2018

Segmented forefoot plate in basketball footwear: Does it influence performance and foot joint kinematics and kinetics?

Wing-Kai Lam
Shenyang Sport University, Li Ning Sports Science Research Center, gilbertlam@li-ning.com.cn

Winson Lee
University of Wollongong, ccwlee@uow.edu.au

Wei Min Lee
Nanyang Technological University

Christina Ma
Hong Kong Polytechnic University

Pui Kong
Nanyang Technological University

Segmented forefoot plate in basketball footwear: Does it influence performance and foot joint kinematics and kinetics?

Abstract

This study examined the effects of shoes' segmented forefoot stiffness on athletic performance and ankle and metatarsophalangeal joint kinematics and kinetics in basketball movements. Seventeen university basketball players performed running vertical jumps and 5-msprints atmaximumeffort with 3 basketball shoes of various forefoot plate conditions (medial plate, medial + lateral plates, and no-plate control). One-way repeated measures ANOVAs were used to examine the differences in athletic performance, joint kinematics, and joint kinetics among the 3 footwear conditions ($\alpha = .05$). Results indicated that participants wearing medial + lateral plates shoes demonstrated 2.9% higher jump height than those wearing control shoes ($P = .02$), but there was no significant differences between medial plate and control shoes ($P > .05$). Medial plate shoes produced greater maximum plantar flexion velocity than the medial + lateral plates shoes ($P < .05$) during sprinting. There were no significant differences in sprint time. These findings implied that inserting plates spanning both the medial and lateral aspects of the forefoot could enhance jumping, but not sprinting performances. The use of a medial plate alone, although induced greater plantar flexion velocity at the metatarsophalangeal joint during sprinting, was not effective in improving jump heights or sprint times.

Disciplines

Engineering | Science and Technology Studies

Publication Details

Lam, W., Lee, W. C. C., Lee, W., Ma, C. Z. H. & Kong, P. W. (2018). Segmented forefoot plate in basketball footwear: Does it influence performance and foot joint kinematics and kinetics?. Journal of Applied Biomechanics, 34 (1), 31-38.

Segmented forefoot plate in basketball footwear – Does it influence performance and foot joint kinematics and kinetics?

Wing-Kai Lam[1,2,*], Winson Chiu-Chun Lee[3], Wei Min Lee[4], Christina Zong-Hao Ma[5], and Pui Wah Kong[4]

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

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

[3]School of Mechanical, Materials, Mechatronic and Biomedical Engineering, University of Wollongong, New South Wales, Australia

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

[5]Interdisciplinary Division of Biomedical Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, China

Funding: None

Conflict of Interest Disclosure: No relevant financial conflict.

Correspondence Address:
Wing-Kai Lam, PhD
Li Ning Sports Science Research Center
No.8 Xing Guang 5th Street Opto-Mechatronics Industrial Park
Zhongguancun Science & Technology Area, Tongzhou District, Beijing, China
Phone: (+86) 10 80801108 Email: gilbertlam@li-ning.com.cn.

Running Title: Segmented forefoot plate in basketball

Abstract

This study examined the effects of shoes' segmented forefoot stiffness on athletic performance and ankle and metatarsophalangeal joint kinematics and kinetics in basketball movements. Seventeen university basketball players performed running vertical jumps and 5-meter sprints at maximum effort with three basketball shoes of various forefoot plate conditions (medial plate, medial+lateral plates, and no-plate control). One-way repeated measures ANOVAs were used to examine the differences in athletic performance, joint kinematics, and joint kinetics among the three footwear conditions (α = .05). Results indicated that participants wearing medial+lateral plates shoes demonstrated 2.9% higher jump height than wearing control shoes (p = .02), but there was no significant differences between medial plate and control shoes (p > .05). Medial plate shoes produced greater maximum plantarflexion velocity than the medial+lateral plates shoes (p < .05) during sprinting. There were no significant differences in sprint time. These findings implied that inserting plates spanning both the medial and lateral aspects of the forefoot could enhance jumping, but not sprinting performances. The use of medial plate alone, though induced greater plantarflexion velocity at the metatarsophalangeal joint during sprinting, was not effective in improving jump heights or sprint times.

Keywords: ankle joint, metatarsophalangeal joint, sprinting, jumping, joint moment

Word Count: 191 (Abstract), 2671 (Main text)

Introduction

Previous studies have shown that shoe bending stiffness was related to changes in joint kinematics and kinetics as well as athletic performance.[1] Increasing forefoot bending stiffness of a shoe, which can be achieved by inserting a forefoot plate or increasing the midsole hardness, has the potential to enhance sports performance such as forward acceleration, jumping and agility tasks.[1-3] Stefanyshyn and colleagues[1] found an improvement in maximum-effort sprint performance when participants ran in shoes inserted with very stiff carbon plates at the soles compared with those without. It has been suggested that increasing shoe bending stiffness could provide a longer lever arm for greater moment generation[4] and reduce the amount of energy absorbed at the metatarsophalangeal joint.[1] The effects of changing stiffness at different forefoot regions of the shoes on sports performance, remains uncertain.[5]

Vertical jumping and forward sprinting and are repetitively performed in the game of basketball.[6] Great jump height and quick sprint actions are expected to take an advantage over opponents, higher propulsive forces are also reported to correlate with better sports performance.[7-9] Previous studies showed higher plantar pressures and shear forces in the medial forefoot region during propulsion in typical basketball manoeuvres (e.g. sprinting, jumping, and side-cutting) when compared with running.[10-12] Although inserting a plate into a basketball shoe may enhance propulsive forces, scientific guidelines on the location of the plate are scarce. On one hand, inserting a medial stiffening only the medial aspect of forefoot region of the shoe may induce forefoot instability.[13] On the other hand, inserting plates in both medial and lateral aspects may increase lateral foot loading.[14] High loading at the lateral aspect of the foot is undesirable as it is associated with Jones fracture (i.e. fifth metatarsal diaphysis), which is one of the recurrent stress fractures in basketball that is difficult to treat.[14,15] Thus, it is of interest to consider if inserting a

plate in the medial region of the forefoot alone would be equally effective to improve athletic performance.

The objective of this study was to examine the influence of locations of stiffness plates at the forefoot regions of the shoes (i.e., medial plate, medial+lateral plates versus no-plate control) on athletic performance and ankle and metatarsophalangeal joint kinematics and kinetics during running vertical jump and sprinting. Based on the previous findings,[1,16,17] the hypotheses were that comparing to the no-plate control shoes, 1) medial plate and medial+lateral plates shoes would enhance jump and sprint performance, and 2) both medial plate and medial+lateral plates shoes would minimise the energy dissipation (i.e., less power absorption) at the ankle and metatarsophalangeal joints.

Methods

Test shoe conditions: Three identical pairs of US9.0 basketball shoes (Li Ning Yushuai 9, Beijing, China), 1) with a medial thermoplastic polyurethane plate, 2) with medial and lateral thermoplastic polyurethane plates, and 3) without any additional plates, were custom-made in this study (Figure 1). The control shoe condition was unmodified from its original specifications (Shoe mass = 392.6g). The medial plate shoe (Shoe mass = 408.6g) was customised by positioning one thermoplastic polyurethane plate at the medial forefoot midsole. The medial+lateral plates shoe (Shoe mass = 410.1g) was customised by positioning one plate in the medial and one plate in the lateral forefoot midsole. All plates used in the medial plate and medial+lateral plates shoes had identical material thickness (3mm) and hardness (Shore 90A). The plates were embedded in the foam underneath the sockliner during the shoe construction process. The shoe mass was affected by both the plate and the amount of sole materials taken out when embedding the plates. Forefoot bending stiffness of each test shoe was quantified with a mechanical flexion tester (ASTM F911-

85). In brief, 65 consecutive mechanical flexion trials were performed at the forefoot at about 70% shoe length with a flexion angle of 45 deg at a frequency of 2.7 Hz. The mechanical axis was carefully aligned with the axis of the flexion at the metatarsophalangeal joint of the shoe.[18] The trials from the 61th to 65th were averaged for the calculation of shoe bending stiffness. The overall bending stiffness for medial plate, medial+lateral plates, and no-plate control shoes were 0.277, 0.376, and 0.261, Nm/deg, respectively.

Participants: Seventeen male university basketball players (mean age 24.5 ± 1.5 years; height 172.9 ± 6.4 cm; body mass 68.3 ± 6.3 kg; playing experience 8.4 ± 2.9 years) were recruited. Only participants having the foot length of American size 9 with a maximum tolerance of ± 0.5 for heel-to-toe length were included. All participants were right leg dominant and had no lower extremity injuries in the past six months prior to the start of the study. The study was approved by the Nanyang Technological University Institutional Review Board. All the participants signed a written informed consent form before the test.

Movement protocols: Maximum running vertical jump and 5-meter forward sprint were evaluated as these movements were commonly investigated in previous studies on basketball shoes[19] and footwear bending stiffness.[1,16] In brief, for running vertical jump (Figure 2a), participants approached from a 5-meter distance and performed a maximum hand reach after taking off with the left foot on the force plate (Kistler, Winterthur, Switzerland). Participants took off with left leg for a stimulated lay-up shooting with right (preferred) hand. The hand reach height was measured with the Vertec height measurement system (Sports Imports, Columbus, OH). Jump height was calculated by subtracting the participant's standing hand reach height from the maximum jumping hand reach height. A pair of double beam timing gates (SWIFT Timing Gates, SWIFT Performance Equipment, Alstonville, Australlia) were used to measure the approach speed

prior to contact with the force plate. One set of timing gates was placed near edge of the force platform, while the other set was placed 1.0 meter ahead.

For the 5-meter sprint test (Figure 2b), participants were instructed to sprint with maximum-effort until passing through the end position. The start and end positions were pre-determined for individual participants in order to have the second acceleration step (left foot) striking on the force plate. The elapsed times determined from the timing gates set at 0-meter and 5-meter were taken to indicate sprint performance (Figure 2b).

Procedures: Prior to the actual data collection, participants performed five minutes of self-selected warm-up protocol. They were then given time to familiarise themselves with the testing protocol including the placement of the left foot on the force platform in each of the tested movements (running vertical jump and 5-meter forward sprint). Thirteen reflective markers (95 mm diameter) were firmly affixed on the left leg (Figure 3).[11] For the actual tests, participants were instructed to perform five trials of each movement while wearing all three pairs of test shoes (medial plate, medial-lateral plates, and control). The trial order was randomized. A trial was considered valid only if the position of the entire left foot was within force platform during ground contact. In total, each participant performed 30 trials (5 valid trials × 3 shoes x 2 movements). To minimise the influence of fatigue, 1-minute and 10-minute resting periods were mandatory between trials and between shoe conditions, respectively.

During these movements, synchronised ground reaction force and lower limb kinematics data were taken using a force platform (Kistler, Winterthur, Switzerland, sampled at 1000 Hz) and an eight-camera motion analysis system (Vicon, Oxford Metrics, UK, sampled at 200 Hz). Marker trajectories were low-pass filtered at 16Hz using a Butterworth filter. A spline interpolation was performed for minor missing marker trajectories using three frames of data before and after the

missing data point.[20] From the ground reaction force, ankle and metatarsophalangeal joint angles, angular velocities, moments, and powers were calculated as these variables are of direct relevance to athletic performances.[1,2,16] An inverse dynamic model in Visual 3D (C-Motion Inc, Germantown, USA), which comprised of shank, rearfoot and forefoot segments, was used for calculation of joint moments and powers. The metatarsophalangeal joint was modeled as a single hinge joint rotating about an axis perpendicular to the sagittal plane. The segmental masses of the shank and foot were taken from a previous study.[21] In brief, the foot mass was then partitioned between the rearfoot and forefoot segments in the same ratios as their respective volumes, modeling each as simple geometric solids with uniform densities.[21] Positive work or energy generation (negative work or energy absorption) occurs when the resultant joint moment is in the same (opposite) direction as the joint angular velocity.

Statistical analyses: Maximum jump height, approach speed for vertical jump, fastest sprint time, ankle and metatarsophalangeal joint angles, angular velocities, moments and powers were averaged across all trials for each shoe condition and then analysed using SPSS 22.0 (IBM Corp., Armonk, NY, USA). In each tested movement, a one-way repeated measures analysis of variance (ANOVA) was performed to examine if there was any significant difference ($\alpha = 0.05$) across three shoes for each variable of interest. Bonferroni corrected *post-hoc* tests were employed for any significant main effect.

Results

In running vertical jump, there was a significant difference on jump height ($F_{2,32} = 3.47$, $p = 0.04$, $n^2 = 18$, Figures 4 & 5) among shoe conditions. *Post-hoc* tests indicated that participants wearing medial+lateral plates shoes (63.2 cm) jumped higher than that wearing the control shoes (61.5cm, $p < 0.05$, ~2.9%) but the performance did not differ between medial plate (62.7 cm) and

control shoes (61.5 cm). No significant difference was found for the ankle and metatarsophalangeal joint kinematic, moment or power variables ($p > 0.05$, Table 1).

For the 5-meter sprint, there was no significant difference on sprint time among the medial plate (1.13s), medial+lateral plates (1.12s), and control shoes (1.12s, $p > 0.05$, Figures 4 & 5). There was a significant main effect of shoe in maximum metatarsophalangeal joint plantarflexion velocity ($F_{2,32} = 5.12$, $p < 0.05$, $n^2 = 44$, Table 2). *Post-hoc* tests indicated that participants wearing medial plate shoe (1082 deg/s) experienced higher maximum plantarflexion velocity compared with medial+lateral plates condition (1039 deg/s, $P < 0.05$) but no difference was found between medial plate and control shoe conditions. No other significant differences in ankle or metatarsophalangeal joint kinemtatic, moment, or power variables were found ($p > 0.05$).

Discussion

This study examined the influence of segmented midsole stiffness of basketball footwear at various forefoot regions (medial plate, medial+lateral plates, and no-plate control) on running vertical jump and sprinting performance. The current results indicated that the participants wearing stiffer shoes (i.e. medial+lateral plates) led to an average of 1.7 cm (+2.9%) improvement in running vertical jump. On the contrary, some other studies found no difference in vertical jump performance when wearing the test shoes inserted with increased forefoot stiffness.[2,22] These opposing results in the literature may be due to the differences in shoe prototype constructions. When this study inserted plates at different forefoot regions of the shoes, Worobets and Wannop (2015) changed the stiffness of the shoes by cutting out a small vertical portion of the exterior midsole on the lateral side of the shoe. These cutting procedures might have caused structural damage to their shoe prototypes and thereby influence jump performance. The differences in findings could further reflect the importance of locations of plates. The other plausible

explanations would be related to the participants' characteristics (anthropometry, comfort preference, training background, playing level, etc) and the methodologies used in assessing jump performances. Further investigations on the influence of shoe bending stiffness on both performance and comfort perception would be helpful to guide how forefoot plate should be inserted to meet individual needs.

Regarding the 5-meter forward sprint performance, although participants wearing less stiff shoes (i.e. medial plate) displayed greater maximum plantarflexion velocity compared with the stiffer shoes (i.e. medial+lateral plates), no difference in sprint time was found between these two shoes (Figure 4c). The lack of benefit of stiffer shoes in sprinting performance was in contrast with others.[3,22] One plausible explanation is that the subtle increase in footwear bending stiffness (stiffer shoes versus less-stiff shoes) may not elicits a decrease in metatarsophalangeal joint motions which are important in sprint performance. This argument agrees with a previous study on straight line sprinting which showed 1.0% faster in 10-meter sprint time between the least stiff and the stiffest shoes only, while no improvement was seen in the medium stiff shoe.[21] Another factor that may be associated with the lack of improvement in sprint performance is the location of the inserted plate. Asymmetrical segmented shoe hardness across the medio-lateral direction of forefoot (e.g., harder at medial than the lateral side) might comprise the frontal foot placement and alignment for the overall ability of muscle-tendon unit to allow for fast plantarflexion.[24] Quantifying the metatarsophalangeal joint stiffness and torque of the human foot[25,26] may provide further insights on the application of forefoot plate in athletic footwear. While the beneficial effect of wearing stiffer shoes on sprint performance might be rather individualised (Figure 5), the current findings provided no clear evidence that implementing forefoot plate can enhance sprint performance.[5]

Although significant increase in running vertical jump height was found in the stiffer shoes (medial+lateral plates) compared with less stiff shoes (i.e. control shoe), no difference in ankle or metatarsophalangeal joint kinematics or kinetics was found (Table 1). The values of joint moment and power absorption in the present study were comparable to those reported in previous studies on jumping[2] and sub-maximal running.[4] However, the ankle power absorption (29 to 60 J) were less than the values (64 to 86 J) reported by Stefanyshyn and colleagues.[16,17,27] These differences in the magnitudes of joint energetics may be due to the methodology involved in obtaining joint kinematic data. The present study and studies of Toon et al. and Willwacher et al.,[2,4] utilised 3D motion capture systems whereas the studies of Stefanyshyn and colleagues.[16,17,27] obtained kinematic data via 2D video analysis. Furthermore, compared to the low-collar running shoes used in studies of Stefanyshyn and colleagues, the present study used high-collar basketball shoes which might limit the total ankle range of motion.[7,28] The restricted ankle motion may affect joint kinematics as well as joint energy generation and absorption. In the future, the effects of systematic changes in segmental forefoot plate stiffness and location (e.g. combined effect of location, shape and thickness of plate) on sports performance and the underlying mechanisms (via analysing joint moment and power) should be investigated before a valid conclusion can be made.

When interpreting our results, it is important to consider several limitations to the present study. First, we did not differentiate foot type[29] nor anthropometry[30] of the participants and these factors like the length of forefoot bones, metatarsophalangeal joint and Achilles tendon stiffness, and medial arch stiffness may have influenced the jumping and sprinting performance. Second, we did not measure plantar pressure nor comfort perception. Adding forefoot plate at the forefoot region might induce discomfort and mechanical stress. Studying plantar pressure on the plate locations would provide insights into plantar stress-related injuries and stability.[13] For performance

aspect, the optimal pathway hypothesis proposed that better comfort perception might allow for optimal movement pathway of individual.[31] Future investigation should strike a balance between performance and comfort associated with different forefoot bending stiffness and locations of the inserted plates. Thirdly, we included only male basketball players and did not consider their playing levels or positions. It is possible that loading characteristics are influenced by sex, playing level and position. Finally, it should be noted that both the location of the plates and their bending stiffness could have contributed to the observed changes in jumping and sprinting performance.

In summary, basketball shoes inserted with medial+lateral plates in the forefoot region could enhance running vertical jumping but not sprinting performances. The use of medial plate alone was not effective in improving jump heights or sprint times, though it induced greater plantarflexion velocity at the metatarsophalangeal joint during sprinting. Although the underlying mechanism remains unclear, further optimisation of forefoot plate location may be useful in the development and design of basketball footwear.

Acknowledgments

The authors would like to thank Yong-Dan Du from Beijing Fusheng Biotechnology Research Institute for his assistance in mechanical stiffness measurement of the tested shoes.

References

1. Stefanyshyn D, Fusco C. Increased shoe bending stiffness increases sprint performance. *Sports Biomech.* 2004;3(1):55-66.

2. Toon D, Vinet A, Pain MTG, Caine MP. A methodology to investigate the relationship lower-limb dynamics and shoe stiffness using custom-built footwear. *J Sports Eng Technol.* 2010;225(P):32-37.

3. Tinoco N, Bourgit D, Morin JB. Influence of midsole metatarsophalangeal stiffness on jumping and cutting movement agility. *J Sports Eng Technol.* 2010;224(3):209-217.

4. Willwacher S, Konig M, Potthast W, Bruggemann GP. Does specific footwear facilitate energy storage and return at the metatarsophalangeal joint in running? *J Appl Biomech.* 2013;29(5):583-592.

5. Stefanyshyn DJ, Wannop JW. The influence of forefoot bending stiffness of footwear on athletic injury and performance. *Footwear Sci.* 2016;8(2):51-63.

6. Ben Abdelkrim N, El Fazaa S, El Ati J. Time-motion analysis and physiological data of elite under-19-year-old basketball players during competition. *Br J Sports Med.* 2007;41(2):69-75.

7. Lam WK, Park EJ, Lee KK, Cheung JT. Shoe collar height effect on athletic performance, ankle joint kinematics and kinetics during unanticipated maximum-effort side-cutting performance. *J Sports Sci.* 2015;33(16):1738-1749.

8. McClay IS, Robinson JR, Andriacchi TP, et al. A profile of ground reaction forces in professional basketball. *J Appl Biomech.* 1994;10:222-236.

9. Shimokochi Y, Ide D, Kokubu M, Nakaoji T. Relationships among performance of lateral cutting maneuver from lateral sliding and hip extension and abduction motions, ground reaction force, and body center of mass height. *J Strength Cond Res.* 2013;27(7):1851-1860.

10. Lam WK, Ng WX, Kong PW. Influence of shoe midsole hardness on plantar pressure distribution in four basketball-related movements. *Res Sports Med.* 2017;25(1):37-47.

11. Cong Y, Lam WK, Cheung JT, Zhang M. In-shoe plantar tri-axial stress profiles during maximum-effort cutting maneuvers. *J Biomech.* 2014;47(16):3799-3806.

12. Pau M, Ciuti C. Stresses in the plantar region for long- and short-range throws in women basketball players. *Eur J Sport Sci.* 2013;13(5):575-581.

13. Sterzing T, Custoza G, Ding R, Cheung JT. Segmented midsole hardness in the midfoot to forefoot region of running shoes alters subjective perception and biomechanics during heel-toe running revealing potential to enhance footwear. *Footwear Sci*. 2015;7(2):63-79.

14. Queen RM, Verma R, Abbey AN, Nunley JA, Butler RJ. Plantar loading during jumping while wearing a rigid carbon graphite footplate. *Gait Posture.* 2014;39(2):707-711.

15. Kavanaugh JH, Brower TD, Mann RV. The Jones fracture revisited. *J Bone Joint Surg Am.* 1978;60(6):776-782.

16. Stefanyshyn DJ, Nigg BM. Contribution of the lower extremity joints to mechanical energy in running vertical jumps and running long jumps. *J Sports Sci.* 1998;16(2):177-186.

17. Stefanyshyn DJ, Nigg BM. Influence of midsole bending stiffness on joint energy and jump height performance. *Med Sci Sports Exerc.* 2000;32(2):471-476.

18. Miller JE, Nigg BM, Liu W, Stefanyshyn DJ, Nurse MA. Influence of foot, leg and shoe characteristics on subjective comfort. *Foot Ankle Int.* 2000;21(9):759-767.

19. Guettler JH, Ruskan GJ, Bytomski JR, Brown CR, Richardson JK, Moorman CT. Fifth metatarsal stress fractures in elite basketball players: evaluation of forces acting on the fifth metatarsal. *Am J Orthop.* 2006;35(11):532-536.

20. Sigward S, Powers CM. The influence of experience on knee mechanics during side-step cutting in females. *Clin Biomech.* 2006;21(7):740-747.

21. Hanavan EP, Jr. A Mathematical Model of the Human Body. Amrl-Tr-64-102. *AMRL-TR. Aerospace Medical Res Laboratories.* 1964:1-149.

22. Worobets J, Wannop JW. Influence of basketball shoe mass, outsole traction, and forefoot bending stiffness on three athletic movements. *Sports Biomech.*2015;14(3):351-360.

23. Oleson M, Adler D, Goldsmith P. A comparison of forefoot stiffness in running and running shoe bending stiffness. *J Biomech.* 2005;38(9):1886-1894.

24. Luo G, Stefanyshyn D. Ankle moment generation and maximum-effort curved sprinting performance. *J Biomech.* 2012;45(16):2763-2768.

25. Man HS, Lam WK, Lee J, Capio CM, Leung AK. Is passive metatarsophalangeal joint stiffness related to leg stiffness, vertical stiffness and running economy during sub-maximal running? *Gait Posture.*2016;49:303-308.

26. Heng ML, Chua YK, Pek HK, Krishnasamy P, Kong PW. A novel method of measuring passive quasi-stiffness in the first metatarsophalangeal joint. *J Foot Ankle Res.* 2016;9:41.

27. Stefanyshyn DJ, Nigg BM. Mechanical energy contribution of the metatarsophalangeal joint to running and sprinting. *J Biomech.* 1997;30(11-12):1081-1085.

28. Brizuela G, Llana S, Ferrandis R, Garcia-Belenguer AC. The influence of basketball shoes with increased ankle support on shock attenuation and performance in running and jumping. *J Sports Sci.* 1997;15(5):505-515.

29. Chuckpaiwong B, Nunley JA, Mall NA, Queen RM. The effect of foot type on in-shoe plantar pressure during walking and running. *Gait Posture.* 2008;28(3):405-411.

30. Nin DZ, Lam WK, Kong PW. Effect of body mass and midsole hardness on kinetic and perceptual variables during basketball landing manoeuvres. *J Sports Sci.* 2016;34(8):756-765.

31. Nigg BM. The role of impact forces and foot pronation: A new paradigm. *Clin J Sport Med.* 2001;11:2-9.

Figure 1 — Test shoe conditions

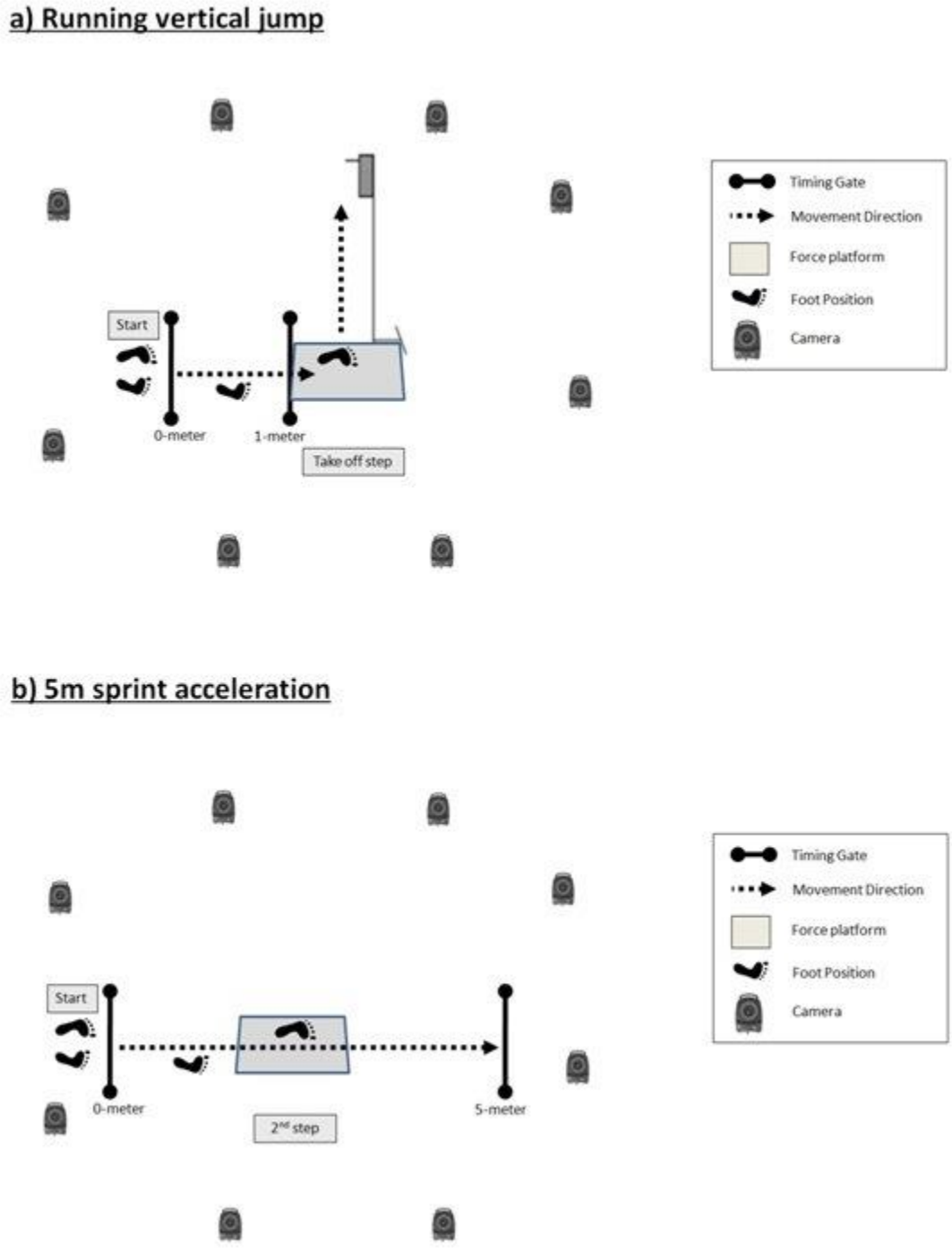

Figure 2 — Equipment setup and movement sequences: a) running vertical jump and b) 5m sprint acceleration.

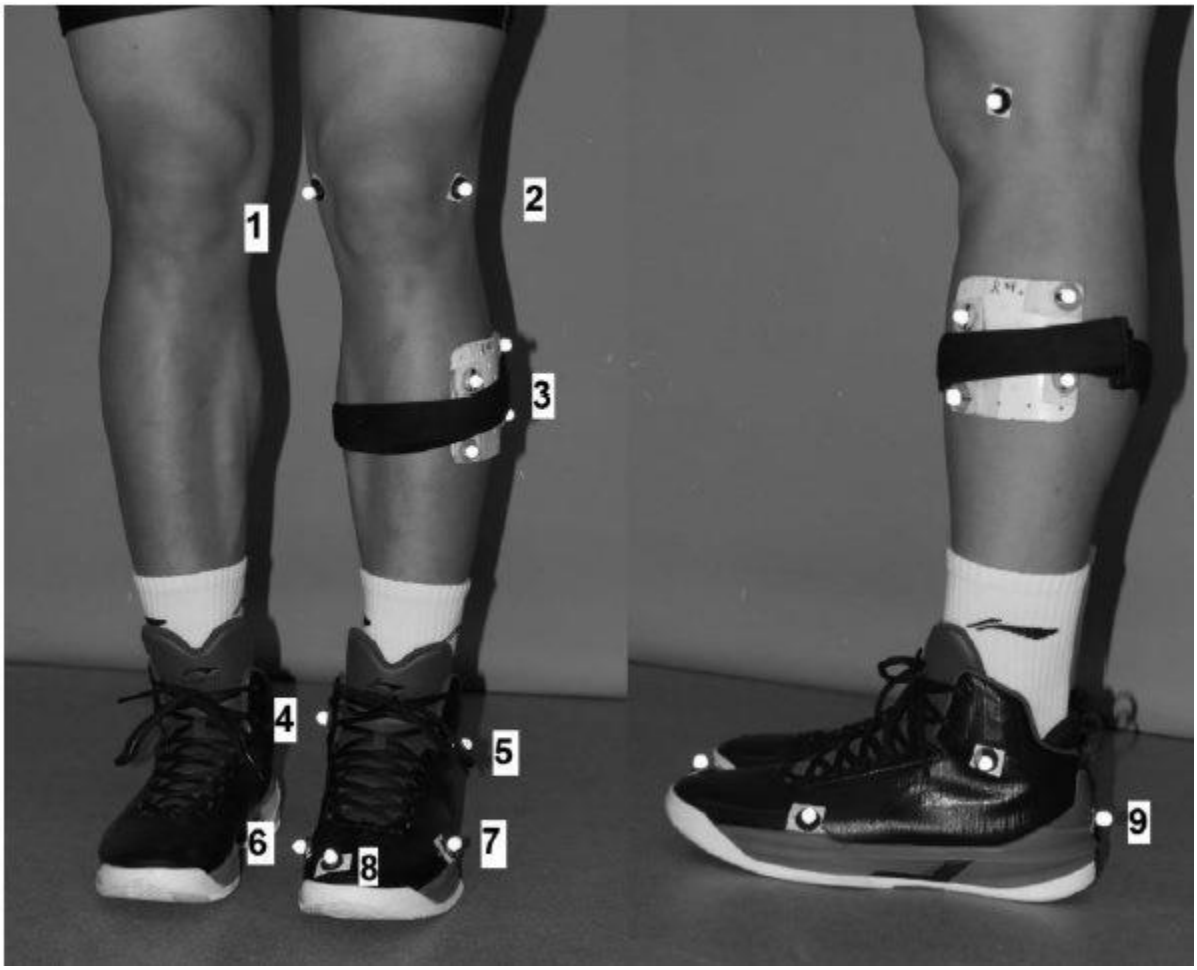

Figure 3 — Placement of retro-reflective marker on the left leg: 1) medial malleolus, 2) lateral malleolus, 3) four-marker cluster on the shank, 4) medial epicondyle, 5) lateral epicondyle, 6) lateral aspect of first metatarsal, 7) lateral aspect of fifth metatarsal, 8) superior aspect of hallux and 9) heel.

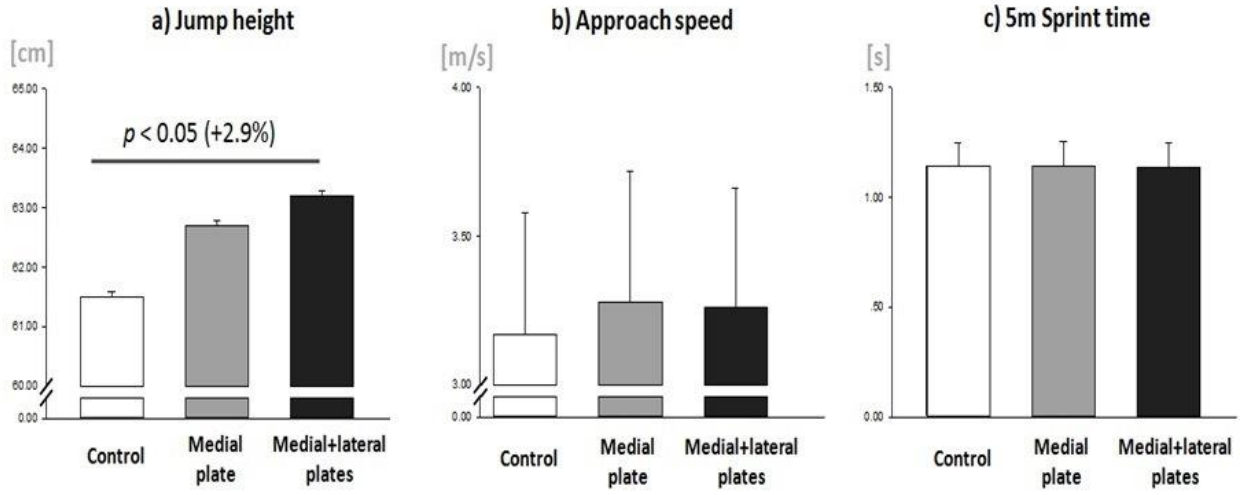

Figure 4 — a) Maximum jump height, b) approach speed for vertical jump, and c) fastest sprint time across three shoe conditions.

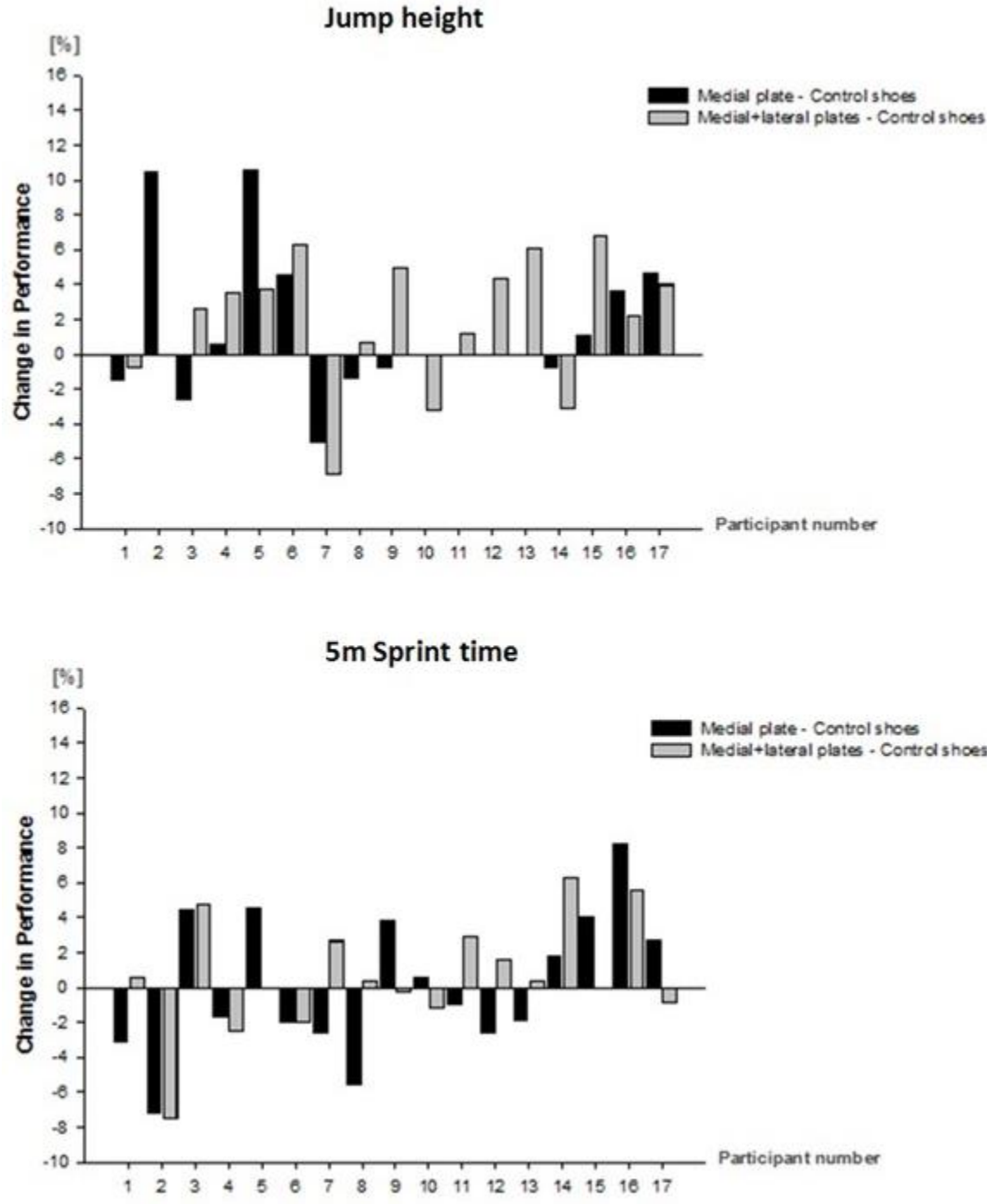

Figure 5 — Relative improvement (With plate – without plate) of individual participants in maximum jump height and fastest sprint time.

Table 1: Ankle and metatarsophalangeal joint kinematics and kinetics variables during running vertical jump expressed in mean (standard deviation).

	Control	Medial plate	Medial+lateral plates	Shoe effect		
				p	η_p^2	β
Ankle joint						
Total ankle range of motion (deg)	49(5.2)	48(5.3)	48(4.4)	0.82	0.01	0.08
Maximum dorsiflexion (deg)	10(4.4)	9(4.4)	10(4.0)	0.56	0.09	0.13
Maximum plantarflexion (deg)	-38(4.0)	-39(4.0)	-38(3.9)	0.16	0.25	0.36
Maximum plantarflexion velocity (deg/s)	-968(94.6)	-955(89.1)	-960(99.2)	0.83	0.03	0.07
Resultant joint moment (Nm)	85.51(19.30)	89.19(20.89)	90.72(20.23)	0.07	0.15	0.53
Joint power absorption (J)	-24.21(9.17)	-23.73(7.73)	-25.28(7.64)	0.64	0.03	0.12
Joint power generation (J)	59.56(10.61)	59.68(12.38)	61.34(13.42)	0.39	0.06	0.21
Metatarsophalangeal joint						
Total metatarsophalangeal range of motion (deg)	47(5.9)	46(5.6)	45(4.7)	0.15	0.13	0.39
Maximum dorsiflexion (deg)	8(3.0)	7(2.5)	8(2.4)	0.13	0.27	0.39
Maximum plantarflexion (deg)	-5(1.3)	-5(1.8)	-5(1.7)	0.91	0.02	0.06
Maximum plantarflexion velocity (deg/s)	-389(97.2)	-362(76.6)	-363(77.3)	0.15	0.25	0.37
Resultant joint moment (Nm)	8.91(8.81)	9.59(7.90)	12.73(13.94)	0.14	0.12	0.40
Joint power absorption (J)	-1.46(2.80)	-1.22(1.80)	-2.39(4.00)	0.12	0.13	0.43
Joint power generation (J)	0.49(0.30)	0.62(0.36)	0.52(0.47)	0.42	0.05	0.19

Note. η_p^2 =partial eta squared; β=observed power.

Table 2: Ankle and metatarsophalangeal joint kinematics and kinetics variables during 5-meter sprint expressed in mean (standard deviation).

	Control	Medial plate	Medial+lateral plates	Shoe effect			
				p	η_p^2	β	*Post-hoc*
Ankle joint							
Total ankle range of motion (deg)	50(5.5)	51(5.1)	49(5.0)	0.63	0.03	0.12	-
Maximum dorsiflexion (deg)	30(5.6)	29(5.3)	29(5.5)	0.24	0.20	0.28	-
Maximum plantarflexion (deg)	-20(7.9)	-22(5.2)	-21(5.2)	0.34	0.15	0.21	-
Maximum plantarflexion velocity (deg/s)	-1025(171.7)	-1030(166.5)	-1001(146.80)	0.21	0.21	0.30	-
Resultant joint moment (Nm)	104.28(24.96)	105.81(17.01)	107.45(21.39)	0.51	0.04	0.16	-
Joint power absorption (J)	-29.14(8.97)	-28.78(7.51)	-30.6(9.41)	0.38	0.06	0.21	-
Joint power generation (J)	43.81(16.08)	44.38(13.88)	44.21(12.71)	0.94	0.00	0.06	-
Metatarsophalangeal joint							
Total metatarsophalangeal range of motion (deg)	52(11)	53(8.7)	53(7.5)	0.57	0.04	0.14	-
Maximum dorsiflexion (deg)	32(5.4)	32(4.7)	32(4.2)	0.99	0.00	0.05	-
Maximum plantarflexion (deg)	4.0(2.6)	4(2.8)	4(2.3)	0.70	0.05	0.10	-
Maximum plantarflexion velocity (deg/s)	-1029(273.8)	-1082(199.1)	-1039(177.1)	**0.02**	0.44	0.72	Medial > Medial+lateral
Resultant joint moment (Nm)	20.23(12.29)	16.83(7.68)	14.19(7.09)	0.69	0.16	0.53	-
Joint power absorption (J)	-8.09(6.18)	-6.38(4.12)	-5.27(3.45)	0.13	0.13	0.36	-
Joint power generation (J)	4.81(5.69)	13.60(3.01)	2.66(1.96)	0.11	0.13	0.44	-

Note. η_p^2 =partial eta squared; *β*=observed power. Significant *p*-values ($p < .05$) are shown in bold