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Sinclair, Jonathan Kenneth, Rooney, Elliot, Naemi, Roozbeh, Chockalingam, Nachi and Atkins, Stephen

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EFFECTS OF FOOTWEAR VARIATIONS ON THREE-DIMENSIONAL KINEMATICS AND TIBIAL ACCELERATIONS OF SPECIFIC MOVEMENTS IN AMERICAN FOOTBALL

SINCLAIR J^{*,‡}, ROONEY E^{*}, NAEMI R., ATKINS S^{*}
and CHOCKALINGAM N[†]

**Division of Sport Exercise and Nutritional Sciences
School of Sport Tourism and Outdoors
University of Central Lancashire UK*

*†Faculty of Health Sciences, Staffordshire University
College Road, Stoke-on-Trent, Staffordshire ST4 2DE, UK
‡jksinclair@uclan.ac.uk*

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AQ: Please provide
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Naemi R.

American football is associated with a high rate of non-contact chronic injuries. Players are able to select from both high and low cut footwear. The aim of the current investigation was to examine the influence of high and low cut American football specific footwear on tibial accelerations and three-dimensional (3D) kinematics during three sport specific movements. Twelve male American football players performed three movements, run, cut and vertical jump whilst wearing both low and high cut footwear. 3D kinematics of the lower extremities were measured using an eight-camera motion analysis system alongside tibial acceleration parameters which were obtained using a shank mounted accelerometer. Tibial acceleration and 3D kinematic differences between the different footwear were examined using either repeated measures or Friedman's ANOVA. Tibial accelerations were significantly greater in the low cut footwear in comparison to the high cut footwear for the run and cut movements. In addition, peak ankle eversion and tibial internal rotation parameters were shown to be significantly greater in the low cut footwear in the running and cutting movement conditions. The current study indicates that the utilization of low cut American football footwear for training/performance may place American footballers at increased risk from chronic injuries.

Keywords: American football; footwear; chronic injuries; lower extremity; biomechanics.

1. Introduction

American football is one of the world's most popular sports, particularly in North America and Canada although a strong following and professional structure now also exists in Europe. Currently, over one million high school and 70 000 college athletes take part in this sport annually in the USA.¹

[‡]Corresponding author.

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1 American football is known to be associated with a high rate of lower extremity
2 injuries when compared to other team-based sports.² Aetiological work has dem-
3 onstrated that in excess of 61% of athletes will suffer from an injury over the course
4 of one playing season.³ Although American football is recognized as a high contact
5 sport, 25–36% of all reported injuries have been demonstrated as non-contact in
6 nature.¹ Injuries to the lower extremity are the most prevalent in American football,
7 with injuries to the ankle and knee joint being the most common.^{4,5}

8 It has been recognized that one of the key mechanisms by which non-contact
9 American football injuries occur, is the interaction between the shoe and surface.⁶

10 In a number of studies, the effects of different American football surface condi-
11 tions on the biomechanical mechanisms linked to the aetiology of injury have been
12 investigated.^{7–10} However, despite being potentially important in terms of the
13 mechanisms by which lower extremity injuries are considered to occur, there is
14 currently a paucity of research concerning American football specific footwear.
15 American football footwear are specifically designed to use in a game of American
16 football footwear and feature cleated outsoles which serve the purpose of enhancing
17 traction on the synthetic surfaces that American football is typically played on.¹¹
18 American football players are able to select from both high and low cut footwear for
19 their training and performance requirements. High and low cut footwear are typi-
20 cally designed for different playing positions. Running backs and wide receivers
21 typically utilize low cut footwear, whilst tackles, guards and linebackers typically
22 select higher cut footwear.¹² Low cut footwear have a lower mass, whereas higher
23 cut footwear are heavier but provide additional support.¹² Although the effects of
24 high and low cut footwear in other sports have been investigated previously,^{13–15}
25 these effects have not been examined in American football.

26 There is a clear lack of published work investigating the effects of different
27 footwear on the parameters linked to the aetiology of injury development in
28 American footballers. Currently, both high and low cut shoes are utilized for
29 American football performance, yet there is no published information regarding the
30 3D kinematic and tibial acceleration parameters linked to the aetiology of lower
31 extremity injuries. Therefore, the aim of the current investigation was to examine
32 the influence of high and low cut American football specific footwear on the 3D
33 kinematics and tibial accelerations of three sport specific movements. An investi-
34 gation of this nature can provide players with information regarding selection of
35 appropriate footwear, which may help to attenuate the high incidence of lower
36 extremity injuries in this sport.

37 38 **2. Methods**

39 **2.1. Participants**

40
41 Twelve experienced university first team level male American football players took
42 part in the current investigation. All participants habitually wore low cut footwear
43

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1 and played at “offense” positions, which included wide receiver, running back,
2 quarter back, offensive tackle and tight end. All were free from lower extremity
3 injuries at the time of data collection and provided written informed consent. The
4 Mean (\pm Standard Deviation) anthropometric characteristics of the participants
5 were: Age = 22.47 (\pm 1.13) years, Height = 1.77 (\pm 0.08) m, Mass = 80.32 (\pm 6.33) kg.
6 Ethical approval was sought and granted by the University Ethics Committee for
7 the procedure utilized in this investigation.
8

2.2. Procedure

9
10 Participants completed five trials of three movements specific to American football;
11 run, cut and vertical jump in both footwear conditions. These movements were
12 selected based on previous recommendations as being fundamental to most sports.¹⁶
13 Participants performed their trials on a synthetic grass surface which overlaid the
14 laboratory floor. Kinematics and tibial acceleration data were collected synchro-
15 nously using an analogue to digital interface board (Qualisys Medical AB, Gote-
16 burg, Sweden). Kinematic information was obtained from the lower extremities
17 using an eight camera optoelectronic motion capture system (Qualisys Medical AB,
18 Goteburg, Sweden) using a capture frequency of 250 Hz. Dynamic calibration of the
19 camera system was performed before each data collection session. To control for any
20 order effects the order in which participants performed in each footwear and
21 movement condition was randomized. As ground reaction force information was not
22 available, the stance phase for running and cutting trials and the impact phase for
23 jumping trials were determined using kinematic information.

24 A uni-axial (Biometrics ACL 300, Cwmfelinfach, Gwent United Kingdom) ac-
25 celerometer which collected data at 1000 Hz was used to measure vertical accel-
26 erations at the tibia. The accelerometer was positioned onto a piece of carbon-fiber
27 in accordance with the protocol used by Sinclair *et al.*¹⁷ The device was mounted to
28 the antero-medial aspect of the tibia, 0.08 m above the malleolus. This location
29 served to decrease the influence that sagittal plane motion about the ankle can have
30 on the acceleration signal.¹⁸ To reduce the influence of movement artifact a strong
31 adhesive tape was placed over the device and the lower leg.

32 To quantify lower extremity joint kinematics in all three planes of rotation, the
33 calibrated anatomical systems technique¹⁹ was utilized. Retroreflective markers
34 (19 mm) were positioned unilaterally allowing the right; foot, shank and thigh to be
35 defined. The foot was defined via the first and fifth metatarsal heads, medial and
36 lateral malleoli and tracked using the calcaneus, first metatarsal and fifth meta-
37 tarsal heads.²⁰ The shank was defined via the medial and lateral malleoli and medial
38 and lateral femoral epicondyles and tracked using a cluster positioned onto the
39 shank.²¹ The thigh was defined via the medial and lateral femoral epicondyles and
40 the hip joint center and tracked using a cluster positioned onto the thigh.²¹ To
41 define the pelvis, additional markers were positioned onto the anterior (ASIS) and
42 posterior (PSIS) superior iliac spines and this segment was tracked using the same
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1 markers. The hip joint center was determined using a regression equation that uses
2 the positions of the ASIS markers.²² The centers of the ankle and knee joints were
3 delineated as the mid-point between the malleoli and femoral epicondyle mar-
4 kers.^{21,23} Each tracking cluster comprised four retroreflective markers mounted
5 onto a thin sheath of lightweight carbon-fiber with length to width ratios in ac-
6 cordance with Cappozzo *et al.*²⁴ Static calibration trials were obtained allowing for
7 the anatomical markers to be referenced in relation to the tracking markers/clus-
8 ters. The *Z*-(transverse) axis was oriented vertically from the distal segment end to
9 the proximal segment end. The *Y*-(coronal) axis was oriented in the segment from
10 posterior to anterior. Finally, the *X*-(sagittal) axis orientation was determined
11 using the right hand rule and was oriented from medial to lateral. All retroreflective
12 markers were positioned via manual palpation by the lead author.

13 Data were collected during run, cut and jump movements as follows:
14

15 **2.3. Run**

16 Participants ran at $40 \text{ m} \cdot \text{s}^{-1} \pm 5\%$, running velocity was monitored using infra-red
17 timing gates (SmartSpeed Ltd. UK). Footstrike was determined as the point at
18 which the vertical velocity of the calcaneus marker changed from negative to posi-
19 tive and toe-off was delineated using the second instance of peak knee extension.²⁵
20

21 **2.4. Cut**

22 Participants completed 45° sideways cut movements using an approach velocity of
23 $4.0 \text{ m} \cdot \text{s}^{-1} \pm 5\%$. Cut angles were defined using masking tape so that it was clearly
24 evident to participants.²⁶ Once again, footstrike was delineated as the point at
25 which the vertical velocity of the calcaneus marker changed from negative to posi-
26 tive and toe-off was delineated using the second instance of peak knee extension.²⁵
27

28 **2.5. Jump**

29 Participants completed counter movement vertical jumps in which they were re-
30 quired to use full arm swing. The impact phase of the jump movement was quan-
31 tified and was considered to have begun when the vertical velocity of the metatarsal
32 markers changed from negative to positive and ended at the point of maximum knee
33 flexion.²⁷
34

35 **2.6. Experimental footwear**

36 The footwear used during this study consisted first of a high cut shoe (Nike Lunar
37 code pro) that have a seven cleat outsole and a mass range across sizes of 387–396 g.
38 In addition, a low cut shoe (Nike Vapor pro low TD) which features a 16 cleat
39 outsole and a mass range of 285–296 g across sizes was considered. Both footwear
40 were available in sizes 8–10 UK. Each participant performed the run, cut and jump
41 movements in both footwear conditions.
42
43

2.7. Data processing

Trials were processed in Qualisys Track Manager in order to identify anatomical and tracking markers and were then exported as C3D files. Kinematic parameters were quantified using Visual 3D (C-Motion Inc, Gaithersburg, USA) after marker data were smoothed using a low-pass Butterworth fourth-order zero-lag filter at a cut off frequency of 12 Hz.¹⁶ Kinematics of the hip, knee, ankle and tibial segment were quantified. Segmental rotations were calculated using an *XYZ* cardan sequence of rotations (*X* = sagittal plane; *Y* = coronal plane and *Z* = transverse plane). All data were normalized to 100% of the stance (run and cut movements) and impact phases (jump movement) of the examined movements. 3D kinematic measures from the hip, knee, ankle and tibia that were extracted for statistical analysis were (1) angle at footstrike, (2) peak angle during stance and (3) relative range of motion (ROM) from footstrike to peak angle.

The acceleration signal was filtered using a 60 Hz Butterworth zero-lag fourth-order low pass filter to prevent any resonance effects on the acceleration signal.¹⁷ Peak tibial acceleration was defined as the highest positive acceleration peak measured during each movement. Jump height during the vertical jump trials was also quantified using the technique adopted by Read and Cisar,²⁸ via the vertical rise of the iliac crest marker. The vertical height rise of the iliac crest was determined as the difference between iliac crest during the standing static trial and the height attained at the peak of the flight phase.

2.8. Statistical analysis

Descriptive statistics (means and standard deviations) were obtained for each footwear and movement condition. Shapiro–Wilk tests were used to screen the data for normality. Depending on whether the data exhibited a normal distribution, footwear mediated differences in 3D kinematic and tibial acceleration parameters from each movement were examined using either repeated measures or Friedman’s ANOVA. Statistical significance was accepted at the $p < 0.05$ level.²⁹ Effect sizes were calculated using partial Eta² ($p\eta^2$). All statistical actions were conducted using SPSS v22.0 (SPSS Inc, Chicago, USA).

3. Results

3.1. Run

Tables 1 and 2 present the discrete 3D kinematic information obtained during running as a function of footwear. Figures 1 and 2 show the 3D kinematic curves during the stance phase as a function of footwear.

3.1.1. Tibial accelerations

Peak tibial accelerations were significantly ($F_{(11)} = 12.59$, $p < 0.05$, $p\eta^2 = 0.53$) lower in the high (6.81 ± 2.51 g) compared to the low cut footwear (9.73 ± 3.33 g).

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Table 1. Hip, knee and ankle joint kinematics (means \pm standard deviation) during running.

	Hip						Knee						Ankle						
	High		Low		SD		High		Low		SD		High		Low		SD		
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	
<i>Sagittal plane</i>																			
X (+ = flexion/ - = extension)																			
Angle at Footstrike (°)	51.68	16.64	57.98	16.72	19.05	14.21	20.61	8.81	5.06	5.19	7.49	3.79							
Peak Range of Motion (°)	0.21	0.35	0.29	0.12	26.73	7.94	25.28	4.41	21.87	5.88	20.01	2.24							
Peak Flexion (°)	51.89	16.43	58.11	16.72	45.78	8.11	45.89	5.34	26.93	7.34	27.50	3.64							
<i>Coronal plane</i>																			
Y (+ = adduction/inversion - = abduction/eversion)																			
Angle at Footstrike (°)	-0.12	5.41	-0.41	3.99	2.72	5.11	7.51	5.25	-6.88	4.37	-8.12	5.07							
Peak Range of Motion (°)	5.04	3.86	6.40	3.05	7.82	3.80	11.89	3.93	6.84	3.97	8.02	3.66							
Peak Angle (°)	4.92	5.13	6.14	3.98	-5.14	6.41	-4.40	4.70	-13.65	4.22	-16.08	5.66							
<i>Transverse plane</i>																			
Z (+ = internal/- = external)																			
Angle at Footstrike (°)	0.29	11.04	9.88	15.94	-3.73	9.91	-11.89	8.43	-9.16	6.75	-15.93	5.80							
Peak Range of Motion (°)	11.35	4.25	16.98	5.21	11.98	5.81	16.41	5.48	7.26	2.92	7.43	2.85							
Peak Internal Rotation (°)	-11.03	14.73	-7.24	9.55	8.11	8.73	4.51	7.99	-1.86	6.19	-7.40	3.78							

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Table 2. Tibial internal rotation (means \pm standard deviation) during running.

	Tibia			
	High		Low	
	Mean	SD	Mean	SD
Transverse plane				
Z_i (+ = internal/ - = external)				
Angle at Footstrike ($^\circ$)	8.04	5.45	10.35	5.78
Peak Range of Motion ($^\circ$)	7.35	3.65	6.70	2.44
Peak Internal Rotation ($^\circ$)	13.39	5.77	16.54	5.66

3.1.2. 3D Kinematics

Peak eversion was shown to be significantly ($F_{(11)} = 11.22, p < 0.05, \eta^2 = 0.48$) larger in the low cut compared to the high top footwear. In addition, peak tibial internal rotation was significantly ($X^2_{(1)} = 10.65, p < 0.05, \eta^2 = 0.42$) greater in

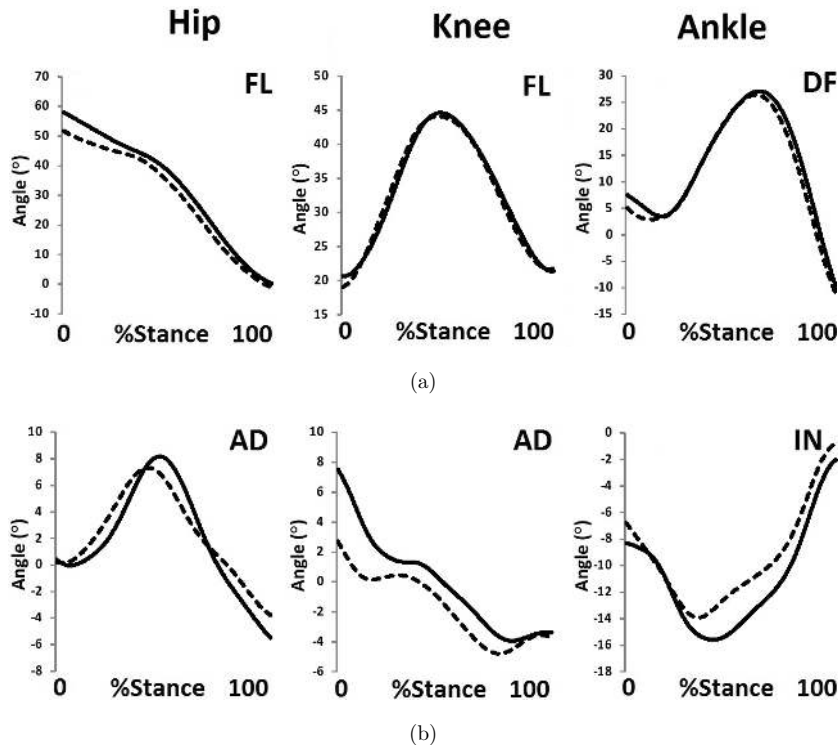
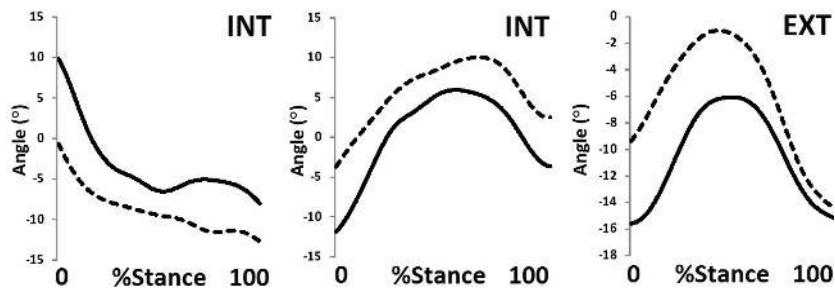


Fig. 1. Hip, knee and ankle joint angles measured during running in the (a) sagittal, (b) coronal and (c) transverse planes (black = low, dash = high) (FL = flexion, DF = dorsiflexion, AD = adduction, IN = inversion, INT = internal, EXT = external).

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(c)

Fig. 1. (Continued)

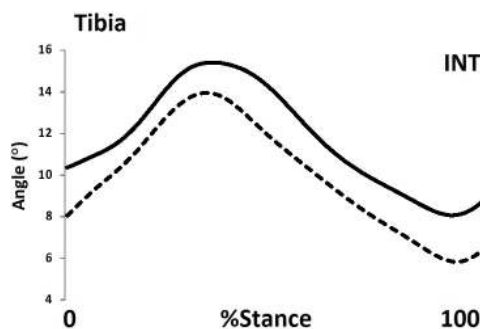


Fig. 2. Tibial internal rotation measured during running (black = low, dash = high) (INT = internal).

the low compared to the high top footwear. Peak ankle external rotation was shown to be significantly ($F_{(11)} = 9.88, p < 0.05, p\eta^2 = 0.40$) greater in the high top footwear compared to the low cut condition (Figs. 1 and 2 and Tables 1 and 2).

3.2. Cut

Table 3 presents the discrete 3D kinematic information obtained during the cut movement as a function of footwear. Figure 3 shows the 3D kinematic curves during the stance phase as a function of footwear.

3.2.1. Tibial accelerations

Peak tibial accelerations were significantly ($X^2_{(1)} = 24.88, p < 0.05, p\eta^2 = 0.69$) lower in the high (8.32 ± 2.14 g) compared to the low cut footwear (12.49 ± 2.89 g).

3.2.2. 3D Kinematics

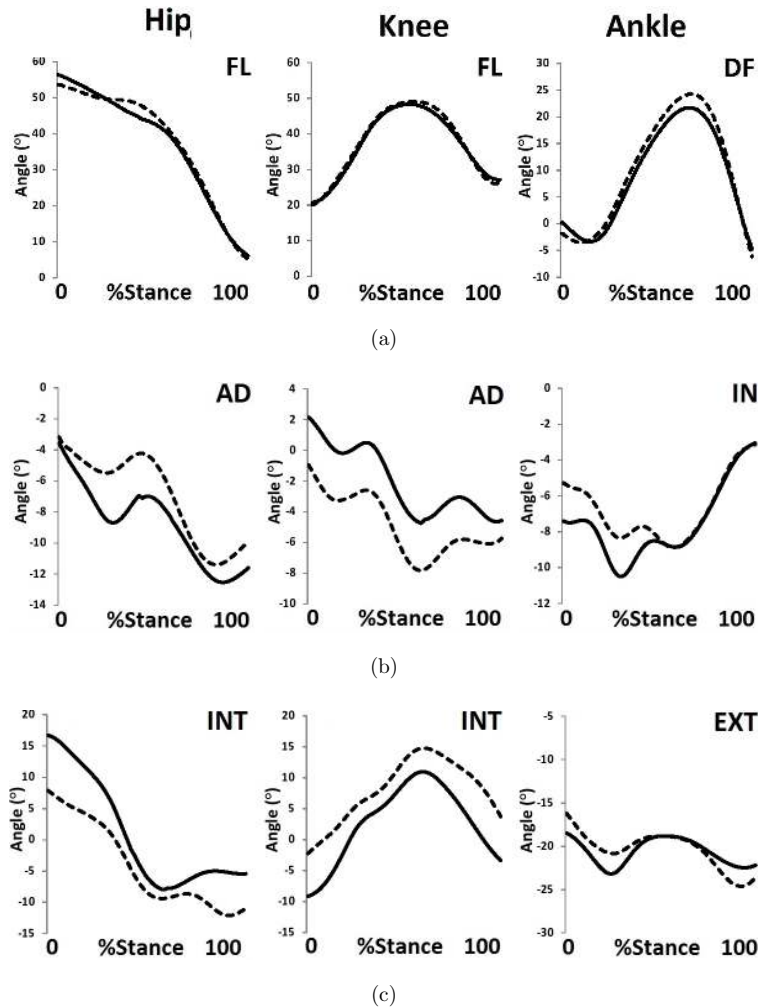
Peak eversion was shown to be significantly ($F_{(11)} = 9.45, p < 0.05, p\eta^2 = 0.39$) larger in the low compared to the high top footwear (Fig. 3 and Table 3).

Effects of Footwear Variations on 3D Kinematics and Tibial Accelerations

Table 3. Hip, knee and ankle joint kinematics (means \pm standard deviation) during the cut movement.

	Hip						Knee						Ankle					
	High		Low		SD		High		Low		SD		High		Low		SD	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<i>Sagittal plane</i>																		
<i>X (+ = flexion/ - = extension)</i>																		
Angle at Footstrike (°)	53.36	12.27	56.43	11.31	20.28	7.89	20.72	6.28	-1.66	6.05	0.28	3.77						
Peak Range of Motion (°)	2.22	1.74	0.37	0.69	30.81	8.25	29.22	9.28	26.37	3.73	22.66	3.12						
Peak Flexion (°)	54.83	11.94	56.80	11.04	51.09	8.50	49.94	6.79	24.71	5.75	22.95	4.08						
<i>Coronal plane</i>																		
<i>Y (+ = adduction/inversion - = abduction/eversion)</i>																		
Angle at Footstrike (°)	-3.66	6.46	-3.55	8.41	-0.79	4.37	2.15	2.89	-5.16	3.52	-7.83	3.97						
Peak Range of Motion (°)	15.08	2.97	15.42	2.68	6.80	3.13	6.60	2.71	3.56	2.84	3.89	2.69						
Peak Angle (°)	11.55	6.06	12.08	6.92	-7.60	4.48	-4.55	4.20	-8.68	3.77	-11.76	4.93						
<i>Transverse plane</i>																		
<i>Z (+ = internal/ - = external)</i>																		
Angle at Footstrike (°)	7.51	12.48	16.75	16.01	-1.07	8.60	-9.19	7.43	-15.86	5.36	-18.18	5.45						
Peak Range of Motion (°)	2.97	3.57	0.74	0.92	14.57	5.56	18.77	5.39	2.78	2.33	6.03	3.39						
Peak Internal Rotation (°)	-11.87	7.90	-8.49	7.43	13.51	8.71	9.86	8.11	-24.25	5.27	-22.86	4.03						

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31 Fig. 3. Hip, knee and ankle joint angles measured during the cut movement in the (a) sagittal, (b)
32 coronal and (c) transverse planes (black = low, dash = high) (FL = flexion, DF = dorsiflexion, AD =
33 adduction, IN = inversion, INT = internal, EXT = external).

34 3.3. Vertical jump

35 Table 4 presents the discrete 3D kinematic information obtained during the jump
36 movement as a function of footwear. Figure 4 shows the 3D kinematic curves during
37 the impact phase as a function of footwear.
38

39 3.3.1. Tibial accelerations and jump height

40
41 No significant differences ($p > 0.05$) were found between the two footwear for
42 tibial accelerations (high = 10.45 ± 3.28 g and low = 11.92 ± 3.31 g) or jump height
43 (high = 0.32 ± 0.04 m and low = 0.32 ± 0.04 m).

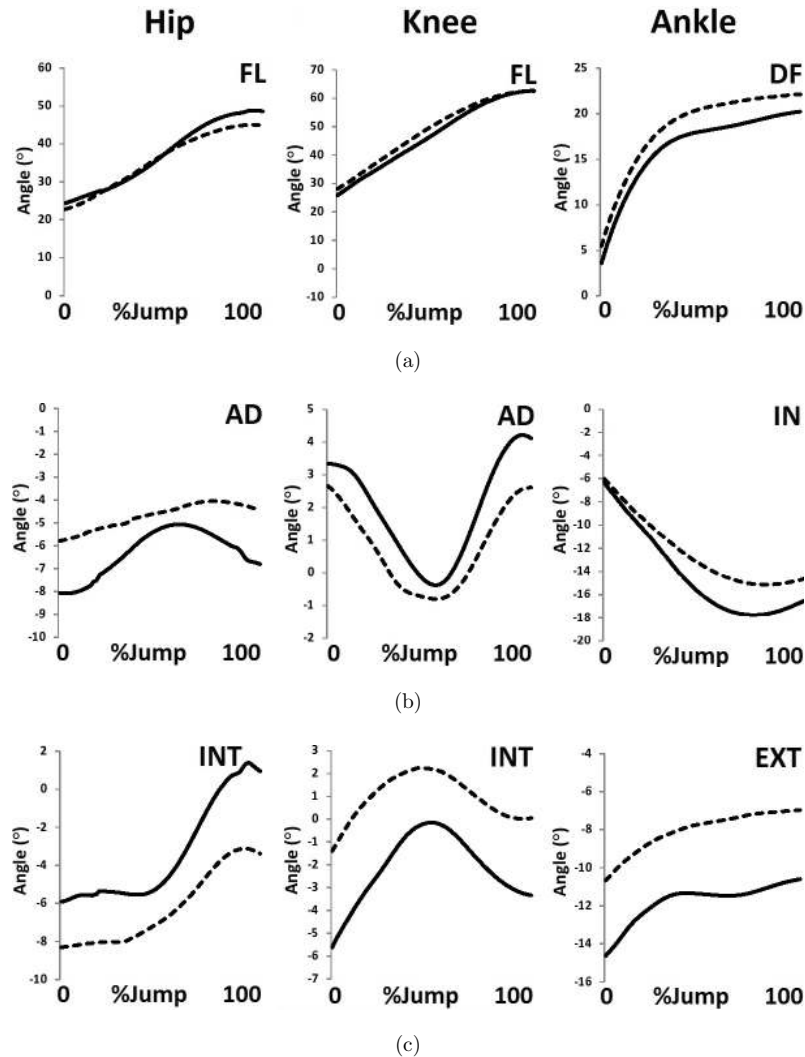
Effects of Footwear Variations on 3D Kinematics and Tibial Accelerations

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Table 4. Hip, knee and ankle joint kinematics (means \pm standard deviation) during the jump movement.

	Hip						Knee						Ankle																										
	High		Low				High		Low				High		Low																								
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD																					
<i>Sagittal plane</i>																																							
<i>X (+ = flexion/ - = extension)</i>																																							
Angle at Footstrike (°)	23.15	13.17	24.34	10.79	28.02	8.22	25.88	8.11	5.40	9.16	3.57	10.85	26.13	6.27	24.84	9.04	35.22	11.29	36.81	10.09	18.08	8.46	17.70	10.95	47.02	15.07	49.17	17.33	63.24	12.67	62.70	13.63	23.18	5.17	21.27	4.74			
Peak Range of Motion (°)																																							
Peak Flexion (°)																																							
<i>Coronal plane</i>																																							
<i>Y (+ = adduction/inversion - = abduction/eversion)</i>																																							
Angle at Footstrike (°)	-5.90	5.85	-8.06	4.40	2.75	2.65	3.34	4.72	-6.12	3.45	-6.35	3.19	1.23	2.29	2.33	2.92	3.46	2.18	3.58	2.28	8.11	2.16	11.08	2.68	-4.56	5.47	-5.86	5.58	-0.68	4.72	-0.23	4.71	-14.24	6.74	-17.60	6.19			
Peak Range of Motion (°)																																							
Peak Angle (°)																																							
<i>Transverse plane</i>																																							
<i>Z (+ = internal/ - = external)</i>																																							
Angle at Footstrike (°)	-7.87	9.83	-5.91	8.63	-1.82	11.04	-5.62	8.80	-10.28	6.46	-14.09	6.02	7.41	2.87	1.84	2.02	3.88	3.65	4.76	3.77	3.41	2.64	4.74	2.85	0.59	9.57	-4.02	8.78	2.10	9.24	-0.85	8.77	-7.78	5.90	-10.78	5.07			
Peak Range of Motion (°)																																							
Peak Internal Rotation (°)																																							

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33 Fig. 4. Hip, knee and ankle joint angles measured during the vertical jump in the (a) sagittal, (b)
34 coronal and (c) transverse planes (black = low, dash = high) (FL = flexion, DF = dorsiflexion, AD =
35 adduction, IN = inversion, INT = internal, EXT = external).

36 3.3.2. 3D Kinematics

37 No significant differences ($p > 0.05$) were found between footwear (Fig. 4 and
38 Table 4).

40 4. Discussion

41 This study aimed to examine the influence of high and low cut American football
42 specific footwear on the 3D kinematics and tibial accelerations of three sport specific
43

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1 movements. This represents the first comparative analysis of high and low cut
2 footwear on the 3D kinematics and tibial accelerations of American football specific
3 movements.

4 The important finding from the current investigation is that the low cut footwear
5 were associated with significant increases in tibial accelerations for both the running
6 and cutting movements. Given the positive association between the magnitude of
7 transient accelerations and the development of degenerative chronic pathologies,³⁰
8 this observation may have clinical relevance for the pathogenesis of impact related
9 injuries. Therefore, based on the analysis of tibial accelerations it appears that the
10 low cut footwear may place American footballers at an increased risk from injuries
11 related to excessive impacts.³⁰ It is proposed that this finding relates to the addi-
12 tional cleats that are typically associated with low cut American football footwear
13 which serve to stiffen the midsole in these footwear. Greater stiffness leads to an
14 increase in the rate at which foot decelerates upon landing, increasing the magni-
15 tude of the impact transient associated with footstrike.³⁰

16 A further important finding from this study is that the low cut footwear were
17 associated with significantly larger peak ankle joint eversion and tibial internal
18 rotation parameters in relation to the high top footwear during the running and
19 cutting movements. This observation may have further relevance clinically as
20 increases in eversion/tibial internal rotation have been associated with the aetiology
21 of a number of chronic pathologies.^{31,32} This also suggests that when performing
22 running and cutting movements' American football players who wear low cut
23 footwear are more susceptible to chronic injuries relating to excessive motions of the
24 ankle and tibia in the coronal and transverse planes. It is proposed that this finding
25 may be caused by the high cut nature of these footwear which provide a much more
26 pronounced medial support mechanism when contrasted against the low cut foot-
27 wear. This observation is in agreement with the findings in relation to tibial ac-
28 celeration in that low cut footwear may facilitate an increase in chronic injury
29 aetiology related to excessive ankle eversion and tibial internal rotation parameters.

30 The current investigation also confirms that there were no differences between
31 high and low cut footwear for the vertical jump. This concurs with the findings of
32 Sinclair *et al.*¹⁶ who also showed no kinematic differences between footwear when
33 examining this movement. It is proposed that this observation related to the fact
34 that vertical jumping is a more explosive movement than either running or cut-
35 ting,³³ thus the perceptual effects of the footwear on lower extremity movement are
36 vastly reduced. During running and cutting, the body receives feedback from
37 mechanoreceptors concerning the movement, allowing kinematic adaptations to be
38 made in response to external factors such as footwear.³⁴ During singular explosive
39 movements like the vertical jump there is no opportunity for kinematic alterations
40 to be mediated by the external environment, thus there were no footwear effects for
41 this motion.

42 A limitation to the current investigation is that it utilized an all-male sample.
43 Although American football is played predominantly by males, both amateur and

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1 professional female participation has expanded considerably in recent years.²⁵
2 Females are known to be associated with distinct loading mechanics and lower body
3 kinematics in comparison to age matched males and thus it is unlikely that the
4 findings from the current investigation can be generalized to females.^{36,37} It is
5 recommended that the current investigation to be repeated using a female sample in
6 order to determine appropriate footwear characteristics for female American foot-
7 ball players.

8 A further potential drawback of the current study is that the running and cutting
9 movements were not performed at velocities that are representative of American
10 football performance.³⁸ Therefore, differences between the different footwear at
11 game specific velocities were not extrapolated from this investigation. This was
12 necessary due to the laboratory-based nature of the current work. Nonetheless,
13 future biomechanical research may wish to examine the mechanics of running and
14 cutting at velocities more replicable of American football performance in order to
15 improve ecological validity.

16 In conclusion, the current investigation adds to the current knowledge in the area
17 of American football biomechanics by providing a comprehensive evaluation of the
18 3D kinematics and tibial accelerations of movement in high and low cut footwear
19 during three sport specific movements. The significant increases in both impact
20 loading and rearfoot eversion for the running and cutting movements in the low cut
21 footwear indicates this type of shoe may place American footballers at an increased
22 risk from the mechanisms linked to the development of chronic injuries. The current
23 study concludes that it may be prudent for American footballers to utilize high cut
24 footwear for their training/performance needs.

25 26 References

- 27 1. Wannop JW, Luo G, Stefanyshyn DJ, Footwear traction and lower extremity non-
28 contact injury, *Med Sci Sports Exerc* **45**:2137–2143, 2013.
- 29 2. Fernandez WG, Yard EE, Comstock RD, Epidemiology of lower extremity injuries
30 among U.S. high school athletes, *Acad Med* **14**:641–645, 2007.
- 31 3. Nelson AJ, Collins CL, Yard EE, Fields SK, Comstock RD, Ankle injuries among
32 United States high school sports athletes, 2005–2006, *J Athl Train* **42**:381–387, 2007.
- 33 4. Fong DTP, Hong Y, Chan L-K, Yung PS, Chan KM, A systematic review on ankle
34 injury and ankle sprain in sports, *Sports Med* **37**:73–94, 2007.
- 35 5. Turbeville SD, Cowan LD, Owen WL, Asal NR, Anderson MA, Risk factors for injury in
36 high school football players, *Am J Sports Med* **31**:974–980, 2003.
- 37 6. Iacovelli JN, Yang J, Thomas G, Wu H, Schiltz T, Foster DT, The effect of field
38 condition and shoe type on lower extremity injuries in American Football, *Br J Sports
39 Med* **47**:789–793, 2013.
- 40 7. Ekstrand J, Timpka T, Hagglund M, Risk of injury in elite football played on artificial
41 turf versus natural grass: A prospective two-cohort study, *Br J Sports Med* **40**:975–980,
42 2006.
- 43 8. Meyers MC, Incidence, mechanisms, and severity of game-related college football in-
44 juries on Field-Turf versus natural grass: A 3 year prospective study, *Am J Sports Med*
45 **38**:687–697, 2010.

Effects of Footwear Variations on 3D Kinematics and Tibial Accelerations

- 1 9. Hershman EB, Anderson R, Bergfeld JA, Bradley JP, Coughlin MJ, Johnson RJ,
2 Tucker A, An analysis of specific lower extremity injury rates on grass and Field Turf
3 playing surfaces in National Football League Games: 2000–2009 Seasons, *Am J Sports*
4 *Med* **40**:2200–2205, 2012.
- 5 10. Dragoo JL, Braun HJ, Harris AHS, The effect of playing surface on the incidence of ACL
6 injuries in National Collegiate Athletic Association American Football, *Knee* **20**:191–
7 195, 2013.
- 8 11. Lambson RB, Barnhill BS, Higgins RW, Football cleat design and its effect on anterior
9 cruciate ligament injuries a three-year prospective study, *Am J Sports Med* **24**:155–159,
10 1996.
- 11 12. Faganel PP, Drake TC, Dahl-Miller AR, Senchina DS, Height variation in football shoes
12 (cleats) for running backs and receivers may not alter ankle sparring effects in football
13 field drills, *J Undergrad Res* **4**:6–10, 2013.
- 14 13. Ricard MD, Schulties SS, Saret JJ, Effects of high-top and low-top shoes on ankle
15 inversion, *J Athl Train* **35**:38–43, 2000.
- 16 14. Barrett JR, Tanji JL, Drake C, Fuller D, Kawasaki RI, Fenton RM, High versus low-top
17 shoes for the prevention of ankle sprains in basketball players. A prospective randomized
18 study, *Am J Sports Med* **21**:582–585, 1992.
- 19 15. Fu W, Fang Y, Liu Y, Hou J, The effect of high-top and low-top shoes on ankle inversion
20 kinematics and muscle activation in landing on a tilted surface, *J Foot Ankle Res* **7**:14–
21 24, 2014.
- 22 16. Sinclair J, Chockalingam N, Naemi R, Vincent H, The effects of sport-specific and
23 minimalist footwear on the kinetics and kinematics of three netball-specific movements,
24 *Footwear Sci* **7**:31–36, 2015.
- 25 17. Sinclair J, Bottoms L, Taylor K, Greenhalgh A, Tibial shock measured during the
26 fencing lunge: The influence of footwear, *Sports Biomech* **9**:65–71, 2010.
- 27 18. Lafortune MA, Hennig EM, Contribution of angular motion and gravity to tibial ac-
28 celeration, *Med Sci Sports Exerc* **23**:360–363, 1991.
- 29 19. Cappozzo A, Catani F, Leardini A, Benedetti MG, Della CU, Position and orientation in
30 space of bones during movement: Anatomical frame definition and determination, *Clin*
31 *Biomech* **10**:171–178, 1995.
- 32 20. Sinclair J, Taylor PJ, Edmundson CJ, Brooks D, Hobbs SJ, Influence of the helical and
33 six available Cardan sequences on 3D ankle joint kinematic parameters, *Sp Biomech*
34 **11**:430–437, 2013.
- 35 21. Sinclair J, Hebron J, Taylor PJ, The test-retest reliability of knee joint center location
36 techniques, *J App Biomech* **31**:117–121, 2015.
- 37 22. Sinclair J, Taylor PJ, Currigan G, Hobbs SJ, The test-retest reliability of three different
38 hip joint center location techniques, *Movement Sport Sci* **83**:31–39, 2014.
- 39 23. Graydon R, Fewtrell D, Atkins S, Sinclair J, The test-retest reliability of different ankle
40 joint center location techniques, FAOJ (In press).
- 41 24. Cappozzo A, Cappello A, Croce UD, Pensalfini F, Surface-marker cluster design criteria
42 for 3-D bone movement reconstruction, *IEEE Trans Biomed Eng* **44**:1165–1174, 1997.
- 43 25. Sinclair J, Hobbs SJ, Edmundson CJ, Brooks D, Evaluation of kinematic methods of
identifying foot strike and toe-off during running, *Int J Sp Sci Eng* **5**:188–192, 2011.
26. McLean SG, Huang X, Su A, Van Den Bogert AJ, Sagittal plane biomechanics cannot
injure the ACL during sidestep cutting, *Clin Biomech* **19**:828–838, 2004.
27. Flanagan EP, Ebben W, Jensen RL, Reliability of the reactive strength index and time
to stabilization during depth jumps, *J Strength Condit Res* **22**:1677–1682, 2008.
28. Read MM, Cisar C, The influence of varied rest interval lengths on drop jump perfor-
mance, *J Strength Condit Res* **15**:279–283, 2001.

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Ref. 23.

J. Sinclair et al.

- 1 29. Sinclair J, Taylor PJ, Hobbs SJ, Alpha level adjustments for multiple dependent vari-
2 able analyses and their applicability – A review, *Int J Sport Sci Eng* **7**:17–20, 2013.
- 3 30. Whittle MW, The generation and attenuation of transient forces beneath the foot; a
4 review, *Gait Posture* **10**:264–275, 1999.
- 5 31. Taunton JE, Clement DB, McNicol K, Plantar fasciitis in runners, *Can J Appl Sport Sci*
6 **7**:41–44, 1982.
- 7 32. Eslami M, Begon M, Farahpour N, Allard P, Forefoot rearfoot coupling patterns and
8 tibial internal rotation during stance phase of barefoot versus shod running, *Clin Bio-
9 mech* **22**:74–80, 2007.
- 10 33. Markovic G, Does plyometric training improve vertical jump height? A meta-analytical
11 review, *Br J Sports Med* **41**:349–355, 2007.
- 12 34. Pearson KG, Proprioceptive regulation of locomotion, *Curr Opin Neurobiol* **5**:786–791,
13 1995.
- 14 35. Ezechieli M, Berger S, Siebert CH, Miltner O, Injury rates of the German Women’s
15 American Football National Team from 2009 to 2011, *Orthop Rev* **4**:124–127, 2012.
- 16 36. Ferber R, McClay DI, Williams III DS, Gender differences in lower extremity mechanics
17 during running, *Clin Biomech* **18**:350–357, 2003.
- 18 37. Sinclair J, Greenhalgh A, Edmundson CJ, Brooks D, Hobbs SJ, Gender differences in
19 the kinetics and kinematics of distance running: Implications for footwear design, *Int J
20 Sp Sci Eng* **6**:118–128, 2012.
- 21 38. Black W, Roundy E, Comparisons of size, strength, speed and power in NCAA division
22 I-A football players, *J Strength Condit Res* **8**:80–85, 1994.

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