



Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

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

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ARTICLE INFO

Article history:

Accepted 8 September 2019

Keywords:

Insole

Orthotic

Postural stability

Sports

Shooting

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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1. Introduction

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

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

It is not uncommon for athletes to use foot orthoses to relieve pain (Hirschmuller et al., 2011) and improve sport performance (Banwell et al., 2014; Mills et al., 2010). More than 50% of basketball players were reported to use foot orthoses in competition and training (Losito, 2010), as they could improve balance, foot alignment, strain and load on soft tissues, as well as receptor sensory

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on the foot plantar (Davidson, 2010; Ho et al., 2019; Lusardi and Nielsen, 2007). Biomechanically, foot orthoses with medial arch-support increase the foot-insole contact area and pressure at the medial longitudinal arch of a foot, enhancing somatosensory inputs over the plantar foot. Previous studies showed that they allowed wearers to walk comfortably while enabling them to maintain postural stability using a narrow base of support, which was considered to be more challenging than a wider base of support (Hrysomallis, 2011; Zemkova 2014).

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

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

2. Methods

2.1. Participants

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

2.2. Orthosis and shoe conditions

To eliminate foot size and footwear as confounding factors, all of the participants were tested with the identical high-top basketball shoes (Wade 6, Li Ning, Beijing, China) with US size 9.0 were used with the two orthoses conditions (medial-arch support versus flat control) for this study. The tested orthoses were fabricated with an insole milling machines (CNC Milling machine, Vulcan series, Sensor Medica, Italy) and the height of medial-arch support and forefoot/rearfoot thickness were based upon previous studies (Alavi-Mehr et al., 2018; Zhai et al., 2017). The two orthoses were identical in terms of material, thickness and hardness, except for

the inclusion of medial-arch support (see Fig. 1). The same orthotist quantified the hardness of the orthoses across forefoot, midfoot and rearfoot regions using a Type C shore durometer (1600 Asker SP-698 Rex Durometers, Rex Gauge Co., IL, USA) (Lam et al., 2017; Nin et al., 2016). Five measurements taken at each of the five dots from each respective regions were averaged and both orthoses were confirmed to have the same hardness across different regions.

2.3. Equipment and laboratory setting

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

2.4. Fatigue-inducing protocol

To induce physical fatigue, all participants were asked to perform both Yo-Yo Intermittent 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 2×20 m shuttle runs with a short 10 s 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 a 10 s recovery period between every shuttle run interval. The starting speed was 10.0 km/h and increased to 12 km/h, 13 km/h, then increasing by 0.5 km/h thereafter. The participants continued the running until 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).

2.5. Procedures

The experimental procedure is shown in Fig. 2. After having the anthropometrical measurements, participants wore a new pair of

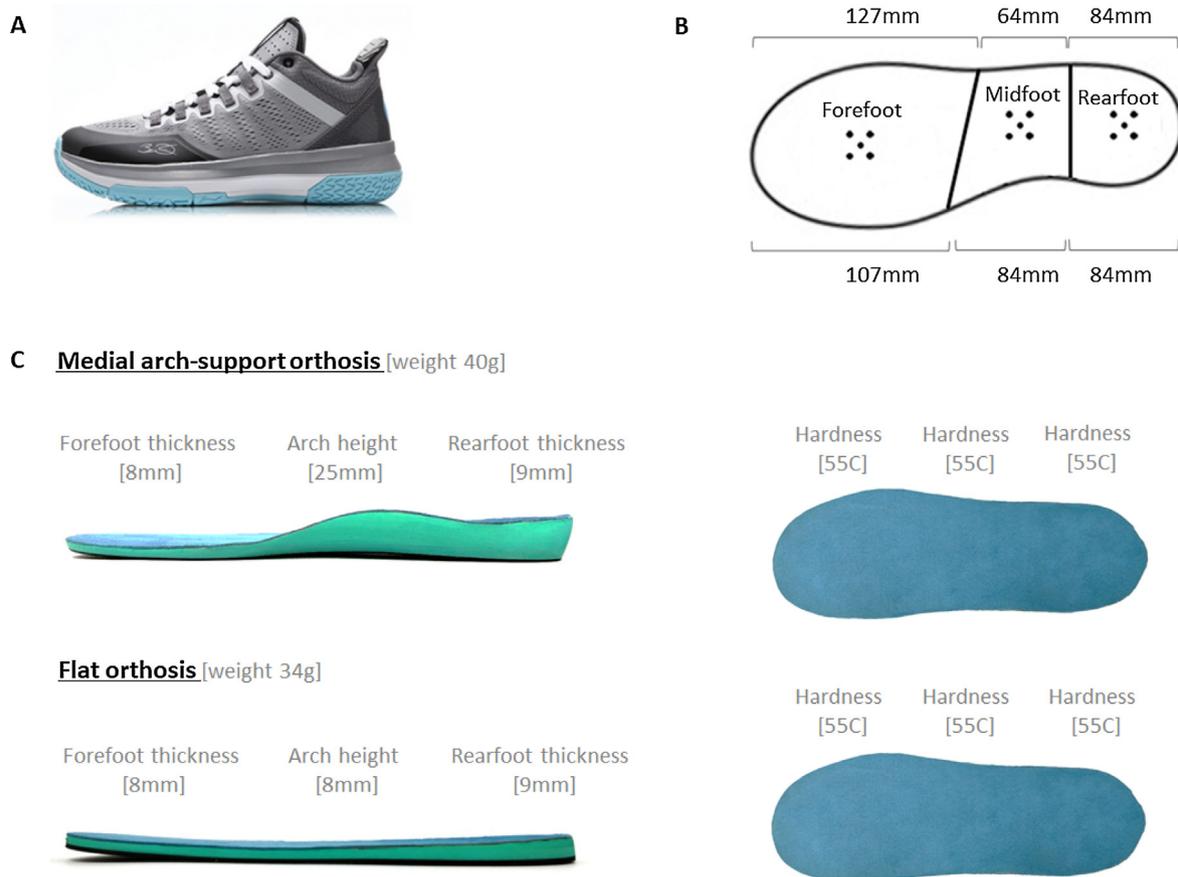


Fig. 1. (A) Standard basketball shoe, (B) Regions for hardness measurement, and (C) Dimensions of medial arch-support and flat orthoses.

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).

Each participant was required to perform 20 free-throw shooting trials using a standard ball (size 7), from the free-throw line (4.0 m from the front part of the basket) into a standard basketball rim (height = 3.05 m; circumference = 0.45 m) in each of the two orthosis conditions (medial-arch support and flat). The participants were then asked to perform the fatigue-inducing protocol, which included YYIR1 and consecutive maximum vertical jumps, separated by a 30-second standing rest on the shooting area. The participants then performed 20 free-throw shooting trials. The trial was discarded if the obvious slippage and discontinuity of movement was present. After the first orthosis condition, the maximal jump protocol was repeated. The second orthosis condition was then tested with another 20 free-throw shooting trials (Fig. 2). The orders of the use of the foot orthoses were randomised in all conditions across participants.

2.6. Data reduction

The analysed period of a free-throw was defined manually from the lowest point of elbow joint to the point of basketball release of the shooting arm. A spline interpolation was performed for minor missing data using three frames of data before and after the miss-

ing data. All signals were smoothed with a fourth order Butterworth bidirectional filter (DiDomenico et al., 2015). The cut-off frequencies of were determined using a residual analysis (Winter, 1990). The marker trajectories were identified using Vicon Clinical Manager Software (Oxford Metrics Ltd, Oxford) and then transferred into Visual3D software (C-Motion Inc.) for definition of area of base of support during free-throw shooting trial (DiDomenico et al., 2015).

The following posturography variables were selected to denote the dynamic balance during each shooting trial (Zemkova, 2014): maximum range of resultant, medial-lateral (ML) and anterior-posterior (AP) center of pressure (CoP) excursion (sway range; mm), total resultant, ML and AP CoP excursion (sway excursion; mm), mean resultant, ML and AP sway velocity along the CoP path (sway velocity; mm/s), and 95% ellipse sway area included within the COP path (sway area; mm²). Resultant CoP travelling distance was defined as the distance of the present CoP coordinate relative to the coordinate of the previous frame. The sway range was defined as the largest coordinates subtracted the smallest coordinates in each shooting cycle. Total excursion was defined as sum of the resultant CoP path covered the whole shooting period. The 95% ellipse sway area was defined as an estimated ellipse to the CoP data that encompassed 95% of the data. The mean sway velocity was defined as rate of change of CoP path of a body between frames. Maximum range of resultant, ML and AP CoP excursions, ML and AP sway velocities and 95% ellipse sway area are commonly used to assess postural balance of human (Distefano et al., 2009). The literature reported very little about the postural balance of basketball players. However, these parameters have been studied in other sports which included soccer (Paillard and NOE, 2006), dancers (Gerbino et al., 2007), swimmers and gymnasts (Hrysomallis, 2011). Small CoP excursion,

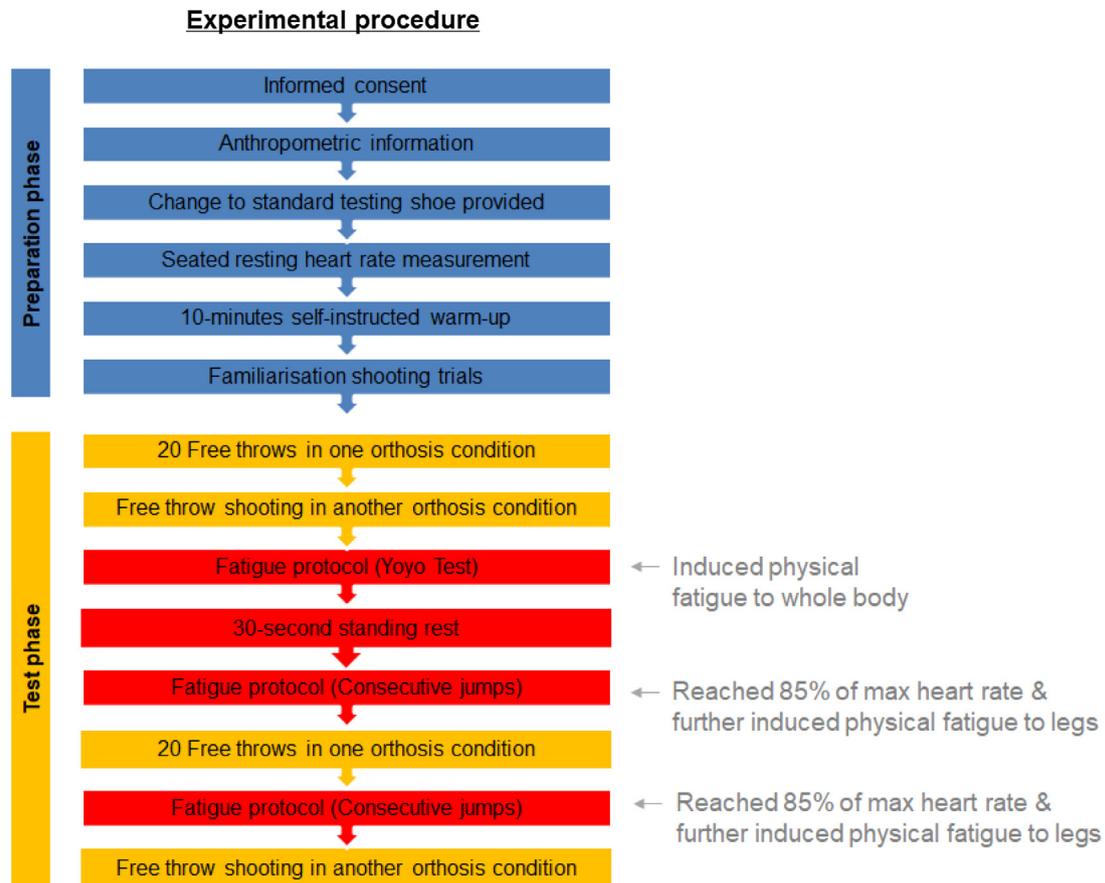


Fig. 2. Overall experimental procedure.

variability of AP and ML excursion and velocity, and sway ellipse area were indicative of good balance.

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

2.7. Data analysis

To assess the main effects and interaction of fatigue and orthosis conditions (independent variables) on dynamic balance and shooting performance (dependent variables), a 2×2 two-way (Orthosis \times Fatigue-level) ANOVA with repeated measures was performed on both mean and coefficient of variation (CV) in each of the dependent variables. The CV was defined as the standard deviation divided by mean, which allowed comparing the degree of variability across variables (Reed et al., 2002). The CVs across 20 free-throw shooting trials were calculated for respective fatigue and orthosis conditions for each of the participants for subsequent analyses. Bonferroni corrected post-hoc tests, involving four paired *t*-tests, were performed accordingly, if the two-way ANOVA indicated a significant interaction among the independent variables. The pair-wise *t*-tests were conducted for each orthosis type between pre and post fatigue states, as well as, at each fatigue state between the flat and MAS orthoses. Bonferroni correction was

applied to reduce the familywise error-rate. Level of significance was set at 0.05. All statistical analyses were performed using the SPSS statistical analysis computer program package, version 21.0 (SPSS, Inc., Chicago, IL, U.S.A.).

3. Results

3.1. Dynamic balance during free-throw shooting

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

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

3.2. Basketball free-throw scores

The Orthosis \times Fatigue-level (2×2) ANOVA with repeated measures did not reveal any significant effect of Orthosis,

Table 1

ANOVA results for mean dynamic balance performances by orthosis and fatigue-level conditions. MAS denotes medial arch-support orthosis. Significance ($P < .05$) is shown in Bold.

	Fatigue-level	Orthosis		Interaction			Fatigue-level			Orthosis		
		Flat	MAS	P	η^2	β	P	η^2	β	P	η^2	β
<i>Maximum sway range (mm) – the largest coordinates subtracted the smallest coordinates</i>												
Resultant CoP excursion	Pre	65.2(19.1)	64.9(17.9)	0.523	0.04	0.43	0.611	0.02	0.08	0.458	0.05	0.59
	Post	69.0(25.8)	66.7(25.0)									
ML CoP excursion	Pre	129.2(78.1)	132.5(71.4)	0.184	0.14	0.26	0.140	0.17	0.31	0.149	0.17	0.30
	Post	147.2(72.6)	132.2(78.8)									
AP CoP excursion	Pre	197.2(73.7)	179.5(65.1)	0.515	0.04	0.10	0.902	0.00	0.05	0.176	0.15	0.26
	Post	188.0(67.9)	183.9(62.0)									
<i>Total sway excursion (mm) – the sum of the distance of present CoP to the coordinate of the previous frame</i>												
Resultant CoP excursion	Pre	1335.6 (351.5)	1208.3 (242.4)	0.736	0.01	0.06	0.504	0.04	0.10	<0.05	0.29	0.54
	Post	1278.9 (270.9)	1180.3 (224.3)									
ML CoP excursion	Pre	733.8(203.1)	665.1(165.8)	0.678	0.02	0.07	0.630	0.02	0.07	0.055	0.27	0.50
	Post	704.9(126.0)	656.2(125.9)									
AP CoP excursion	Pre	978.0(268.6)	885.8(182.7)	0.827	0.00	0.06	0.628	0.02	0.07	<0.05	0.29	0.53
	Post	949.4(219.8)	871.5(163.8)									
<i>Mean sway velocity (mm/s) – rate of change of CoP path of a body between frames</i>												
Resultant CoP velocity	Pre	669.5(176.2)	605.7(121.5)	0.736	0.01	0.06	0.504	0.04	0.10	<0.05	0.29	0.54
	Post	641.0(135.8)	591.6(112.4)									
ML CoP velocity	Pre	367.8(101.8)	333.4(83.1)	0.678	0.02	0.07	0.630	0.02	0.07	0.055	0.27	0.50
	Post	353.3(63.1)	328.9(63.1)									
AP CoP velocity	Pre	490.3(134.6)	444.0(91.6)	0.827	0.00	0.06	0.628	0.02	0.07	<0.05	0.29	0.53
	Post	475.9(110.2)	436.8(82.1)									
95% ellipse sway area (mm ²) – an estimated ellipse to the 95% of data	Pre	42625.5 (25720.6)	44565.3 (25376.3)	0.218	0.12	0.22	0.412	0.06	0.12	0.743	0.01	0.06
	Post	49956.0 (34794.4)	46526.3 (33631.7)									
Base of support area (mm ²) – contact area of the supporting surface	Pre	708.3(85.4)	681.7(92.4)	0.974	0.00	0.05	0.490	0.04	0.10	<0.05	0.30	0.56
	Post	723.0(116.9)	695.8(101.0)									

Note: CoP = Center of pressure, ML = medial-lateral, AP = anterior-posterior.

Fatigue-level nor interaction between Orthosis and Fatigue-level for mean and CV of shooting performance ($P > 0.05$, Table 3).

4. Discussion

This study examined whether foot orthoses would influence the dynamic balance and free-throw accuracy before and after physical fatigue. Our results 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 (Hrysmallis, 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., 2008) and neuro-musculoskeletal disorders (Lusardi and Nielsen, 2007), this study further demonstrated the beneficial effects in

basketball playing. Interestingly, while the orthoses supported 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 sagittal plane. In the future, more investigation should be carried out before a viable conclusion can be made.

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

Our findings which indicated that medial arch-support orthoses improved dynamic balance but not shooting accuracy were in line

Table 2
ANOVA results for coefficient of variation (CV) of dynamic balance performances by orthosis and fatigue-level conditions. MAS denotes medial arch-support orthosis. Significance ($P < .05$) is shown in Bold.

	Fatigue-level	Orthosis		Interaction			Fatigue-level			Orthosis		
		Flat	MAS	P	η^2	β	P	η^2	β	P	η^2	β
<i>Maximum sway range (mm) – the largest coordinates subtracted the smallest coordinates</i>												
Resultant CoP excursion	Pre	16.4 (3.0)	20.8 (9.7)	0.112	0.20	0.35	0.590	0.03	0.08	0.948	0.00	0.05
	Post	23.5 (22.1)	18.7 (6.7)									
ML CoP excursion	Pre	31.1 (12.3)	38.2 (20.4)	<0.05	0.32	0.60	0.549	0.03	0.09	0.887	0.00	0.05
	Post	41.0 (23.0)	32.6 (11.4)									
AP CoP excursion	Pre	20.3 (10.7)	26.7 (17.9)	0.073	0.24	0.44	0.572	0.03	0.08	0.863	0.00	0.05
	Post	29.4 (25.8)	24.1 (14.4)									
<i>Total sway excursion (mm/s) – rate of change of CoP path of a body between frames</i>												
Resultant CoP velocity	Pre	14.3 (7.6)	15.8 (8.9)	0.325	0.08	0.16	0.775	0.01	0.06	0.867	0.00	0.05
	Post	16.0 (6.9)	15.0 (6.0)									
ML COP velocity	Pre	14.6 (6.2)	16.1 (7.6)	0.139	0.17	0.31	0.226	0.12	0.22	0.913	0.00	0.05
	Post	18.4 (6.4)	16.6 (7.6)									
AP COP velocity	Pre	15.1 (8.2)	16.5 (9.7)	0.659	0.02	0.07	0.501	0.04	0.10	0.528	0.03	0.09
	Post	16.8 (8.5)	16.9 (7.4)									
95% ellipse sway area (mm ²) – an estimated ellipse to the 95% of data	Pre	32.5 (6.9)	45.0 (23.7)	0.055	0.27	0.50	0.610	0.02	0.08	0.639	0.02	0.07
	Post	47.1 (36.9)	39.1 (14.3)									

Note: CoP = Center of pressure, ML = medial-lateral, AP = anterior-posterior.

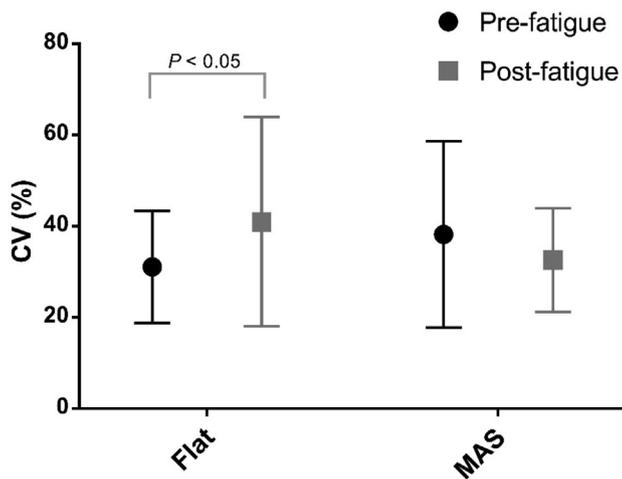


Fig. 3. Interaction of coefficient of variation (CV) of M-L CoP excursion by orthosis and fatigue-level conditions. MAS denotes medial arch-support orthoses.

with previous studies done on the jump shot (Chen et al., 2016) and free-throw performance (Zemkova, 2014). These findings also showed that more pronounced side-to-side CoM movement (i.e., less postural stability) does not affect the accuracy of basketball free-throw shots (Zemkova, 2014). Such findings were contrast with shooting performances of other sports, which included rifle and archery, in which dynamic balance was found to be significantly related to shooting accuracy (Hrysomallis, 2011). Such discrepancies could be due to different movement strategies between rifle archery shooting and basketball free-throw shooting. While rifle and archery involves smaller number of joint coordination (e.g., fingers), basketball involves larger number of joint coordination (e.g., knee, shoulder, elbow, wrist) which makes accuracy less influence by dynamic balance. Principal components and minimal number of movement components techniques would help to quantify the degree of self-organisation in basketball shooting (Kelso, 1995; Lam et al., 2009b).

Although our studies did not measure the comfort perception variables, comfort perception has been received considerable interest by coaches and sports scientists. Foot orthoses would increase the perceived comfort and reduce the pain/discomfort (Esfandiari

Table 3
ANOVA results for mean and coefficient of variation (CV) of free throw shooting scores by orthosis and fatigue-level conditions. MAS denotes medial arch-support orthosis.

	Fatigue-level	Orthosis		Interaction			Fatigue-level			Orthosis		
		Flat	MAS	P	η^2	β	P	η^2	β	P	η^2	β
Mean shooting score	Pre	2.8(0.4)	2.9(0.4)	0.310	0.09	0.16	0.495	0.04	0.10	0.800	0.01	0.06
	Post	2.9(0.5)	2.8(0.3)									
CV shooting score (%)	Pre	46.7(10.2)	45.6(7.2)	0.747	0.01	0.06	0.437	0.05	0.12	0.291	0.09	0.18
	Post	48.6(6.4)	46.4(7.5)									

et al., 2018; Lucas-Cuevas et al., 2014; Mills et al., 2010). In rugby, the increase of comfort perception was related to higher actual performance (Kinchington et al., 2012) and lower incidence of injuries (Kinchington et al., 2011) in both competition and training. Additionally, higher comfort perception was associated with improved running economy (Luo et al., 2009) and impact attenuation (Mills et al., 2010) during running. The evidence from these previous studies suggested that foot orthoses improved sport performance via increased comfort perception on the wearers. Since comfort perception is highly related to past experience, age, gender, and task difficulty (e.g., Kong & Bagdon, 2010; Lam et al., 2011; Schubert et al., 2011), methodology for valid assessments of footwear comfort require further investigation (Lam et al., 2011, 2013, 2015). More research is also required to determine the efficacy of the foot orthoses on shooting and other functional movements in basketball.

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

5. Conclusion

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

6. Financial disclosure

Beijing Municipal Science and Technology Commission (Project number: Z1811100920000) and Beijing Technology and Innovation Service Development Research Fund (Project number: KM201710029004).

Declaration of Competing Interest

The authors declared that there is no conflict of interest.

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