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Author(s)	Hin Fong Leong, Wing-Kai Lam, Wei Xuan Ng and Pui Wah Kong
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Center of pressure and perceived stability in basketball shoes with soft and hard midsoles

Hin Fong Leong[1], Wing Kai Lam[2,3], Wei Xuan Ng[1] and Pui Wah Kong[1*]

[1]Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, Singapore

[2]Li Ning Sports Science Research Center, Beijing, China

[3]Department of Kinesiology, Shenyang Sport University, Shenyang, China

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***Corresponding author:**

Pui W. Kong, Ph.D.

Address: Physical Education and Sports Science Academic Group, National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore, 637616.

Phone: (+65) 6219 6213

Fax: (+65) 6896 9260

E-mail: puiwah.kong@nie.edu.sg

Running head: COP and stability perception

Abstract

This study aimed to investigate the effects of varying midsole hardness on center of pressure (COP) and perceived stability during basketball-specific tasks, as well as the correlation between COP and perception measurements. Twenty male basketball players performed 45° cutting and lay-up while wearing basketball shoes with soft and hard midsoles. COP trajectories were obtained from the Pedar insole system. Stability perceptions at the forefoot and rearfoot were assessed using 150-mm visual analogue scales (VAS). Results indicated greater COP mediolateral deviations in soft midsole compared with hard midsole during lay-up (soft 16.6 ± 4.7 mm, hard 15.8 ± 4.6 mm, $p = .025$) but not 45° cutting (soft 15.7 ± 5.9 mm, hard 15.8 ± 5.6 mm, $p = .601$). While 16 out of 20 participants preferred soft midsole, no significant difference in VAS ratings was found between shoes for both tested movements. There was no significant correlation between COP and perceived stability during lay-up or 45° cutting. In conclusion, midsole hardness of basketball shoes did not consistently affect mediolateral stability of the foot during 45° cutting and lay-up. Subjective perception alone cannot be used to indicate mediolateral deviation of the foot when executing basketball-specific maneuvers.

Keywords: Cutting, lay-up, midsole hardness, plantar pressure, visual analogue scale

Word Count: 195 (abstract); 3138 (text)

Introduction

Injuries to the ankle are prevalent and debilitating in the game of basketball, with ankle ligament sprains alone accounting for about a quarter of collegiate basketball injuries in both male and female players.[1,2] Previous studies have identified footwear type as a modifiable risk factor for ankle injury in basketball.[3] McKay and colleagues[3] postulated that instability, particularly in the rearfoot, may increase the risks of ankle injury in basketball players. Based on a study involving large scale survey feedback on basketball shoe functionality, stability seems to be an important protective function of basketball shoes and was rated as the key feature of basketball footwear.[4] Both the collar and sole of a shoe are crucial aspects of athletic footwear that might influence stability during basketball maneuvers. High-cut basketball shoes were reported to improve ankle stability[5,6] and shoe sole properties were shown to affect lateral stability during cutting performance.[6]

Among the properties of shoe sole, midsole hardness has been found to be positively related to stability, in which hard soles enhanced stability by optimizing proprioceptive inputs.[7] A softer midsole, on the other hand, is likely to diminish foot positional awareness and impair stability.[8] While there is no dearth of literature on the influence of shoe midsole hardness on stability, most studies were done on running which predominantly involves forward motion in a straight line.[9-13] It is important to note that lateral cutting and jump landing movements occur frequently during basketball games in addition to forward movements. Furthermore, basketball shoes are distinct from walking or running footwear since each type of footwear should be customized for performance of a specific activity, which imposes specific functional demands on shoe properties. Given that the effect of varying midsole hardness on stability in the basketball context is not well-established, further investigation using basketball movements with greater lateral deviations and challenge is necessary to provide insights into the development of stability-optimized basketball shoes.

Biomechanically, stability can be measured objectively with center of pressure (COP) changes during locomotion. The COP, quantified using a force/pressure plate system or plantar pressure insole system, is the point where resultant plantar pressure acts on the foot.[14] During the stance phase of gait, COP shifts primarily in the posterior-to-anterior direction. Displacements of COP in the mediolateral direction when walking are indicative of perturbations of foot stability.[15] During running, COP deviations have been associated with increased risk of inversion ankle injuries.[16] Additionally, the pattern of COP excursion observed in an injury case study has elucidated the mechanism of ankle sprain during side-cutting movements.[17] Another study on lateral shuffling showed that athletes with ankle instability were characterized by more laterally located COP from early to mid-stance when compared to normal controls, suggesting that the ability to control COP displacement should be of great concern when performing movements with challenge in the frontal plane.[18] Since the magnitude of mediolateral COP variables increased with the challenge of the task,[19] one can expect that evaluating COP during dynamic basketball movements can yield meaningful information regarding foot stability. While COP assessments have been used to facilitate the selection of appropriate footwear for athletes, sophisticated laboratory equipment and complex data processing procedures are often involved. This makes COP assessment an impractical option for the vast majority of basketball players outside the laboratory environment. Athletes and coaches are inclined to select footwear based on subjective evaluations instead. Thus, investigating how COP measurements corroborate with subjective stability perceptions seems warranted.

The primary purpose of this study was to examine the influence of midsole hardness on COP and perceived stability during basketball-specific maneuvers. A secondary purpose was to investigate the relationship between COP and perception measurements. It was hypothesized that (i) smaller COP deviation would be found in basketball shoes with harder midsoles, (ii) superior stability perception would be found in shoes with harder midsoles, and (iii) COP deviation and stability perception score would be negatively correlated.

Methods

Participants: Twenty male recreational basketball players (mean age 24.8 ± 1.5 years; height 1.73 ± 0.06 m; body mass 66.7 ± 10.1 kg; playing experience 8.7 ± 2.1 years) took part in the study. All participants were right-leg dominant and free of lower extremity injuries for six months prior to the study. Participants had a foot size of US 9.0 ± 0.5, determined using a Brannock foot measuring device (The Brannock Device, Syracuse, NY, USA). Experimental procedures were approved by the Nanyang Technological University Institutional Review Board. Signed informed consent from each participant was obtained before the start of data collection.

Test shoe conditions: Single shoe size design was adopted to eliminate foot size as a confounding factor and align with previous studies on basketball footwear.[5,20,21] Two identical pairs of US 9.0 high-top basketball shoes (Li Ning Cloud, Beijing, China) with soft and hard midsole hardness were used in this study (Table 1). The soft midsole and hard midsole conditions were 50 versus 60 Shore C stiffness. To confirm the hardness specifications, midsole hardness was measured with a durometer (Rex Durometers, Rex Gauge Co., Buffalo Grove, IL, USA) following the same procedures described in a recent study on basketball shoes.[20] Mechanical characteristics were quantified by an impact tester (Exeter Research Version 2.6, Brentwood, NH, USA). Thirty consecutive mechanical impact trials were performed at the center of the heel region with an 8.5-kg mass released from a 50-mm height. The cushioning properties were averaged from the last five trials.[20]

(Insert Table 1 here)

Movement protocols: Two basketball-specific maneuvers that involve considerable lateral components were chosen for this study: 45° cutting and lay-up (Figure 1).[21] These movements are relevant and important as cutting is a highly repetitive evasive maneuver[22] while lay-up is an effective scoring technique in basketball games.[23] For 45° cutting, participants were instructed to perform the cutting step with right foot planted towards a 45° left orientation, at maximal effort. For lay-up, participants took off from the right foot and approached the basket with a standard basketball from the right side in a curved manner; dribbling was not allowed. The right cutting step and the first step of lay-up were selected for analysis.

(Insert Figure 1 about here)

Procedures: Two test sessions were conducted on the same day to separately evaluate the perceptual and biomechanical aspects of the shoes. Both sessions involved identical movement protocols (45° cutting followed by lay-up) and were carried out on a standard asphalt-based outdoor basketball court. To prevent possible interference of the instrumented pressure insoles with participants' perceptions of shoes properties, perceptual data acquisition (without pressure insoles) was conducted before biomechanical data acquisition (with pressure insoles) with a 10-min rest period between sessions. The order of shoe conditions was randomized among participants while the same order was kept within an individual for the perceptual and biomechanical test protocols. To ensure a consistent foot-shoe interface, each participant was given a new pair of standard socks to wear throughout the experiment.

During the perceptual test session, the variables (forefoot and rearfoot stability) were defined in a set of written explanations and provided to all participants at the start. Perception assessment procedures were initiated after a 10-min bout of warm-up and lower limb stretching exercise. Perceived stability was assessed using a 150-mm visual analogue scale (VAS), which had the left end (0 mm) labeled as 'very unstable' and the right end (150 mm) as 'very stable'. The VAS is a tool with high sensitivity and low bias tendency, and hence often used to evaluate perceptions of footwear.[24,25] Participants were tasked to execute five trials of 45° cutting and lay-up while wearing each of the test shoes. Throughout the study, measures were taken to blind participants to the nature of the shoe conditions. For each maneuver performed, participants rated their forefoot stability after the third trial and their rearfoot stability after the fifth trial. By asking participants to consider only one perceptual variable would allow for better and more reliable footwear perception.[26] To minimize the influence of fatigue, 90-sec and 8-min rest periods were administered between trials and between shoe conditions, respectively. After undergoing all maneuvers in both shoes, participants ranked the shoes according to individual preference.

For the biomechanical test session, an in-shoe plantar pressure measuring system (Pedar Mobile System, GmbH, Munich, Germany) was used to record COP trajectories at a sampling rate of 100 Hz when participants executed the basketball movements. The pressure insole has been documented as a reliable method of evaluating plantar pressures within a shoe.[27,28] Each pressure insole was embedded with a matrix of 99 sensors and calibrated to 700 kPa using the Trublu calibration device (Novel GmbH, Munich, Germany) according to manufacturer's instructions. Pressure insoles were fitted into the experimental shoes and a data logger was attached to the participant's trunk for telemetric transmission of data to the computer. Participants performed the 45° cutting and lay-up maneuvers, protocols identical to those in the perception test session, while wearing the insole-incorporated shoes. A total of five successful trials were collected for each maneuver, in each shoe condition. Allocation of rest times was consistent with the perception test to minimize fatigue.

Data processing: While the Pedar Mobile System is portable and allows for data collection outside the laboratory to simulate realistic playing conditions, it has technical limitation in that COP data can only be sampled at up to 100 Hz. Given that the stance phases of 45° cutting (mean (SD), 317 (84) ms) and lay-up (383 (136) ms) maneuvers are very short, we have too few data points to pursue meaningful sub-phase analysis of the rearfoot and forefoot separately. To provide a proxy measure for the extent of medial and lateral foot movements throughout the entire stance phase, we derived the total COP mediolateral deviation using the following procedures (Figure 2). First, the origin was defined as the most posterior point of the COP trajectory. Next, mediolateral deviation was determined with respect to the *x*-axis, perpendicular to the longitudinal foot axis.[29] The *x*-coordinates (mediolateral locations of COP) throughout stance phase of the selected steps (right cutting step and first step of lay-up) were extracted. The total COP mediolateral deviation was then calculated by summing the absolute differences between *x*-coordinates and the COP path, i.e. $|X_1| + |X_2| + \ldots + |X_i|$. During the initial and final phases of ground contact, COP data typically contain errors because the vertical ground reaction force/pressure values are low.[30,31] We have, therefore, omitted the initial and final 5 to 10% (2 to 3 points) of the COP data series for better accuracy.[32]

(Insert Figure 2 about here)

Statistical analyses: Statistical analyses were performed using SPSS (Version 23.0, Chicago, IL). Normality was first ascertained by visual inspection of frequency distributions and Probability-Probability (P-P) plots, and subsequently by implementing the Kolmogorov-Smirnov test. The COP mediolateral deviations for 45° cutting [soft $D(20) = .207$, $p = .025$; hard $D(20) = .226$, $p = .009$] and lay-up [soft $D(20) = .213$, $p = .018$; hard $D(20) = .200$, $p = .035$] were both significantly non-normal. Wilcoxon Signed-Rank Test was used to compare means between shoe conditions for each of the tested movements; the dependent variables were COP mediolateral deviation, forefoot perceived stability, and rearfoot perceived stability. Spearman's rho was employed to examine correlations between COP and perception measurements. Statistical significance was accepted at alpha level <.05. Effect size (r) was computed from the Z-score and interpreted as small ($|r| < .3$), medium ($.3 \leq |r| < .5$), or large ($|r| \geq .5$). Data are reported as means with standard deviations.

Results

During lay-up, COP mediolateral deviation was significantly greater in soft midsole compared with hard midsole shoe condition, though the effect size was very small (Table 2). There was no significant difference in perceived stability between soft and hard midsoles for both 45° cutting and lay-up maneuvers, across the different plantar regions examined (Table 2). Regardless of significance, the effect sizes for all comparisons were small. On the contrary, when participants indicated their preferences, the majority (80%) selected shoes with soft midsole over hard midsole. The objective COP and subjective VAS variables were not significantly correlated during 45° cutting (Figure 3) or lay-up (Figure 4).

(Insert Table 2 and Figures 3 and 4 here)

Discussion

This study investigated the effect of midsole hardness on COP mediolateral trajectory and perceived stability, as well as the relationship between objective and subjective measures of stability in basketball shoes. The primary findings were that (i) COP mediolateral deviation was greater in soft midsole than hard midsole during lay-up, (ii) participants perceived similar stability for soft and hard midsoles, and (iii) objective COP deviation and subjective stability perception were not correlated.

Our first hypothesis that COP mediolateral deviation would be smaller in shoes with harder midsoles was only partially supported since the results of 45° cutting and lay-up were inconsistent. Total COP mediolateral deviation did not differ between the shoe conditions during 45° cutting. While significantly smaller COP deviation was found when performing lay-up in shoes with harder midsoles as hypothesized, the magnitude (0.8 mm) and effect size ($r = .079$) of the differences were rather small. One possible reason for the lack of COP differences between shoes with soft and hard midsoles during 45° cutting is that additional stabilization factors in the basketball shoes might have confounded the effect on COP induced by midsole hardness alteration alone. For example, high shoe collar and sole torsional rigidity have been found to augment lateral stability during cutting movements.[6] In a comparison of forward-stepping and upward-stepping tasks, Sims and Brauer[19] demonstrated that the more challenging step up task was characterized by greater extent and velocity of mediolateral COP excursion. It is possible that the lay-up, which requires a rapid forward and upward movement followed by shooting, presented a greater challenge than the 45° cutting and hence induced larger change in the magnitude of COP mediolateral deviation. Nevertheless, we acknowledge that our test protocol was completed in a systematic order (45° cutting followed by lay-up) such that learning and familiarization effects may partly account for the difference in COP mediolateral deviation noted only in lay-up (i.e. the second task).

Contrary to our second hypothesis, perceived stability was not significantly different between soft and hard midsoles during both tested movements. This implies that participants were unable to discriminate the stability features between the soft and hard midsoles. Although it may be attributed to the narrow variation in hardness (10 Shore C), the experimental shoe conditions are representative of the range of commercially available basketball shoes. Previous research on running footwear has established that consumer's ability to distinguish differences in footwear properties is positively related to the magnitude of the difference.[33] In a recent study, Nin and colleagues[20] observed a significant difference in stability perceptions during lay-up when the basketball shoes tested differed by approximately 20 Shore C in midsole hardness. In the present study, the difference in peak pressure between soft and hard midsoles was less than 30 kPa across the medial, central, and lateral foot regions.[21] It is likely that a certain threshold in midsole hardness variation may exist for participants to perceive changes in shoe stability. This speculation can be verified through touch pressure skin sensitivity and threshold analysis in future work.[34] Despite the absence of perceptual differences in the present study, most participants demonstrated a clear preference for basketball shoes with soft midsole. This finding is consistent with previous studies on running shoes[13,24] and basketball shoes,[20] which concluded that footwear with softer midsoles were generally favored by participants. Thus, it is suggested that players' preferences for shoes are unlikely to be determined by stability perceptions alone but rather, a combination of other perceptual qualities such as fit, cushioning, and arch support.[35]

Lastly, no significant correlation exists between objective and subjective evaluations of stability during either maneuver, as opposed to our third hypothesis. This outcome is not surprising since stability perceptions for soft and hard midsole conditions did not differ significantly. Our findings suggest that subjective perception alone cannot be used to indicate mediolateral deviation of the foot, as quantified by COP measurements, when executing basketball-specific maneuvers. Therefore, players should not rely solely on subjective perception when evaluating the stability properties of basketball footwear. One recent study using in-shoe pressure measuring instrument (Tekscan F-Scan) and VAS to examine objective plantar pressure and subjective comfort, respectively, was carried out on football boots.[36] The authors reported a weak and negative correlation between peak plantar pressure and comfort ratings, possibly related to the much wider range of shoes tested as compared to the present study. Collective evidence from the literature and the present study suggest that VAS outcomes may be influenced by factors involved in the complex interaction between the foot and the shoe, rather than a specific factor such as insole or midsole hardness. Subjective perception, nonetheless, remains an essential assessment tool for comprehensive evaluation of footwear alongside mechanical and biomechanical tests.

One limitation to the present study is that only male basketball players with foot size of US 9.0 were recruited. The findings may not be generalizable to female basketball players or males with smaller or larger shoe sizes as biomechanical and subjective measurements may be mediated by intrinsic gender differences and anatomical variations. The influence of gender is evident in a running study which reported that shoe midsole hardness alteration affected female participants to a greater extent compared to their male counterparts.[37]A second limitation is that the 45° cutting protocol, carried out in the absence of a defender and dribbling action, may not reflect the game situation well. McLean and colleagues[22] highlighted that as cutting is evasive in nature, the presence of a defensive opponent may be crucial in determining the manner the maneuver is executed; a simulated defensive character indeed elicited increased lower limb movements and forces. Similarly, a study on soccer players concluded that cutting in response to virtual defensive players triggered distinct lower limb postures and knee moments.[38] In basketball games, the cutting maneuver is also often accompanied by ball dribbling. Cutting with dribbling apparently resulted in increased sagittal, frontal, and transverse movements and forces on knee, compared to without dribbling.[39] This additional upper limb activity during cutting may influence muscle coordination and stability of lower extremity. As such, future investigations should aim to replicate a more realistic game condition by introducing a simulated defender and dribbling actions in the cutting protocol. Future studies should also include a wider range of midsole hardness to better understand the influence of midsole hardness on stability in basketball footwear.

In conclusion, midsole hardness of basketball shoes did not consistently influence mediolateral stability of the foot, quantified by COP measurements, when performing 45° cutting and lay-up maneuvers. Subjectively, participants indicated similar perceived stability for shoes with softer and harder midsoles. There was no relationship between objective and subjective measurements of stability during both tested tasks, suggesting that subjective perception cannot be used as an indicator of mediolateral deviation of the foot when executing basketball-specific maneuvers.

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Table 1. Physical and mechanical characteristics of experimental basketball shoes

	Soft midsole shoes	**Hard midsole shoes**
Mass (g)	450	455
Midsole length (mm)	275	275
Forefoot midsole thickness (mm)	17	17
Rearfoot midsole thickness (mm)	25	25
Forefoot midsole hardness (Shore C)	50.2	60.1
Rearfoot midsole hardness (Shore C)	50.1	59.9
Forefoot impact score (g)	19.8	18.6
Rearfoot impact score (g)	11.1	12.4
Forefoot energy return (%)	49.8	48.2
Rearfoot energy return (%)	45.7	48.2

Note. Discrepancy in mass was attributed to different midsole material density.

Table 2. Comparison of center of pressure (COP) mediolateral deviations and stability perceptions between shoes of different midsole hardness, during the 45° cutting and lay-up movements

	Shoe midsole hardness				
	Soft	**Hard**	***p***	**Z**	***r***
45° cutting					
COP deviation (mm)	15.7 (5.9)	15.8 (5.6)	.601	0.52	.151
Perceived stability (mm)					
Forefoot	94.7 (30.8)	98.3 (28.1)	.466	0.73	.116
Rearfoot	98.6 (21.2)	92.6 (19.3)	.360	0.92	.150
Lay-up					
COP deviation (mm)	16.6 (4.7)	15.8 (4.6)	.025*	2.24	.079
Perceived stability (mm)					
Forefoot	96.8 (26.7)	99.0 (24.6)	.268	1.11	.182
Rearfoot	103.7 (15.1)	98.0 (21.8)	.455	0.74	.119

* *Significant difference ($p < .05$)*

Note. Perceived stability was assessed using a 150-mm Visual Analogue Scale; 0-mm represents ‘very unstable’, 150-mm represents ‘very stable’. Effect size (r) was computed from the Z-score and interpreted as small ($|r| < .3$), medium ($.3 \leq |r| < .5$), or large ($|r| \geq .5$).

List of Figures

Figure 1 – Illustration of two basketball-specific maneuvers: (a) Maximal 45° cutting and (b) Lay-up. Start (i) denotes the beginning of the movement. Highlighted step (ii) represents the analyzed step. End (iii) denotes the completion of the movement.

Figure 2 – An example illustrating the calculation of total mediolateral center of pressure (COP) deviation. Note: Solid line through foot indicates the COP path.

Figure 3 – Correlations between center of pressure (COP) mediolateral deviations and stability perceptions in (a) forefoot and (b) rearfoot, during the 45° cutting maneuver. Note: Soft = soft midsole basketball shoes; Hard = hard midsole basketball shoes.

Figure 4 – Correlations between center of pressure (COP) mediolateral deviations and stability perceptions in (a) forefoot and (b) rearfoot, during the lay-up maneuver. Note: Soft = soft midsole basketball shoes; Hard = hard midsole basketball shoes.

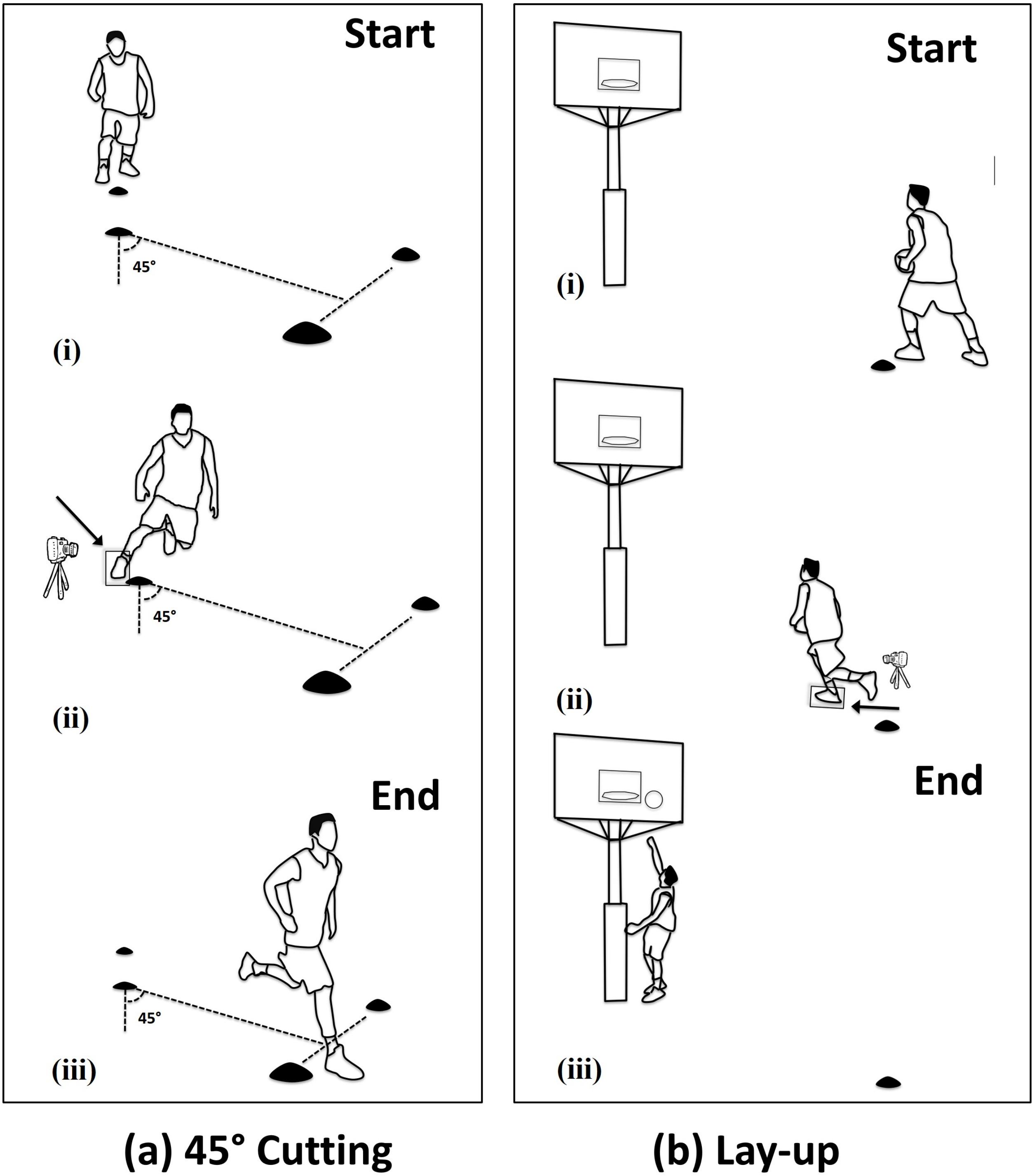

Start
45°
(i)
45°
(ii)
End
45°
(iii)
(a) 45° Cutting
Start
(i)
(ii)
End
(iii)
(b) Lay-up

Figure 1

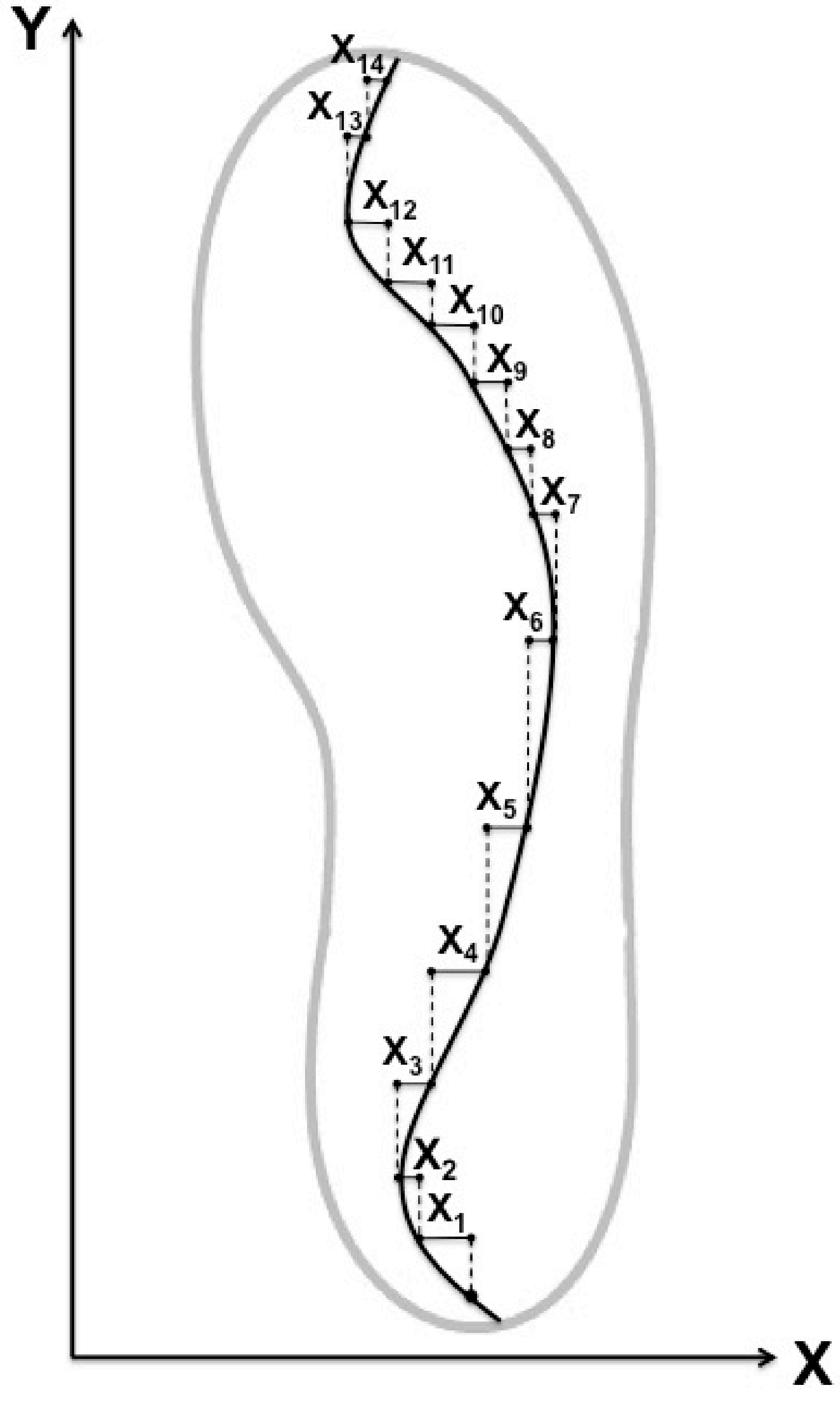


Figure 2

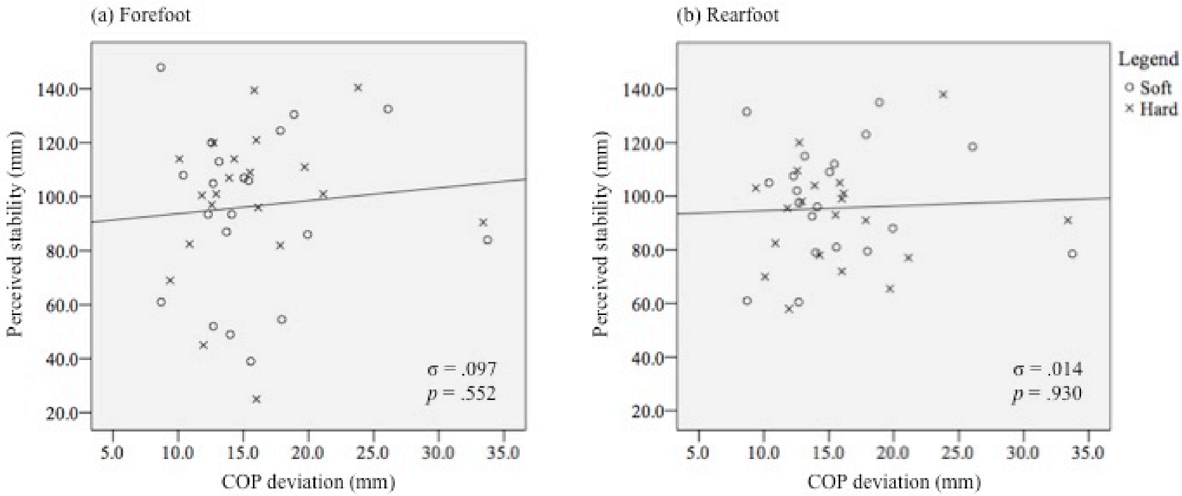
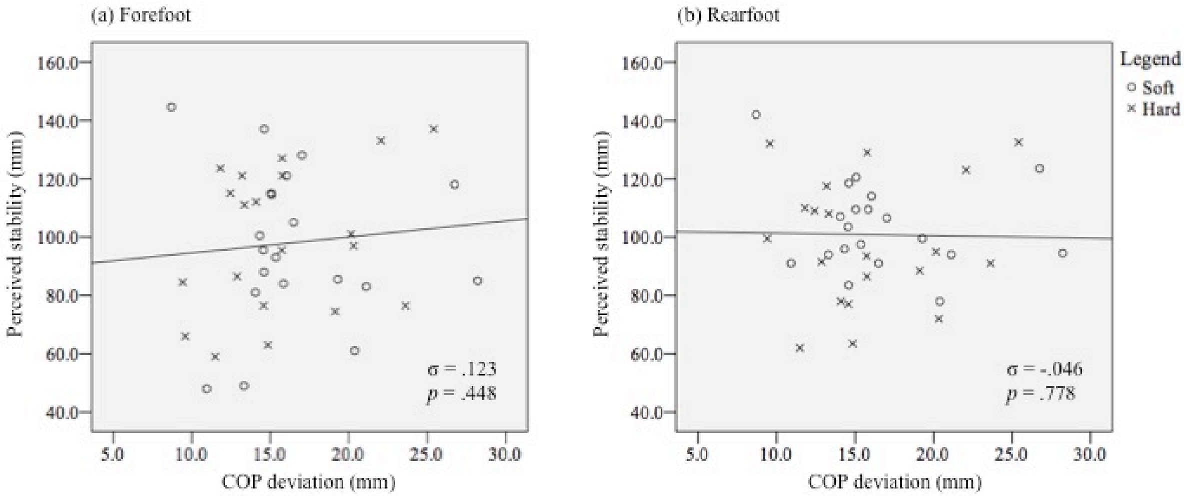

(a) Forefoot
Perceived stability (mm)
COP deviation (mm)
σ = .097
p = .552
(b) Rearfoot
Perceived stability (mm)
COP deviation (mm)
σ = .014
p = .930
Legend
Soft
Hard

Figure 3



(a) Forefoot
Perceived stability (mm)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
σ = .123
p = .448
5.0
10.0
15.0
20.0
25.0
30.0
COP deviation (mm)
(b) Rearfoot
Perceived stability (mm)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
σ = -.046
p = .778
5.0
10.0
15.0
20.0
25.0
30.0
COP deviation (mm)
Legend
Soft
Hard

Figure 4