yo Intermitted Recovery protocol - level 1 (YYIR1, Bangsbo et al., 2008) and consecutive maximal vertical jumps (Zemkova and Hamar, 2010) in this study. The YYIR1 consisted of multiple 2 x 20 m shuttle runs with a short 10s recovery period between sets, as previously described (Bangsbo et al., 2008). In brief, participants were instructed to complete the full 20 run and turn indicated by the audio beep sound, and return to the starting point. There was an 10s recovery period between every shuttle run interval. The starting speed was 10.0 km/hr and increased to 12 km/hr, 13km/hr, then increasing by 0.5 km/hr thereafter. The participants continued running as long as they were unable to continue. The maximum running speed sustained by participants was 14.8 ± 1.0 km/h.

Consecutive maximal vertical jumps involved at least 10 times maximal-effort vertical jumps, which were shown to sufficiently deteriorate the dynamic balance (Zemkova and Hamar, 2010). After 10 consecutive maximal jumps, the participants were required to continue the maximum-effort jumps until their heart

rate attained 85% of the maximum heart rate, which was found to be experienced by most players in basketball competitions (McInnes et al., 1995). The maximum heart rate was determined when multiply individual age by 0.7, then subtract the results from 207 (Gelish equation, Pescatello et al., 2013). Heart rate was recorded with a heart rate monitor system (Polar PCX3, Polar, Kempele, Finland).

163

164 2.5 Procedures

The experimental procedure is shown in Fig. 2. After having the anthropometrical measurements, participants wore a new pair of standard socks and test basketball shoes (Wade 6, Li Ning, Beijing, China) to prevent the potential influences due to the socks and footwear (Ho et al., 2019; Lam et al., 2018; Liu et al., 2017; Nin et al., 2016). They were then instructed to administer a 10-min self-instructed warm-up including stretching and jogging and then familiarise themselves with the testing tasks and footwear condition, which was comparable with previous studies on basketball footwear and orthoses (Ho et al., 2019; Lam et al., 2018; Liu et al., 2017; Nin et al., 2016).

174

175 *****Fig. 2 near here*****

176

Each participant was required to perform 20 free-throw shooting trials using a standard ball (size 7), from the free-throw line (4.0m from the front part of the basket) into a standard basketball rim (height = 3.05m; circumference = 0.45m) in each of the two orthosis conditions (medial-arch support and flat). The participants were then asked to perform the fatigue-inducing protocol, which

182 included YYIR1 and consecutive maximum vertical jumps, separated by a 30-
 183 second standing rest on the shooting area. The participants then performed 20
 184 free-throw shooting trials. The trial was discarded if the obvious slippage and
 185 discontinuity of movement was present. After the first orthosis condition, the
 186 maximal jump protocol was repeated before the second orthosis measurements
 187 were made to maintain the physical fatigue state (Fig. 2). The orders of the use of
 188 the foot orthoses were randomised in all conditions across participants.

189

190 *2.6 Data reduction*

191 The analysed period of a free-throw was defined manually from the
 192 lowest point of elbow joint to the point of basketball release of the shooting arm.
 193 A spline interpolation was performed for minor missing data using three frames
 194 of data before and after the missing data. All signals were smoothed with a fourth
 195 order Butterworth bidirectional filter (DiDomenico et al., 2015). The cut-off
 196 frequencies of were determined using a residual analysis (Winter, 1990). The
 197 marker trajectories were identified using Vicon Clinical Manager Software
 198 (Oxford Metrics Ltd, Oxford) and then transferred into Visual3D software (C-
 199 Motion Inc.) for definition of area of base of support during free-throw shooting
 200 trial (DiDomenico et al., 2015).

201 The following posturography variables were selected to denote the
 202 dynamic balance during each shooting trial (Zemkova, 2014): maximum range of
 203 resultant, medial-lateral (ML) and anterior-posterior (AP) center of pressure
 204 (CoP) excursion (sway range; mm), total resultant, ML and AP CoP excursion
 205 (sway excursion; mm), mean resultant, ML and AP sway velocity along the CoP
 206 path (sway velocity; mm/s), and 95% ellipse sway area included within the COP

207 path (sway area; mm^2). Resultant CoP travelling distance was defined as the
 208 distance of the present CoP coordinate relative to the coordinate of the previous
 209 frame. The sway range was defined as the largest coordinates subtracted the
 210 smallest coordinates in each shooting cycle. Total excursion was defined as sum
 211 of the resultant CoP path covered the whole shooting period. The 95% ellipse
 212 sway area was defined as an estimated ellipse to the CoP data that encompassed
 213 95% of the data. The mean sway velocity was defined as rate of change of CoP
 214 path of a body between frames. Maximum range of resultant, ML and AP CoP
 215 excursions, ML and AP sway velocities and 95% ellipse sway area are
 216 commonly used to assess postural balance of human (Distefano et al., 2009). The
 217 literature reported very little about the postural balance of basketball players.
 218 However, these parameters have been studied in other sports which included
 219 soccer (Paillard and Noe, 2006), dancers (Gerbino et al., 2007), swimmers and
 220 gymnasts (Hrysomallis, 2011). Small CoP excursion, variability of AP and ML
 221 excursion and velocity, and sway ellipse area were indicative of good balance.

222 The shooting performance was quantified using a six-point scale to
 223 examine the differences in performance over sessions (Lam et al., 2009a). In
 224 brief, 5 was awarded for a 'clean' basket (i.e., "swish"); 4 for rim and in; 3 for
 225 backboard and in; 2 for rim and out; 1 for backboard and out; and 0 for a
 226 complete miss. The shooting score of each shooting trial was recorded by the
 227 same researcher and then averaged for each fatigue and orthosis condition as the
 228 dependent variable for shooting performance. All participants were reminded of
 229 the scoring system and encouraged to score as many points as possible (Lam et
 230 al., 2009a).

231

232 ***Data analysis***

233 To assess the main effects and interaction of fatigue and orthosis conditions
 234 (independent variables) on dynamic balance and shooting performance
 235 (dependent variables), a 2×2 two-way (Orthosis x Fatigue-level) ANOVA with
 236 repeated measures was performed on both mean and coefficient of variation
 237 (CV) in each of the dependent variables. The CV was defined as the standard
 238 deviation divided by mean, which allowed comparing the degree of variability
 239 across variables (Reed et al., 2002). The CVs across 20 free-throw shooting trials
 240 were calculated for respective fatigue and orthosis conditions for each of the
 241 participants for subsequent analyses. Bonferroni corrected post-hoc tests were
 242 performed accordingly, if the two-way ANOVA indicated a significant
 243 interaction among the independent variables. Level of significance was set at
 244 0.05. All statistical analyses were performed using the SPSS statistical analysis
 245 computer program package, version 21.0 (SPSS, Inc., Chicago, IL, U.S.A.).

246

247 **3. Results**

248 *3.1 Dynamic balance during free-throw shooting*

249 The Orthosis x Fatigue-level (2×2) ANOVA with repeated measures revealed
 250 significant main effects of Orthosis ($P < 0.05$, Table 1), but no main effect of
 251 Fatigue-level or interaction between Orthosis and Fatigue-level ($P > 0.05$) in
 252 mean values of CoP data. The medial arch-support orthoses produced
 253 significantly smaller total resultant and AP sway excursions, resultant and AP
 254 CoP velocities, and base of support area than the flat control orthoses ($P < 0.05$,
 255 Table 1).

256

257 ***** Table 1 near here*****

258

259 ANOVA of CV CoP data (Table 2 and Fig. 3) revealed significant
 260 interactions on maximum sway range in ML CoP excursion ($P < 0.05$). The
 261 simple main effect revealed that participants wearing flat control orthoses
 262 displayed higher CV ML CoP excursion in post-fatigue (41%) compared to pre-
 263 fatigue shooting condition [31%, $P < 0.05$, 95% CI = -9.85 (-20.14 to 0.45)],
 264 while there was no significant difference when wearing medial arch-support
 265 orthoses [$P > 0.05$, 95% CI = 5.65 (-4.49 to 15.78)].

266

267 ***** Table 2 & Fig. 3 near here*****

268

269 *3.2 Basketball free-throw scores*

270 The Orthosis x Fatigue-level (2 x 2) ANOVA with repeated measures did
 271 not reveal any significant effect of Orthosis, Fatigue-level nor interaction
 272 between Orthosis and Fatigue-level for mean and CV of shooting performance
 273 ($P > 0.05$, Table 3).

274

275 ***** Table 3 near here*****

276

277 **4. Discussion**

278 This study examined whether foot orthoses would influence the dynamic
 279 balance and free-throw accuracy before and after physical fatigue. Our results
 280 indicated that physical fatigue significantly increased coefficient of variance

(CV) of ML CoP excursion in the condition of flat control orthoses. This is consistent with previous studies, which suggested that fatigue had detrimental effect on balance control in a rifle shooting position (Bermejo et al., 2017), marksmanship shooting score (Gil-Cosano et al., 2018), throwing speed and accuracy (Nuno et al., 2016). Once medial-arch support orthoses were used, physical fatigue no longer had any significant effects on all analysed dynamic balance parameters. This indicated the positive effect of orthoses on dynamic balance during basketball free-throw shooting.

There was further evidence supporting the benefits of medial-arch support orthoses on dynamic balance during basketball free-throw shooting. The orthoses induced smaller sway excursions, sway velocities, and base of support area. Smaller CoP motion and sway were indicative of better postural balance (Hrysomallis, 2011). In addition, the medial arch-support orthoses allowed participants to maintain stability using a narrow area of support, which was considered to be more difficult than a wider area of support (Zemkova 2014; Zemkova and Hamar, 2010). While previous studies have indicated the positive effects of foot orthoses on dynamic balance of people with old age (Ma et al., 2018) and neuro-musculoskeletal disorders (Lusardi and Nielsen, 2007), this study further demonstrated the beneficial effects in basketball playing.

Interestingly, while the orthoses support the medial midfoot influencing foot motions primarily in the frontal plane (Davidson, 2010; Lusardi and Nielsen, 2007), our findings showed medial arch-support orthoses was associated with dynamic balance in anterior-posterior direction, but not medial-lateral direction. This can be explained by the shooting movement which is executed primarily in

305 sagittal plane. In the future, more investigation should be carried out before a
306 viable conclusion can be made.

307 It is believed that physical fatigues are related to poor performances such
308 as reduced jump, agility, passing, throwing and shooting accuracy (Gil-Cosano et
309 al., 2018; Lyons et al., 2006; Padulo et al., 2015; Nuno et al., 2016). In the
310 present study, the free-throw accuracy was not different across fatigue levels,
311 which contrasted with the previous fatigue studies investigating on basketball
312 shooting (e.g., upper limb fatigue studies: Erculj and Supej, 2009; Padulo et al.,
313 2015). One possible reason could be related to the use of different shooting
314 distances among studies. One previous study (Erculj and Supej, 2009) had
315 participants performing three-point shot (7.2m) from a basket and showed
316 significant changes in shoulder and upper arm biomechanics with growing
317 fatigue. Our study had participants performing standard free-throw shot (4.0m)
318 from the basket and showed no differences in dynamic balance and shooting
319 performance between two fatigue levels. Physical fatigue may pose greater
320 challenge to longer-distance shooting rather than shorter distances. Studying the
321 effects of upper limb and lower limb fatigues on shooting performance in various
322 shooting distances would provide insightful knowledge in developing training
323 regimes.

324 Our findings which indicated that medial arch-support orthoses improved
325 dynamic balance but not shooting accuracy were in line with previous studies
326 done on the jump shot (Chen et al., 2016) and free-throw performance
327 (Zemkova, 2014). These findings also showed that more pronounced side-to-side
328 CoM movement (i.e., less postural stability) does not affect the accuracy of
329 basketball free-throw shots (Zemkova, 2014). Such findings were contrast with

330 shooting performances of other sports, which included rifle and archery, in which
331 dynamic balance was found to be significantly related to shooting accuracy
332 (Hrysomallis, 2011). Such discrepancies could be due to the movement
333 complexity between rifle archery shooting and basketball free-throw shooting.
334 While rifle and archery involves smaller number of joint coordination (e.g.,
335 fingers), basketball involves larger number of joint coordination (e.g., knee,
336 shoulder, elbow, wrist) which makes accuracy less influence by dynamic
337 balance. Principal components and minimal number of movement components
338 techniques would help to quantify the degree of self-organisation in basketball
339 shooting (Kelso, 1995; Lam et al., 2009b).

340 Although our studies did not measure the comfort perception variables,
341 comfort perception has been received considerable interest by coaches and sports
342 scientists. Foot orthoses would increase the perceived comfort and reduce the
343 pain/discomfort (Esfandiari et al., 2018; Lucas-Cuevas et al., 2014; Mills et al.,
344 2010). In rugby, the increase of comfort perception was related to higher actual
345 performance (Kinchington et al., 2012) and lower incidence of injuries
346 (Kinchington et al., 2011) in both competition and training. Additionally, higher
347 comfort perception was associated with improved running economy (Luo et al.,
348 2009) and impact attenuation (Mills et al., 2010) during running. The evidence
349 from these previous studies suggested that foot orthoses improved sport
350 performance via increased comfort perception on the wearers. Since comfort
351 perception is highly related to past experience, age, gender, and task difficulty
352 (e.g., Kong & Bagdon, 2010; Lam et al., 2011; Schubert et al., 2011),
353 methodology for valid assessments of footwear comfort require further
354 investigation (Lam et al., 2011, 2013, 2015). More research is also required to

355 determine the efficacy of the foot orthoses on shooting and other functional
356 movements in basketball.

357 When interpreting our results, it is important to consider some limitations in
358 this study. First, single male group was recruited in this study, which did not
359 allow generalization to other gender or playing positions. Different playing
360 positions in basketball players would have distinct physical attributes (Koklu et
361 al., 2011), which might affect the motor control strategies and performance
362 response to fatigues and foot orthoses. Second, this study did not measure any
363 psychological factors/attention demand during sports performance. Future studies
364 may investigate if they influence fatigue level, dynamic balance and sports
365 performance.

366

367 ***5. Conclusion***

368 Medial arch-support orthoses improved dynamic balance during shooting
369 as they significantly reduced CoP excursion, velocities of movement and base of
370 support area. Although this study found that fatigue and foot orthosis did not
371 significantly affect the scores gained by free-throw shooting, the significant
372 improvements in postural balance during shooting with the use of medial arch-
373 support orthoses could be insightful for motor control in basketball shooting.

374

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550 **Figure Captions**

551 Fig. 1. A) Standard basketball shoe, B) Regions for hardness measurement, and

552 C) Dimensions of medial arch-support and flat orthoses.

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554 Fig. 2. Overall experimental procedure.

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556 Fig. 3. Interaction of coefficient of variation (CV) of M-L CoP excursion by

557 orthosis and fatigue-level conditions. MAS denotes medial arch-support orthoses.

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