Baltic Journal of Health and Physical Activity 2018; 10(4): 89-96
Journal of Gdansk University of Physical Education and Sport
e-ISSN 2080-9999

ORIGINAL

doi: 10.29359/BJHPA.10.4.08

The effects of conventional and minimalist footwear on hip and knee joint kinetics during maximal depth jumps

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

Jonathan Sinclair

Centre for Applied Sport & Exercise Sciences, School of Sport & Wellbeing,
College of Health & Wellbeing, University of Central Lancashire, United Kingdom

abstract

Background: The aim of the current investigation was to examine the effects of minimalist and conventional footwear on the loads experienced by the hip and knee joints during the depth jump.

Material and methods: Ten male participants performed depth jumps onto a force platform in each footwear condition. Kinematics of the lower extremities were also quantified using an eight-camera infra-red motion capture system, allowing hip and knee kinetics to be calculated. Differences between footwear were tested using paired samples t-tests.

Results: Peak hip and knee joint forces were found to be significantly larger in minimalist (hip = 4.62 & knee = 4.74 BW) in comparison to conventional footwear (hip = 4.39 & knee = 4.46 BW). At the hip, average and instantaneous load rates were significantly greater in conventional (average = 64.14 & instantaneous = 234.06 BW/s) compared to minimalist (average = 44.43 & 200.80 BW/s) footwear. At the knee instantaneous load rate was significantly larger in conventional (265.55 BW/s) compared to minimalist (198.07 BW/s) footwear.

Conclusions: Given that the load rate is advocated as a more clinically meaningful measure of injury risk the current study shows that minimalist footwear may be most appropriate for those who are susceptible to hip and knee pathologies.

Key words: depth jump, footwear, tibiofemoral, hip.

article details

Article statistics: **Word count:** 2,087; **Tables:** 2; **Figures:** 2; **References:** 30
Received: April 2016; **Accepted:** July 2018; **Published:** December 2018

Full-text PDF: http://www.balticsportscience.com

Indexation: Celdes, Clarivate Analytics Emerging Sources Citation Index (ESCI), CNKI Scholar (China National Knowledge Infrastructure), CNPIEC, De Gruyter - IBR (International Bibliography of Reviews of Scholarly Literature in the Humanities and Social Sciences), De Gruyter - IBZ (International Bibliography of Periodical Literature in the Humanities and Social Sciences), DOAJ, EBSCO - Central & Eastern European Academic Source, EBSCO - SPORTDiscus, EBSCO Discovery Service, Google Scholar, Index Copernicus, J-Gate, Naviga (Softweco, Primo Central (ExLibris), ProQuest - Family Health, ProQuest - Health & Medical Complete, ProQuest - Illustrata: Health Sciences, ProQuest - Nursing & Allied Health Source, Summon (Serials Solutions/ProQuest, TDOne (TDNet), Ulrich's Periodicals Directory/ulrichsweb, WorldCat (OCLC)

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interests: Author has declared that no competing interest exists.

Corresponding author: Corresponding author: Jonathan Sinclair PhD, Centre for Applied Sport and Exercise Sciences, School of Sport & Wellbeing, College of Health & Wellbeing, University of Central Lancashire, Preston, Lancashire, UK, PR1 2HE; e-mail: jksinclair@uclan.ac.uk.

INTRODUCTION

Plyometrics are used extensively by both recreational and competitive athletes as a means of improving their strength and power [1]. Plyometric activities feature an initial eccentric muscle action which is followed immediately by a concentric contraction [2]. Training using plyometrics has been shown to mediate neuromuscular adaptations to the myotatic reflex, elasticity of muscle and the Golgi tendon organ [3]. The eccentric phase of plyometric activities stimulates the myotatic reflex which allows further recruitment of motor units during the subsequent concentric muscle action [4]. The series and parallel muscle elements are also able to accumulate eccentric strain energy, which generates additional force provided the concentric muscle contraction follows in a sufficiently short time frame [4]. Finally, although the Golgi tendon organs have a protective mechanism which shields against very high tensile loads, plyometric training has been shown to promote Golgi tendon desensitization whereby the muscles elastic components are able to experience greater eccentric lengthening [5]. Plyometric training has been shown to mediate improvements in a range of functional sports tasks [6–13].

However, despite the positive performance alterations associated with this training modality, plyometric activities, such as depth jumping, are associated with rapid decelerations which generate large transient forces [14]. Thus the loading imposed upon specific musculoskeletal structures has been linked to the aetiology of lower extremity injuries [14]. Jump landing actions have been associated with a number of pathologies, with hip and knee pain [15, 16] being amongst the most common injuries related to plyometric activities. Hip and knee pain are common chronic pathologies in athletic populations [17] and their specific aetiology is linked to habitual and excessive joint loading [18, 19]. Hip and knee joint disorders are thus strongly associated with high impact activities, such as depth jumping.

In recent years there has been a shift in footwear selection, with more and more athletes now choosing to perform their activities in minimalist footwear, and plyometric training is no exception [20]. Minimalist footwear is now very popular and has received considerable attention in footwear biomechanics literature [21]. There is only very limited research which has examined the effects of minimalist footwear during plyometric activities, such as depth jumping. LaPorta et al. [22] showed that no significant differences in peak power production and jump height were evident between barefoot, minimalist and conventional footwear during the depth jump. Sinclair et al. [20] investigated the effects of minimalist, conventional and energy return footwear on the kinetics and kinematics of depth jumping. They showed that in minimalist footwear, average and instantaneous loading rate were significantly lower but that jump height was also significantly reduced. Finally, Sinclair et al. [23] examined the effects of minimalist and conventional footwear on patellofemoral and Achilles tendon loads during the depth jump. Their findings showed that whilst no differences were evident in Achilles tendon kinetics, minimalist footwear significantly reduced patellofemoral loading.

There is currently a paucity of information regarding the influence of minimalist footwear on the loads experienced by the hip and knee joints during plyometric activities. Thus the effects of different footwear on the loads experienced by the hip and knee joints remain unknown. The aim of the current investigation was, therefore, to determine the effects of minimalist and conventional footwear on the loads experienced by the hip and knee during the depth jump. An investigation such as this may give important information with regards to the effects of different footwear during plyometric activities.

MATERIAL AND METHODS

PARTICIPANTS

Ten male participants (age 21.56 ±3.25 years; height 1.74 ±0.08 m; mass 69.56 ±5.45 kg) took part in the current study. Participants were university 1st or 2nd team level athletes who currently utilized plyometric drills as part of their training. Approval for this work was acquired from the university ethics committee, and each participant provided written informed consent.

FOOTWEAR

The footwear used during this study consisted of conventional (New Balance 1260 v2) and minimalist footwear (Vibram five-fingers, ELX, shoe size 8–10 in UK men's sizes).

PROCEDURE

This investigation examined hip and knee (tibiofemoral) joint kinetics during the stance phase of the depth jump, i.e. the duration over which the foot was in contact with the ground. Participants completed five depth jumps in each footwear condition, landing with their dominant (right) limb onto a piezoelectric force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire). Participants jumped from a 0.4 m box placed 0.3 m in front of the platform [20], which captured kinetic data at 1000 Hz. The stance phase initiated at the instance of foot contact and ended at the time of foot take-off. This was quantified as the duration over which >20 N of vertical force was applied to the platform. To avoid any sequence effects the order in which participants performed in each footwear was randomized. Kinematic information was collected at a capture rate of 250 Hz using an eight-camera motion analysis system (Qualisys Medical AB, Goteburg, Sweden).

The lower extremities were defined using the calibrated anatomical systems technique [24]. To delineate the segment co-ordinate axes of the right foot, shank and thigh, retroreflective markers were placed unilaterally onto the 1st metatarsal, 5th metatarsal, calcaneus, medial and lateral malleoli, medial and lateral epicondyles of the femur. To define the pelvis segment further markers were positioned onto the anterior (ASIS) and posterior (PSIS) superior iliac spines. Carbon fibre tracking clusters were positioned onto the shank and thigh segments. The foot was tracked using the 1st metatarsal, 5th metatarsal and calcaneus markers and the pelvis using the ASIS and PSIS markers. The centres of the ankle and knee joints were delineated as the mid-point between the malleoli and femoral epicondyle markers [25, 26], whereas the hip joint centre was obtained using the positions of the ASIS markers [27]. Static calibration trials were collected in each footwear allowing for the anatomical markers to be referenced in relation to the tracking markers/clusters. The Z (transverse) axis was oriented vertically from the distal segment end to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior to anterior. Finally, the X (sagittal) axis orientation was determined using the right hand rule and was oriented from medial to lateral.

PROCESSING

Dynamic kinematic trials were digitized using Qualisys Track Manager software and then exported as C3D files into Visual 3D (C-Motion, Germantown, MD, USA). Ground reaction force and kinematic data were smoothed using cut-off frequencies of 50 and 10 Hz using a low-pass Butterworth 4th order zero lag filter.

Hip and knee kinetics were computed using Newton-Euler inverse-dynamics. To quantify joint forces anthropometric data, ground reaction forces and angular kinematics were used. The net joint forces were normalized by dividing the values by each participant's bodyweight (BW). Knee contact stress (MPa) was calculated as a function of the contact force integrated over the tibiofemoral contact area. The contact area was determined by fitting a polynomial curve to the data of Shiramizu et al. [28].

In addition, total hip and knee impulse were calculated (BW·s) by multiplying the mean contact force by the stance time. Finally, hip and knee joint average and instantaneous load rates (BW/s) were also quantified. The average load rate was calculated as a function of the change in force from initial contact to peak force divided by the duration over which the force occurred, and instantaneous load rate as the peak increase in force between adjacent data points.

STATISTICAL ANALYSIS

Differences in hip and knee joint kinetics as a function of footwear was examined using paired samples t-tests with statistical significance accepted at the $P < 0.05$ level. All statistical analyses were conducted using SPSS v22.0 (SPSS Inc., Chicago, USA).

RESULTS

Figures 1 and 2 present the hip and knee joint kinetics as a function of footwear and Tables 1 and 2 show discrete hip and knee kinetic parameters. The results indicate that the experimental footwear significantly influenced both hip and knee kinetics during the depth jump.

HIP KINETICS

Peak hip force was shown to be significantly ($t(9) = 4.06$, $P < 0.05$) larger in minimalist footwear (Figure 1; Table 1). In addition, the hip average ($t(9) = 3.12$, $P < 0.05$) and instantaneous ($t(9) = 7.28$, $P < 0.05$) load rate were shown to be significantly larger in conventional footwear (Table 1).

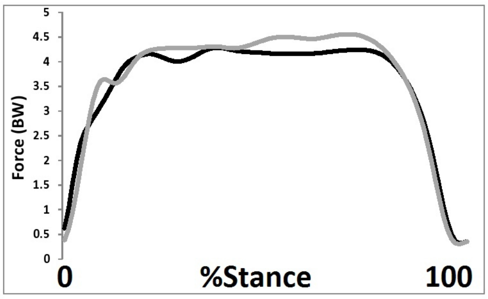

Fig. 1. Hip joint kinetics as a function of footwear (black = minimalist & grey = conventional)

Baltic Journal of Health and Physical Activity 2018; 10(4): 89-96
Journal of Gdansk University of Physical Education and Sport
e-ISSN 2080-9999

Table 1. Hip joint kinetics as a function of footwear

	Conventional		Minimalist	
	Mean	SD	Mean	SD
Peak hip force (BW)	4.39	0.44	4.62	0.40
Time to hip force (s)	0.13	0.04	0.17	0.07
Hip average load rate (BW/s)	64.14	21.44	44.43	19.43
Hip instantaneous load rate (BW/s)	234.06	29.83	200.80	40.19
Hip impulse (BW·s)	1.47	0.18	1.45	0.16

Knee kinetics

Peak knee force was shown to be significantly (t (9) = 3.74, $P < 0.05$) larger in minimalist footwear (Figure 2a; Table 2). In addition, peak knee stress was also shown to be significantly (t (9) = 3.51, $P < 0.05$) larger in minimalist footwear (Figure 2b; Table 2). Finally, the knee instantaneous (t (9) = 11.24, $P < 0.05$) load rate was shown to be significantly larger in conventional footwear (Table 2).

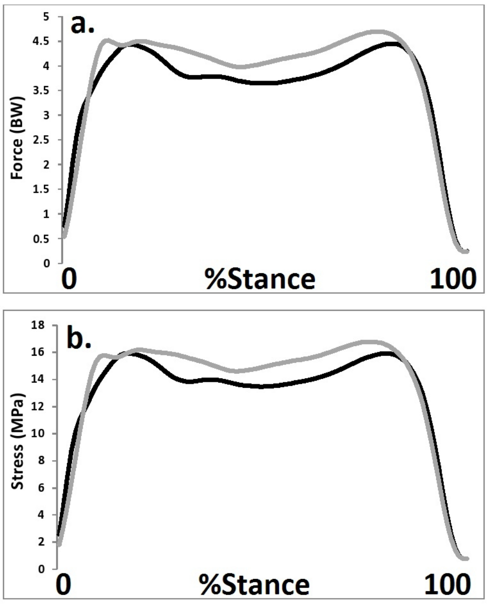

Fig. 2. Knee joint kinetics as a function of footwear (black = minimalist & grey = conventional)

Table 2. Knee joint kinetics as a function of footwear

	Conventional		Minimalist	
	Mean	SD	Mean	SD
Peak knee force (BW)	4.46	0.61	4.74	0.54
Time to knee force (s)	0.13	0.08	0.07	0.03
Knee average load rate (BW/s)	93.33	12.78	95.71	21.78
Knee instantaneous load rate (BW/s)	265.55	23.97	198.07	30.98
Knee impulse (BW·s)	1.33	0.09	1.37	0.09
Knee stress (MPa)	16.02	1.76	16.88	1.66

DISCUSSION

The aim of the current investigation was to examine the effects of minimalist and conventional footwear on hip and knee joint kinetics during maximal depth jumping. This represents the first comparative analysis regarding the influence of minimalist and conventional footwear on hip and knee joint kinetics during depth jumping and may thus be utilized to inform athletes regarding footwear selection.

The first key finding from the current investigation is that peak hip and knee joint forces were shown to be significantly larger in the minimalist in comparison to conventional footwear. This observation opposes the findings of Sinclair et al. [23], who found that minimalist footwear reduced the specific loads experienced at the patellofemoral joint. It is proposed that this divergence relates to the distinct nature of the loading patterns associated with the two knee joint articulations. This finding shows that further investigation of knee loading is required in addition to previous analyses which have habitually investigated only the patellofemoral joint. Given the proposed relationship between excessive joint loading and the aetiology of joint pathology [18, 19], this suggests that minimalist footwear may place athletes at increased risk from chronic hip and knee injuries.

However, this observation is confounded somewhat as the magnitude of the rate of loading at both the hip and knee joints was found to be significantly larger in conventional footwear. It is proposed that this finding relates to the alterations in lower body joint alignment in minimalist footwear during depth jumping [20], which increase the body's propensity for deceleration allowing the peak forces experienced by the musculoskeletal structures to be experienced over a longer duration. This finding may also be important from an injury perspective, as Zadpoor & Nikooyan [29] evidenced that the loading rate and not the magnitude of the peak force was most strongly linked to the aetiology of chronic pathology. Indicating that the rate at which the load is applied may be a more clinically meaningful measure of injury risk than indices of peak load. Leading to the speculation that minimalist footwear may ultimately be most appropriate for those who are susceptible to hip and knee pathologies. However, this must be corroborated using further prospective analyses which specifically investigate joint kinetics before this proposition can be fully substantiated.

A potential drawback of the current work is that only male participants were tested. During landing tasks females athletes have been shown to exhibit altered coronal and transverse plane biomechanics at the hip and knee joints in relation to males [30]. Furthermore, Laporta et al. [22] showed that the biomechanical effects of different footwear during jumping and landing activities were gender dependent. Based on this information, the results of the current investigation cannot be generalized to female athletes, and future analyses should seek to repeat the current analysis using a female sample.

CONCLUSIONS

Although the effects of different footwear on the mechanics of depth jumping have been investigated previously, the current knowledge regarding the influence of minimalist and conventional footwear on hip and knee kinetics is limited. Therefore, the present study contributes to the current literature base by providing a comprehensive investigation of hip and knee joint loads whilst performing depth jumps in minimalist and conventional footwear. The current study showed that peak hip and knee forces were greater in minimalist footwear but that rates of loading were the highest in the conventional condition. Given that the rate at which the load is applied has been advocated as a more clinically meaningful measure of injury risk, the current study shows that minimalist footwear may be the most appropriate for those who are susceptible to hip and knee injuries. However, further prospective work is necessary specifically investigating the rate at which joint kinetics are applied as a risk factor for joint pathology before this proposition can be substantiated.

REFERENCES

[1] Chu DA. Jumping into plyometrics. Champaign, IL: Human Kinetics; 1998.

[2] Markovic, G. Does plyometric training improve vertical jump height? A meta-analytical review. B J Sports Med. 2007;41:349-355. https://doi.org/10.1136/bjsm.2007.035113

[3] Wilk KE, Voight ML, Keirns MA, Gambetta V, Andrews JR, Dillman CJ. Stretch-shortening drills for the upper extremities: theory and clinical application. J Orthop Sports Phys Ther. 1993;17:225-239. https://doi.org/10.2519/jospt.1993.17.5.225

[4] Chimera, NJ, Swanik KA, Swanik CB, Straub, SJ. Effects of plyometric training on muscle-activation strategies and performance in female athletes. J Ath Train. 2004;39:24-31.

[5] Hutton RS, Atwater SW. Acute and chronic adaptations of muscle proprioceptors in response to increased use. Sports Med. 1992;14:406-421. https://doi.org/10.2165/00007256-199214060-00007

[6] Adams K, O'Shea JP, O'Shea KL, Climstein M. The effects of six weeks of squat, plyometrics, and squat plyometric training on power production. J App Sport Sci Res. 1992;6:36-41. https://doi.org/10.1519/00124278-199202000-00006

[7] Anderst WJ, Eksten F, Koceja, DM. Effects of plyometric and explosive resistance training on lower body power. Med Sci Sport Ex. 1994;26:S31. https://doi.org/10.1249/00005768-199405001-00177

[8] Harrison AJ, Gaffney S. Motor development and gender effects on stretch-shortening cycle performance. J Sci Med Sport. 2001;4:406-415. https://doi.org/10.1016/S1440-2440(01)80050-5

[9] Hennessy L, Kilty J. Relationship of the stretch-shortening cycle to spring performance in trained female athletes. J Strength Cond Res. 2001;15:326-331. https://doi.org/10.1519/00124278-200108000-00011

[10] Holcomb WR, Lander JE, Rutland RM, Wilson GD. A biomechanical analysis of the vertical jump and three modified plyometric depth jumps. J Strength Cond Res. 1996:10;83-88. https://doi.org/10.1519/00124278-199605000-00004

[11] Miller J, Hilbert SC, Brown LE. Speed, quickness, and agility training for senior tennis players. Strength Cond. 2001;23:62-66. https://doi.org/10.1519/00126548-200110000-00017

[12] Paasuke M, Ereline J, Gapeyeva H. Knee extensor muscle strength and vertical jumping performance characteristics in pre and postpubertal boys. Pediat Ex Sci. 2001;13:60-69. https://doi.org/10.1123/pes.13.1.60

[13] Potteiger JA, Lockwood RH, Haub MD, et al. Muscle power and fiber characteristic following 8 weeks of plyometric training. J Strength Cond Res. 1999;13:275-279. https://doi.org/10.1519/00124278-199908000-00016

[14] Whittle MW. Generation and attenuation of transient impulsive forces beneath the foot: a review. Gait Posture. 1999;10:264-275. https://doi.org/10.1016/S0966-6362(99)00041-7

[15] Waryasz GR, McDermott AY. Patellofemoral pain syndrome (PFPS): A systematic review of anatomy and potential risk factors. Dynamic Med. 2008;7:9-23. https://doi.org/10.1186/1476-5918-7-9

[16] Scopp JM, Moorman CT. The assessment of athletic hip injury. Clin Sports Med. 2001;20:647-659. https://doi.org/10.1016/S0278-5919(05)70277-5

[17] Yang J, Tibbetts AS, Covassin T, Cheng G, Nayar S, Heiden E. Epidemiology of overuse and acute injuries among competitive collegiate athletes. J Ath Train. 2012;47:198-204. https://doi.org/10.4085/1062-6050-47.2.198

[18] Miyazaki T, Wada M, Kawahara H, Sato M, Baba H, Shimada S. Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. Ann Rheum Dis. 2002; 61:617-622. https://doi.org/10.1136/ard.61.7.617

[19] Mavcic B, Iglic A, Kralj-Iglic V, Vengust R. Cumulative hip contact stress predicts osteoarthritis in DDH. Clin Orthop 2008;466:884-891. https://doi.org/10.1007/s11999-008-0145-3

[20] Sinclair J, Toth J, Hobbs SJ. The influence of energy return and minimalist footwear on the kinetics and kinematics of depth jumping in relation to conventional trainers. Kineziologija. 2015;47:11-18.

[21] Esculier JF, Dubois B, Dionne CE, Leblond J, Roy JS. A consensus definition and rating scale for minimalist shoes. J Foot Ankle Res. 2014;8:1-9. https://doi.org/10.1186/s13047-015-0094-5

[22] LaPorta JW, Brown LE, Coburn JW, et al. Effects of different footwear on vertical jump and landing parameters. J Strength Cond Res. 2013;27:733-737. https://doi.org/10.1519/JSC.0b013e318280c9ce

[23] Sinclair J, Hobbs SJ, Selfe J. The Influence of minimalist footwear on knee and ankle load during depth jumping. Res Sports Med. 2015;23:289-301. https://doi.org/10.1080/15438627.2015.1040917

[24] Cappozzo A, Catani F, Leardini A, Benedeti MG, Della CU. Position and orientation in space of bones during movement: Anatomical frame definition and determination. Clin Biomech. 1995;10:171-178. https://doi.org/10.1016/0268-0033(95)91394-T.

[25] Graydon R, Fewtrell D, Atkins S, Sinclair J. The test-retest reliability of different ankle joint center location techniques. Foot Ankle Online J. 2015;8:1-11.

[26] Sinclair, J, Hebron, J, Taylor, PJ. The test-retest reliability of knee joint center location techniques. J Applied Biomech. 2015;31:117-121. https://doi.org/10.1123/JAB.2013-0312

[27] Sinclair, J, Taylor, PJ, Currigan, G, Hobbs, SJ. The test-retest reliability of three different hip joint centre location techniques. Mov Sport Sci. 2014;83:31-39. https://doi.org/10.1051/sm/2013066

[28] Shiramizu K, Vizesi F, Bruce W, Herrmann S, Walsh WR. Tibiofemoral contact areas and pressures in six high flexion knees. Int Orthop. 2009;33:403-406. https://doi.org/10.1007/s00264-007-0478-7

[29] Zadpoor AA, Nikooyan AA. The relationship between lower-extremity stress fractures and the ground reaction force: a systematic review. Clin Biomech. 2011;26:23-28. https://doi.org/10.1016/j.clinbiomech.2010.08.005

[30] Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. Understanding and preventing ACL injuries: current biomechanical and epidemiologic considerations-update 2010. N Am J Sports Phys Ther. 2010;5: 234-251.

Cite this article as:

Sinclair J.
The effects of conventional and minimalist footwear on hip and knee joint kinetics during maximal depth jumps.
Balt J Health Phys Act. 2018;10(4): 89-96.
doi: 10.29359/BJHPA.10.4.08