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Influence of Sport Surface Properties on Utilized Traction and Lower Extremity Biomechanics of American Football Players

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Featured Application

This study provides insight into how variations in artificial turf properties influence the traction athletes can utilize and their lower extremity biomechanics. The findings can inform evidence-based decisions about surface selection to optimize performance and reduce injury risk for different player positions in American football.

Abstract

The purpose of this study was to investigate the athlete biomechanical differences across three artificial turfs associated with changes in athletic performance. Eighteen university grid-iron football players performed three modified football specific movements (agility drill, vcut, three-cone drill) on three artificial turf surfaces (Control, Shockpad and Low Faceweight) that have been shown to alter athletic performance. The utilized traction and player kinematics were recorded and compared between the surfaces using a repeated-measures ANOVA within participant factors of surface and between participants' factors of player position. The significant effect of the surface on utilized traction at takeoff, and the frontal plane ankle angle was present with the players utilizing a lower traction and peak frontal plane ankle angle on the low-traction surface (Low Faceweight). During the agility drill and vcut, the significant effect of the surface was seen for peak frontal plane rearfoot–floor angle, with players having a flatter foot on high-traction surfaces (Control and Shockpad). Across tasks, high-traction surfaces were associated with flatter foot orientations and increased frontal plane ankle and foot kinematics during the cutting movements.

Keywords: artificial turf; footwear; performance; cleat

Academic Editors: Roger Narayan, Andrea Fusco and Barbara Gilic

Received: 11 November 2025
Revised: 2 February 2026
Accepted: 26 February 2026
Published: 2 March 2026

1. Introduction

Artificial turf surfaces have become commonplace on sporting fields at the high school, university, and professional levels, with nearly half of the gameday fields in the National Football League (NFL) being composed of artificial surfaces. Over the past decade, several advancements have been made to artificial sport surfaces, including improvements to elements of the infill material, the underlying shockpad, and the turf fibers [1–6]. Due to the ability to alter the individual components of the artificial turf surfaces, the artificial turf holds a distinct advantage over natural grass, as manipulation of the individual components of the surface can alter specific properties of the surface [7–12].

Many studies have investigated the association of artificial surfaces and injury risk, mechanically or epidemiologically [11,13,14]; however, limited data is available on how changes in artificial turf can alter performance. While there are many studies investigating performance differences between artificial turf and natural grass [15–20], these studies fail to provide specific attributes and mechanical properties of the surfaces tested. Specifically, these performance-based studies did not examine the underlying biomechanical mechanisms, which the present study seeks to address. Two recent studies have investigated if changes in the mechanical properties of artificial turf surface can alter performance. A study by Wannop et al. (2020) [12] indicated that changes in the stiffness of the surface, through alterations in the infill composition or the addition of an underlying shockpad, can alter running and cutting performance.

From a biomechanical perspective, the traction at the shoe–surface interface is imperative for the athletes to transmit forces to the ground. During cutting and change-in-direction tasks, athletes must generate large horizontal forces, which leads to increases in the joint loads of the frontal and transverse planes. If traction is not sufficient, athletes may alter their movement patterns to avoid slippage, while if traction is high, athletes may increase their force transmission, which may increase the non-sagittal plane joint moments. This relationship highlights a potential performance–injury tradeoff, with surfaces that enable increased performance (due to greater traction) altering the lower extremity joint loading patterns associated with potential injury. Despite this theoretical linkage, limited experimental work has quantified how variations in artificial turf properties influence utilized traction and lower extremity biomechanics during football-specific cutting movements.

While these previous studies have shown that changes in sport surface components can alter athlete performance, insight into how these changes in performance manifest in the athletes is missing, with the present study focusing on the biomechanical mechanisms underlying these performance changes as opposed to prior work which quantified performance and perceptual responses to surface properties. Therefore, the purpose of this study was to investigate the biomechanical differences on artificial turf associated with changes in athletic agility performance. It was hypothesized that higher-traction surfaces will increase utilized translational and rotational traction, which would be associated with altered frontal and transverse plane foot and ankle kinematics/kinetics. The Methods, Results and Discussion sections describe the experimental approach, findings and biomechanical implications of the study.

2. Materials and Methods

2.1. Participants

Eighteen university grid-iron football players participated in this study. Participants were eligible for inclusion if they were current university/collegiate grid-iron football players and free from lower-extremity injury at the time of testing. Due to issues in data collection on two players, their data were removed from data analysis, with sixteen players remaining in the study (mean ± SD, height = 1.87 ± 0.08 m, mass = 102.6 ± 22 kg, age = 21.3 ± 2 yrs). The remaining sixteen players were classified into two different categories: (i) speed players (n = 9, height = 1.84 ± 0.09 m, mass = 87.9 ± 11 kg, age = 22.2 ± 2 yrs), which consisted of running backs, wide receivers, quarterbacks, defensive backs, and linebackers and (ii) power players (n = 7, height = 1.92 ± 0.05 m, mass = 121.5 ± 17 kg, age = 19.6 ± 2 yrs), which consisted of offensive and defensive linemen. Athletes were grouped based on their primary positional demands, as speed-type players typically have more frequent changes in direction, whereas power-type players would typically have more linear movements with lower movement velocities. While this classification simplifies positional demands, it was intended to reflect broad differences in movement profiles. Positional grouping was expected to influence the utilized traction and lower extremity biomechanics [21]. All participants were provided with a properly fitting Nike Vapor Edge Speed 360 cleat to perform the study (Figure 1). To minimize footwear-related variability, a single cleat model was used for all participants, which may limit generalization to other footwear designs. This specific cleat was selected as it was used in a previous study, allowing for direct comparisons.

Figure 1. Photograph of the Nike Vapor Edge Speed 360 cleat model used during testing.

2.2. Surfaces

Three artificial turf surfaces were used in the experiment and were constructed by the manufacturer (FieldTurf) in large wooden trays indoors over the lab floor. The surfaces used a sand and styrene–butadiene rubber (SBR) infill mixture. The surfaces consisted of the following: (i) Control, a commonly installed surface for sporting activities, (ii) Low FW, a surface that had identical infill composition to the Control but reduced carpet density, and (iii) Shockpad, the identical Control surface with an additional underlying shockpad. The surfaces were selected based on the performance results from a previous study, with the Low FW surface reducing agility performance, while the Shockpad had the trend of improving agility performance. The surfaces were constructed at the same time and by the same installers as the previous study at which point mechanical testing of the surface samples was performed. The specifics of the surface constructions are shown in Table 1.

Table 1. Properties of the artificial turf surfaces.

#	Property	Carpet Type	Fiber Gauge	Carpet Density	Shockpad	Bottom Layer	Mix	Top Layer	Translational Traction	Rotational Traction [Nm]	Outdoor Peak Deceleration
1	Control	FTHD-1	3/4 inch	36 oz/sq yard		1.0 lbs/sqft sand	5.2 lbs/sqft sand, 2.6 lbs/sqft cryo 14–30	0.4 lbs/sqft cryo 10–14	1.94 ± 0.06	46.8 ± 1.8	64 ± 7
2	Shockpad	FTHD-1	3/4 inch	36 oz/sq yard	ThermaGreen (23 mm)	1.0 lbs/sqft sand	5.2 lbs/sqft sand, 2.6 lbs/sqft cryo 14–30	0.4 lbs/sqft cryo 10–14	2.07 ± 0.07	44.9 ± 1.1	51 ± 6
3	Low FW	Low face weight	3/4 inch	18 oz/sq yard		1.0 lbs/sqft sand	5.2 lbs/sqft sand, 2.6 lbs/sqft cryo 14–30	0.4 lbs/sqft cryo 10–14	1.62 ± 0.11	40.9 ± 1.8	58 ± 9

Mechanical traction measurements were performed using an automated footwear traction-testing machine. This machine consisted of a six-degree of freedom P2000 servo-driven parallel link robotic testing machine (Mikrolar Inc., Hampton, VA, USA) utilizing a movable platform stationed under a rigid steel frame. Each turf surface was rigidly attached to the movable platform of the robotic testing machine and a right prosthetic foot, which was used to simulate a physiological foot, was fitted with the size 10 sample shoe (the same shoe that was used during biomechanical testing). The shoe and foot were attached to the frame of the robotic testing machine at 20° of plantarflexion in series with a triaxial load cell (AMTI, model MC5, Waterton, MT, USA) and used to measure the forces and moments in all three orthogonal directions during testing. Rotational traction testing was performed by raising the platform to apply a 650 N normal load to the shoe, after which the platform was internally rotated 20° at a speed of 75°/s. Translational traction testing was performed by raising the platform to apply a 650 N normal load, after which the platform was translated to simulate the movement of acceleration during running. Force and moment data were recorded by the load cell at 1000 Hz throughout the duration of the test. A total of five trials were performed at different locations on each surface condition.

Stiffness measurements on all surfaces were conducted following laboratory construction using a Clegg Impact Hammer drop test. A standard 2.25 kg Clegg hammer was vertically dropped on the surface samples in accordance with established turf testing procedures and the peak deceleration value was recorded to characterize the surface stiffness across conditions.

2.3. Data Collection

All participants performed three American football-specific movements on each of the different surfaces. Participants were instructed to perform all drills at maximal effort (game-like intensity). Prior to data collection, athletes completed several familiarization trials to minimize learning effects, while the order of the surface conditions and drills was randomized across participants to reduce potential order effects. The selected drills were chosen to represent key movements commonly performed by grid-iron football players including rapid acceleration, deceleration and change-in-direction tasks. These drills were as follows:

1. Agility drill—the initial turn of the 5-10-5 drill from the previous study was performed in the lab with the change in direction occurring on the force platform. Specifically, the player ran five yards (4.57 m), planted and turned on the force platform and returned five yards to the starting position as quickly as possible.
2. vcut—each participant performed a 90° cut, with the change in direction occurring on the force platform. Participants planted their right foot on the force platform and cut to their left-hand side.
3. Three-cone cut—like the Vcut, participants performed a 90° cut with the change in direction occurring on the force platform. Participants planted their right foot on the force platform and cut to their right hand-side. This cut is representative of the initial turn of the three-cone drill that was performed in the previous study.

For all movements, retro-reflective markers were placed over the entire body and shoes of the participant. The right-foot marker set consisted of a modified Oxford foot model with markers placed on the shoe at the following locations: superior calcaneal tuberosity, medial process of the calcaneal tuberosity, lateral process of the calcaneal tuberosity, subtalar shelf of the medial hindfoot, lateral calcaneus of the lateral hindfoot, medial aspect of the proximal first metatarsal, midway along the midline of the first metatarsal, on the distal first metatarsal, on the proximal fifth metatarsal, on the medial hallux, on the superior aspect of the distal second phalange, and on the superior aspect of the distal fourth metatarsal. Markers were also placed on the trunk (C7 vertebrae, T10 vertebra, on the right scapula, on the jugular notch of the clavicle and on the xiphoid process of the sternum), pelvis (left and right posterior superior iliac spine, left and right anterior superior iliac spine), the right thigh (two marker placed on the line between the lateral knee and the trochanter, marker placed on the anterior side of the thigh), and shank (tibial tuberosity, proximal head of the fibula, midway between the knee and ankle on the anterior tibia, on the line between the lateral ankle and lateral knee on the lateral aspect of the shank); a marker was also placed to define the knee joint center (lateral tibial plateau, medial tibial plateau) and ankle joint center (lateral malleolus, medial malleolus), while the forefoot segment was defined with the markers placed on the first and fifth metatarsals. All markers were placed by the same experienced researcher following a standardized placement protocol. Potential marker placement error is acknowledged as a limitation inherent to optical motion capture methods.

Prior to dynamic data collection, a standing neutral trial was performed using the video system to determine the 3D coordinates of lower extremity joint centers. The participants were asked to stand feet–hip width apart, with the knee and hip fully extended. The trajectories of the markers were recorded using a fifteen-camera high-speed motion capture system operating at 240 Hz (Vicon). During each movement, 3D force data were collected using multiple force platforms at 2400 Hz (Kistler AG, Winterthur, Switzerland) mounted in the center of a lab runway floor. The motion capture system and force platforms were calibrated according to the manufacturer's recommended procedures. Kinematic and kinetic data were temporally synchronized through the data acquisition system, allowing direct time alignment between motion capture and force platform signals for analysis. Long trays of each surface were laid along the path of motion, while smaller trays of each surface, isolated and independent from the longer lab runway trays, were bolted directly to the surface of the force plate. Athletes performed five trials of each movement on each surface.

For analysis, kinematic and kinetic data of the right lower extremity, pelvis and trunk were analyzed using Visual3D software (v2020.07.2, C-Motion). Kinematic and kinetic data were both filtered with a low-pass fourth-order Butterworth filter with a cut-off frequency of 25 Hz. A cut-off frequency of 25 Hz was selected based on prior cutting and change-in-direction biomechanics studies, which have demonstrated that this frequency preserves movement-related signal content while attenuating high-frequency noise associated with marker motion impact transients. The same filtering parameters were applied consistently to kinematic and kinetic data to avoid the introduction of artificial phase shifts or inconsistencies between signals used in inverse dynamics calculations. Kinematic and kinetic data were time-aligned through hardware synchronization of the motion capture and force plate systems. Data was normalized to the stance phase from touchdown to toe-off (0–100%). Joint centers of the metatarsophalangeal, ankle, knee, and hip joint were defined, and resultant joint moments were calculated using an inverse dynamics approach.

Outcome variables were selected based on established biomechanical relevance to cutting performance and lower extremity joint loading, informed by the prior literature. The main variables of interest were the ground reaction forces, utilized traction, lower extremity joint angles and peak internal resultant joint moments of the ankle and knee.

2.4. Statistics

Statistical comparisons of all players during each drill were made using a repeated-measures ANOVA with three within participant factors of surface (Control, Low FW, Shockpad) and a between participant factor of position (Speed, Power) at a level of significance of $\alpha = 0.10$, with effect sizes also being reported as partial eta squared (ηp^2). An alpha level of 0.10 was selected to reduce the risk of overlooking potential meaningful effects, with effect sizes provided alongside p-values to aid in the interpretation of the findings. No a priori power analysis was conducted as participant recruitment was constrained by the availability of the defined cohort of colligate athletes. Prior to inferential analysis, data distributions were assessed for normality using the Shapiro–Wilk test. Sphericity for repeated-measures factors was evaluated using Mauchly's test and where violations were detected, Greenhouse Geisser corrections were applied. All statistical analysis was performed using SPSS (Version 27, IBM Corp., Armonk, NY, USA).

3. Results

3.1. Agility Drill

The results of the agility drill are shown in Table 2. During the agility drill, the surface had an effect on the utilized traction at touchdown (F = 5.632, $p = 0.01$) and takeoff (F = 3.656, $p = 0.058$), and in terms of the peak utilized rotational traction (F = 12.763, $p < 0.001$). At midstance, there was an effect of position (F = 15.456, $p = 0.002$) and an interaction of surface and position (F = 3.364, $p = 0.052$). A significant effect of position was present for both the vertical (F = 10.701, $p = 0.006$) and horizontal ground reaction force (F = 3.645, $p = 0.077$). Kinematic differences were observed based on both surface and position with a significant effect of surface (F = 4.876, $p = 0.047$) present for peak forefoot eversion angle and minimum forefoot eversion angle (F = 14.734, $p < 0.001$), and effects of surface (F = 3.423, $p = 0.049$) and position (F = 6.094, $p = 0.03$) present for peak forefoot eversion angular velocity. Foot torsion also had significant effects of surface (F = 4.984, $p = 0.015$) and position (F = 7.453, $p = 0.018$). At the ankle joint, an effect of surface was present for peak ankle inversion angle (F = 8.498, $p = 0.002$), peak ankle eversion moment (F = 4.175, $p = 0.028$) and peak ankle transverse plane moments (F = 6.512, $p = 0.002$). Lastly, at the knee joint, an effect of surface was present for the peak sagittal plane moment (F = 3.419, $p = 0.049$) and transverse plane moments (F = 2.576, $p = 0.097$).

Table 2. Kinematic and kinetic data during the agility drill. Data represent the mean of all players on each of the different surfaces (influence of surface) and the mean of speed and power players on all surfaces (influence of position).

		Influence of Surface				Influence of Position		
		Control	**Low FW**	**Shockpad**	***p*-Value, ηp^2**	**Speed**	**Power**	***p*-Value, ηp^2**
Traction	Utilized Translational Traction at Touchdown	0.49 ± 0.19	0.41 ± 0.15	0.50 ± 0.19	**0.010, 0.32**	0.44 ± 0.17	0.50 ± 0.16	0.377, 0.07
	Utilized Translational Traction at Midstance	0.75 ± 0.11	0.76 ± 0.09	0.75 ± 0.10	0.476, 0.06	0.82 ± 0.04	0.68 ± 0.08	**0.002, 0.56**
	Utilized Translational Traction at Takeoff	1.65 ± 0.30	1.45 ± 0.43	1.56 ± 0.34	**0.058, 0.38**	1.61 ± 0.13	1.49 ± 0.39	0.379, 0.06
	Utilized Rotational Traction [Nm]	36.1 ± 13.0	24.7 ± 9.5	35.5 ± 10.6	**<0.001, 0.52**	30.5 ± 12.4	34.2 ± 5.8	0.629, 0.02
Ground Reaction Force	Peak Horizontal Ground Reaction Force [N]	1959 ± 398	1913 ± 399	1804 ± 436	0.445, 0.06	1766 ± 265	2053 ± 331	**0.077, 0.21**
	Peak Vertical Ground Reaction Force [N]	2287 ± 563	2227 ± 482	2136 ± 515	0.211, 0.11	1943 ± 270	2569 ± 433	**0.006, 0.433**
	Stance Time [s]	0.419 ± 0.092	0.418 ± 0.069	0.422 ± 0.073	0.965, <0.01	0.404 ± 0.056	0.439 ± 0.081	0.362, 0.60
Rearfoot	Minimum Rearfoot Eversion Angle [deg]	17.2 ± 8.5	21.3 ± 8.0	13.9 ± 7.7	**<0.001, 0.60**	19.1 ± 7.1	15.5 ± 10.1	0.539, 0.03
	Peak Rearfoot Inversion Velocity [deg/s]	702 ± 223	634 ± 212	737 ± 250	0.152, 0.15	658 ± 123	731 ± 304	0.570, 0.03
Forefoot	Minimum Forefoot Eversion Angle	3.4 ± 6.9	10.3 ± 9.3	1.3 ± 6.2	**<0.001, 0.55**	4.3 ± 7.3	5.7 ± 6.2	0.507, 0.04
	Peak Forefoot Inversion Velocity [deg/s]	834 ± 208	721 ± 227	840 ± 179	**0.049, 0.22**	870 ± 164	715 ± 176	**0.030, 0.34**
MTP	Peak MTP Extension Angle [deg]	7.0 ± 3.2	5.7 ± 2.3	6.5 ± 3.8	0.140, 0.15	7.0 ± 2.4	5.7 ± 3.4	0.233, 0.12
	Peak MTP Torsion Angle [deg]	17.7 ± 5.4	14.6 ± 5.4	16.8 ± 4.7	**0.015, 0.29**	18.8 ± 3.9	13.5 ± 4.6	**0.018, 0.38**
Ankle	Peak Ankle Inversion Angle [deg]	27.8 ± 9.3	24.1 ± 9.2	30.0 ± 9.2	**0.002, 0.42**	26.5 ± 9.9	28.3 ± 9.5	0.851, <0.01
	Peak Angle Inversion Angular Velocity [deg/s]	691 ± 258	642 ± 248	734 ± 292	0.117, 0.16	648 ± 173	738 ± 334	0.540, 0.03
	Peak Ankle Dorsiflexion Angle [deg]	19.1 ± 9.7	18.8 ± 10.5	17.9 ± 10.4	0.453, 0.06	23.4 ± 7.7	12.8 ± 7.2	**0.031, 0.33**
	Peak Ankle Dorsiflexion Angular Velocity [deg/s]	789 ± 255	700 ± 227	706 ± 225	0.207, 0.123	846 ± 174	598 ± 240	**0.032, 0.33**
	Peak Ankle Plantarflexion Moment [Nm]	217 ± 62	213 ± 49	229 ± 61	0.359, 0.08	214 ± 72	226 ± 51	0.952, <0.01
	Peak Ankle Eversion Moment [Nm]	131 ± 68	100 ± 57	141 ± 49	**0.028, 0.26**	111 ± 31	141 ± 88	0.325, 0.08
	Peak Ankle External Rotation Moment [Nm]	27 ± 13	23 ± 12	33 ± 15	**0.038, 0.24**	26 ± 8	30 ± 18	0.566, 0.03

Table 2. *Cont.*

		Influence of Surface				Influence of Position		
		Control	Low FW	Shockpad	p-Value, ηp^2	Speed	Power	p-Value, ηp^2
Knee	Peak Knee Abduction Angle [deg]	8.1 ± 5.1	7.8 ± 4.1	7.8 ± 3.0	0.826, 0.02	7.5 ± 5.7	8.5 ± 4.3	0.374, 0.07
	Peak Knee Abduction Angular Velocity [deg/s]	356 ± 111	369 ± 144	334 ± 141	0.159, 0.14	367 ± 117	337 ± 111	0.670, 0.02
	Peak Knee Flexion Angle [deg]	58.9 ± 7.0	59.7 ± 6.0	58.8 ± 6.8	0.895, 0.01	59.8 ± 4.8	58.4 ± 8.9	0.677, 0.02
	Peak Knee Flexion Angular Velocity [deg/s]	675 ± 118	695 ± 91	628 ± 71	**0.018, 0.29**	661 ± 70	673 ± 133	0.663, 0.02
	Peak Knee Extension Moment [Nm]	314 ± 69	321 ± 66	302 ± 82	**0.049, 0.22**	285 ± 71	345 ± 64	0.232, 0.12
	Peak Knee Adduction Moment [Nm]	154 ± 47	158 ± 60	142 ± 46	0.166, 0.14	139 ± 45	166 ± 49	0.454, 0.05
	Peak Knee Internal Rotation Moment [Nm]	38 ± 17	35 ± 20	45 ± 24	**0.097, 0.18**	33 ± 14	47 ± 18	0.239, 0.11
Hip	Peak Hip Abduction Angle [deg]	29.0 ± 3.8	29.9 ± 3.8	29.0 ± 5.2	0.651, 0.04	29.5 ± 2.9	29.1 ± 4.8	0.474, 0.04
	Peak Hip Abduction Angular Velocity [deg/s]	225 ± 68	220 ± 64	250 ± 85	**0.042, 0.23**	235 ± 77	227 ± 62	0.680, 0.02
	Peak Hip Flexion Angle [deg]	30.9 ± 12.8	31.3 ± 15.4	32.9 ± 13.7	0.199, 0.13	31.5 ± 13.9	31.9 ± 12.1	0.963, <0.01
	Peak Hip Flexion Angular Velocity [deg/s]	294 ± 93	293 ± 110	265 ± 90	0.366, 0.08	260 ± 83	313 ± 87	0.299, 0.09
	Center of Mass Velocity at Touchdown [m/s]	2.3	2.2	2.2	0.314, 0.09	2.3	2.1	**0.035, 0.32**

Statistical significance was evaluated at $p < 0.10$. Values meeting this criterion are shown in bold.

3.2. Vcut

The results of the vcut are shown in Table 3. During the vcut, a significant effect of surface was seen for the utilized traction at takeoff (F = 3.155, p = 0.061) and for the peak utilized rotational traction (F = 2.615, p = 0.094), while a significant effect of position was seen for utilized translational traction at touchdown (F = 5.242, p = 0.038) and midstance (F = 4.883, p = 0.047). A surface effect was present for the peak vertical ground reaction force (F = 2.607, p = 0.092). Foot angles were influenced by the surface, specifically the minimum rearfoot eversion (F = 13.760, p < 0.001), minimum forefoot eversion (F = 28.345, p < 0.001) and peak MTP torsion (F = 5.768, p = 0.001) angles. At the ankle joint, a significant effect of surface was present for the peak ankle inversion angle (F = 3.775, p = 0.001) and inversion angular velocity (F = 3.689, p = 0.040), the peak ankle dorsiflexion angular velocity (F = 3.228, p = 0.057), and the peak ankle eversion (F = 3.695, p = 0.040) and external rotation moment (F = 3.038, p = 0.067). An influence of position was present for the ankle dorsiflexion angular velocity (F = 3.860, p = 0.073). At the knee joint, a significant effect of surface was present for the peak knee abduction angle (F = 3.455, p = 0.048) and angular velocity (F = 2.906, p = 0.074), while an effect of position was present for the peak knee extension moment (F = 4.129, p = 0.065). At the hip, no significant effects of surface or position were present.

Table 3. Kinematic and kinetic data during the vcut drill. Data represent the mean of all players on each of the different surfaces (influence of surface) and the mean of speed and power players on all surfaces (influence of position).

		Influence of Surface				Influence of Position		
		Control	Low FW	Shockpad	p-Value, ηp^2	Speed	Power	p-Value, ηp^2
Traction	Utilized Translational Traction at Touchdown	0.62 ± 0.12	0.59 ± 0.11	0.58 ± 0.10	0.169, 0.12	0.64 ± 0.09	0.54 ± 0.09	**0.038, 0.27**
	Utilized Translational Traction at Midstance	0.64 ± 0.08	0.63 ± 0.07	0.65 ± 0.06	0.416, 0.07	0.67 ± 0.06	0.60 ± 0.07	**0.047, 0.29**
	Utilized Translational Traction at Takeoff	1.56 ± 0.39	1.34 ± 0.27	1.61 ± 0.37	**0.061, 0.21**	1.54 ± 0.22	1.46 ± 0.28	0.526, 0.03
	Utilized Rotational Traction [Nm]	26.1 ± 14.6	19.5 ± 7.1	19.2 ± 6.8	**0.094, 0.18**	21.7 ± 9.7	21.5 ± 3.7	0.952, <0.01
Ground Reaction Force	Peak Horizontal Ground Reaction Force [N]	2202 ± 883	2171 ± 509	2125 ± 493	0.909, 0.01	2275 ± 674	2026 ± 397	0.402, 0.05
	Peak Vertical Ground Reaction Force [N]	3247 ± 764	3204 ± 709	3033 ± 730	**0.092, 0.16**	3092 ± 794	3251 ± 610	0.668, 0.01
	Stance Time [s]	0.342 ± 0.057	0.338 ± 0.053	0.347 ± 0.059	0.555, 0.04	0.329 ± 0.046	0.359 ± 0.058	0.260, 0.09
Rearfoot	Minimum Rearfoot Eversion Angle [deg]	14.4 ± 5.6	16.6 ± 6.1	11.8 ± 8.2	**<0.001, 0.53**	15.2 ± 6.0	13.2 ± 6.7	0.782, 0.01
	Peak Rearfoot Eversion Velocity [deg/s]	901 ± 412	886 ± 405	982 ± 437	0.105, 0.17	1001 ± 431	834 ± 303	0.450, 0.05

Table 3. *Cont.*

		Influence of Surface				Influence of Position		
		Control	**Low FW**	**Shockpad**	***p*-Value, η*p*²**	**Speed**	**Power**	***p*-Value, η*p*²**
Forefoot	Minimum Forefoot Eversion Angle	3.9 ± 4.5	8.6 ± 6.5	1.2 ± 5.3	**<0.001, 0.70**	4.7 ± 5.6	4.4 ± 4.4	0.931, <0.01
	Peak Forefoot Eversion Velocity [deg/s]	983 ± 377	1003 ± 391	1030 ± 399	0.458, 0.06	1070 ± 434	931 ± 243	0.507, 0.04
MTP	Peak MTP Extension Angle [deg]	11.9 ± 5.1	11.0 ± 4.0	13.1 ± 5.6	0.169, 0.14	12.1 ± 4.7	11.8 ± 4.0	0.763, 0.01
	Peak MTP Torsion Angle [deg]	16.0 ± 4.0	13.9 ± 3.8	17.2 ± 4.1	**0.001, 0.46**	16.2 ± 3.2	15.1 ± 4.0	0.649, 0.02
Ankle	Peak Ankle Inversion Angle [deg]	21.8 ± 7.5	18.2 ± 6.8	23.9 ± 8.1	**0.001, 0.42**	21.4 ± 7.4	21.1 ± 6.7	0.778, 0.01
	Peak Ankle Inversion Angular Velocity [deg/s]	717 ± 311	670 ± 174	869 ± 234	**0.040, 0.24**	827 ± 254	667 ± 109	0.104, 0.21
	Peak Ankle Dorsiflexion Angle [deg]	15.7 ± 6.4	16.1 ± 4.8	16.2 ± 7.4	0.771, 0.02	16.6 ± 4.4	15.3 ± 6.5	0.667, 0.02
	Peak Ankle Dorsiflexion Angular Velocity [deg/s]	626 ± 193	563 ± 188	593 ± 222	**0.057, 0.21**	670 ± 188	507 ± 150	**0.073, 0.24**
	Peak Ankle Plantarflexion Moment [Nm]	251 ± 63	264 ± 65	250 ± 73	0.205, 0.11	236 ± 62	276 ± 66	0.394, 0.06
	Peak Ankle Eversion Moment [Nm]	115 ± 58	95 ± 36	141 ± 31	**0.040, 0.24**	113 ± 29	121 ± 35	0.850, <0.01
	Peak Ankle External Rotation Moment [Nm]	40 ± 22	35 ± 19	49 ± 12	**0.067, 0.20**	43 ± 16	40 ± 14	0.661, 0.02
Knee	Peak Knee Abduction Angle [deg]	6.9 ± 4.8	7.1 ± 5.6	8.4 ± 4.3	**0.048, 0.22**	6.2 ± 5.9	8.9 ± 3.7	0.115, 0.19
	Peak Knee Adduction Angular Velocity [deg/s]	365 ± 124	343 ± 95	406 ± 140	**0.074, 0.20**	387 ± 123	353 ± 100	0.440, 0.05
	Peak Knee Flexion Angle [deg]	55.1 ± 6.6	55.2 ± 7.2	56.6 ± 7.8	0.281, 0.10	56.7 ± 6.6	54.4 ± 7.1	0.582, 0.03
	Peak Knee Flexion Angular Velocity [deg/s]	401 ± 95	405 ± 103	419 ± 83	0.519, 0.05	454 ± 87	356 ± 56	**0.045, 0.29**
	Peak Knee Extension Moment [Nm]	374 ± 68	353 ± 91	366 ± 67	0.366, 0.08	330 ± 70	403 ± 72	**0.065, 0.26**
	Peak Knee Adduction Moment [Nm]	149 ± 62	154 ± 84	141 ± 75	0.623, 0.04	136 ± 58	161 ± 77	0.567, 0.03
	Peak Knee Internal Rotation Moment [Nm]	63 ± 32	59 ± 33	66 ± 29	0.558, 0.05	54 ± 24	74 ± 33	0.242, 0.11
Hip	Peak Hip Abduction Angle [deg]	25.7 ± 6.1	26.2 ± 6.5	25.2 ± 6.2	0.924, 0.01	26.8 ± 5.7	24.4 ± 5.9	0.522, 0.04
	Peak Hip Abduction Angular Velocity [deg/s]	316 ± 138	300 ± 143	304 ± 119	0.616, 0.04	336 ± 143	273 ± 107	0.321, 0.08
	Peak Hip Flexion Angle [deg]	38.2 ± 10.8	38.1 ± 13.0	38.0 ± 11.9	0.215, 0.12	39.6 ± 13.4	36.3 ± 9.6	0.520, 0.04
	Peak Hip Extension Angular Velocity [deg/s]	383 ± 115	363 ± 103	365 ± 72	0.517, 0.05	403 ± 115	332 ± 38	0.135, 0.18
	Center of Mass Velocity at Touchdown [m/s]	3.1 ± 0.4	3.1 ± 0.4	3.1 ± 0.4	0.762, 0.02	3.4 ± 0.3	2.8 ± 0.4	**0.005, 0.49**

Statistical significance was evaluated at $p < 0.10$. Values meeting this criterion are shown in bold.

3.3. Cone Drill

The results of the cone drill are shown in Table 4. During the cone drill, a significant effect of surface was seen for the utilized traction at touchdown (F = 2.725, $p = 0.083$) and takeoff (F = 6.322, $p = 0.005$), with a significant effect of position at midstance (F = 7.811, $p = 0.014$). There were no significant effects for the ground reaction force, except for an effect of position on stance time (F = 4.36, $p = 0.056$). Minimal differences were present for foot–floor angles, with a significant effect of position being present for the peak rearfoot–floor eversion angular velocity (F = 5.693, $p = 0.034$) and the forefoot–floor eversion angular velocity (F = 5.59, $p = 0.033$). At the ankle joint, an effect of surface was present for the peak ankle eversion angle (F = 5.443, $p = 0.011$), peak plantarflexion moment (F = 6.39, $p = 0.005$), peak inversion moment (F = 3.813, $p = 0.034$) and peak external rotation moment (F = 5.098, $p = 0.013$), while a significant effect of position was present for the peak ankle eversion angle (F = 3.62, $p = 0.081$), eversion angular velocity (F = 5.449, $p = 0.038$) and peak plantarflexion moment (F = 5.492, $p = 0.034$). At the knee joint, a significant effect of surface was present for the peak knee internal rotation moment (F = 3.174, $p = 0.057$), while at the hip, a significant effect of surface was present for the peak hip adduction angle (F = 5.452, $p = 0.010$), adduction angular velocity (F = 3.190, $p = 0.056$), hip flexion angle (F = 2.839, $p = 0.075$) and hip extension angular velocity (F = 3.180, $p = 0.057$).

Table 4. Kinematic and kinetic data during the cone drill. Data represent the mean of all players on each of the different surfaces (influence of surface) and the mean of speed and power players on all surfaces (influence of position).

		Influence of Surface				Influence of Position		
		Control	**Low FW**	**Shockpad**	***p*-Value, ηp^2**	**Speed**	**Power**	***p*-Value, ηp^2**
Traction	Utilized Translational Traction at Touchdown	0.58 ± 0.26	0.41 ± 0.19	0.52 ± 0.28	**0.083, 0.16**	0.54 ± 0.19	0.45 ± 0.18	0.358, 0.07
	Utilized Translational Traction at Midstance	0.59 ± 0.09	0.60 ± 0.09	0.60 ± 0.08	0.472, 0.05	0.64 ± 0.05	0.54 ± 0.09	**0.014, 0.36**
	Utilized Translational Traction at Takeoff	1.53 ± 0.43	1.23 ± 0.24	1.34 ± 0.39	**0.005, 0.31**	1.47 ± 0.26	1.23 ± 0.34	0.130, 0.16
	Utilized Rotational Traction [Nm]	22.7 ± 6.8	22.1 ± 5.8	23.9 ± 8.5	0.196, 0.11	23.4 ± 7.0	22.2 ± 6.2	0.708, 0.01
Ground Reaction Force	Peak Horizontal Ground Reaction Force [N]	1221 ± 189	1195 ± 210	1232 ± 237	0.731, 0.02	1227 ± 182	1201 ± 185	0.781, 0.01
	Peak Vertical Ground Reaction Force [N]	1918 ± 287	1883 ± 326	1915 ± 328	0.693, 0.03	1839 ± 291	1991 ± 266	0.299, 0.08
	Stance Time [s]	0.331 ± 0.056	0.318 ± 0.067	0.336 ± 0.059	0.194, 0.11	0.304 ± 0.053	0.359 ± 0.050	**0.056, 0.24**
Rearfoot	Minimum Rearfoot Inversion Angle [deg]	8.6 ± 9.0	9.2 ± 9.6	7.4 ± 6.1	0.262, 0.11	9.3 ± 6.5	7.4 ± 8.7	0.876, 0.02
	Peak Rearfoot Eversion Velocity [deg/s]	758 ± 381	774 ± 388	822 ± 358	0.298, 0.10	948 ± 402	598 ± 179	**0.034, 0.32**
Forefoot	Maximum Forefoot Eversion Angle	2.9 ± 7.7	2.0 ± 7.3	3.4 ± 5.8	0.516, 0.05	2.0 ± 5.8	3.6 ± 4.6	0.644, 0.02
	Peak Forefoot Eversion Velocity [deg/s]	903 ± 397	841 ± 353	940 ± 409	0.447, 0.06	1052 ± 390	693 ± 135	**0.033, 0.29**
MTP	Peak MTP Extension Angle [deg]	24.4 ± 9.3	25.4 ± 8.8	23.9 ± 9.1	0.221, 0.12	23.8 ± 10.7	25.4 ± 6.8	0.624, 0.02
	Peak MTP Torsion Angle [deg]	18.8 ± 3.8	18.7 ± 3.3	18.7 ± 3.2	0.941, 0.01	19.6 ± 3.5	17.7 ± 2.9	0.248, 0.11
Ankle	Peak Ankle Eversion Angle [deg]	28.2 ± 5.5	27.1 ± 5.9	29.5 ± 4.6	**0.011, 0.31**	30.2 ± 5.4	26.0 ± 3.9	**0.081, 0.23**
	Peak Ankle Eversion Angular Velocity [deg/s]	918 ± 430	1014 ± 466	1051 ± 360	0.184, 0.13	1171 ± 419	792 ± 231	**0.038, 0.31**
	Peak Ankle Dorsiflexion Angle [deg]	26.0 ± 4.7	25.0 ± 5.4	23.7 ± 6.6	**0.045, 0.23**	23.8 ± 4.0	26.1 ± 4.8	0.234, 0.12
	Peak Ankle Dorsiflexion Angular Velocity [deg/s]	456 ± 137	432 ± 155	438 ± 175	0.850, 0.01	454 ± 142	428 ± 141	0.863, <0.01
	Peak Ankle Plantarflexion Moment [Nm]	259 ± 69	260 ± 73	233 ± 81	**0.005, 0.31**	218 ± 53	292 ± 67	**0.034, 0.28**
	Peak Ankle Inversion Moment [Nm]	125 ± 62	111 ± 56	126 ± 50	**0.034, 0.21**	113 ± 36	131 ± 71	0.545, 0.03
	Peak Ankle External Rotation Moment [Nm]	38 ± 22	40 ± 20	30 ± 19	**0.013, 0.27**	37 ± 28	34 ± 11	0.761, 0.01
Knee	Peak Knee Adduction Angle [deg]	8.8 ± 5.0	8.6 ± 5.5	7.9 ± 4.7	0.331, 0.08	10.4 ± 5.1	5.9 ± 3.2	**0.059, 0.23**
	Peak Knee Adduction Angular Velocity [deg/s]	334 ± 154	360 ± 141	336 ± 112	0.412, 0.06	374 ± 162	304 ± 60	0.295, 0.08
	Peak Knee Flexion Angle [deg]	48.9 ± 7.5	47.4 ± 8.2	49.2 ± 10.5	0.353, 0.07	51.0 ± 8.5	45.2 ± 7.6	0.179, 0.13
	Peak Knee Flexion Angular Velocity [deg/s]	501 ± 163	473 ± 140	501 ± 200	0.797, 0.02	550 ± 166	417 ± 43	**0.061, 0.023**
	Peak Knee Extension Moment [Nm]	264 ± 49	251 ± 42	260 ± 58	0.481, 0.05	248 ± 41	271 ± 46	0.299, 0.08
	Peak Knee Abduction Moment [Nm]	144 ± 62	148 ± 50	137 ± 53	0.526, 0.05	147 ± 62	137 ± 37	0.701, 0.01
	Peak Knee Internal Rotation Moment [Nm]	66 ± 21	56 ± 20	58 ± 18	**0.057, 0.19**	61 ± 19	59 ± 17	0.814, <0.01
Hip	Peak Hip Adduction Angle [deg]	14.1 ± 5.3	13.2 ± 4.0	12.4 ± 3.7	**0.010, 0.28**	12.3 ± 4.3	14.5 ± 4.0	0.310, 0.07
	Peak Hip Adduction Angular Velocity [deg/s]	292 ± 94	253 ± 74	247 ± 78	**0.056, 0.19**	282 ± 48	241 ± 91	0.267, 0.09
	Peak Hip Flexion Angle [deg]	43.3 ± 10.6	42.0 ± 9.7	40.9 ± 11.1	**0.075, 0.17**	42.8 ± 10.8	41.0 ± 10.3	0.741, 0.01
	Peak Hip Extension Angular Velocity [deg/s]	371 ± 100	375 ± 116	348 ± 100	**0.057, 0.19**	396 ± 87	324 ± 113	0.170, 0.13
	Center of Mass Velocity at Touchdown [m/s]	3.0	3.1	3.1	0.515, 0.05	3.2	2.8	**0.009, 0.40**

Statistical significance was evaluated at $p < 0.10$. Values meeting this criterion are shown in bold.

4. Discussion

As the development of artificial turf continues through advancements in fibers, infill and underlying shock pad materials, improving the mechanistic understanding of how these factors influence athlete performance and lower-extremity biomechanics is imperative. The goal of this study was to quantify changes in biomechanical variables associated with changes in performance, with the study indicating that changes in the utilized traction as well as kinematic and kinetic deviations occur based on the specific surface properties. Although joint moments and loading patterns are frequently examined in relation to injury mechanisms, the present study was biomechanical in nature and did not assess injury incidence. Accordingly, all injury-related discussion is framed in terms of biomechanical-loading relevance rather than injury risk. The findings of study suggest that differences in artificial turf properties influence how forces are generated and transmitted during football-specific cutting movements. In particular, variations in surface traction appear to be associated with changes in lower-extremity kinematics and joint loading across the different tasks. The following sections discuss these findings in the context of cutting biomechanics and prior surface-related research.

4.1. Surface Effect

During all three performance drills, the sport surface had a direct effect on the kinematics and kinetics of the athletes. The amount of utilized traction varied across the different phases of stance with the amount of traction that the athletes could utilize between different surfaces being especially apparent during the late (push-off) stages of stance. On the low face weight surface, athletes had a lower utilized traction, which is expected to contribute to their decreased performance, while on surfaces that provided higher available traction (Control, Shockpad), participants had greater utilized traction and no detriment to their performance. Previous work has shown that lower utilized traction is directly associated with reduced athletic performance where an available traction of 0.8 was needed to maximize curved sprinting performance [22]. From the current study, similar results were attained, and a mechanically available traction coefficient greater than 1.6 at push-off is required to maximize athletic cutting performance in football players.

Changes in athlete movement patterns were also present, specifically at the foot and ankle joint. During the vcut and agility drill on the low-traction surface (Low FW), the athletes' foot was in a more everted position during the change in direction. This result was interesting and unexpected, as it might be anticipated that on a surface with lower traction, participants would place their foot in a flatter orientation to engage more of the footwear traction elements. However, that did not occur, and a flatter foot orientation was attained by athletes on the high-traction surfaces (Control, Shockpad). One possible interpretation of this finding is that the observed foot orientation was not a conscious decision by the participants, but rather a response to the higher-traction surface, with the medial edge of the shoe initially engaging the high-traction surface at touchdown, resulting in rapid inversion of the foot. In contrast, at initial touchdown on the low-traction surface, greater cleat penetration caused by the more freely movable infill occurs. One possible interpretation is that greater cleat penetration on the lower-traction surface may allow infill material to accumulate under the lateral edge of the cleat, thereby reducing the rate of inversion; however, this mechanism was not directly measured in the present study. This speculation is partially supported by the greater foot inversion velocities seen on the high-traction surfaces (Control, Shockpad), which occurred at touchdown; however, further investigation is required to determine the exact cause of the differences in foot orientations.

Flatter foot orientation on the high-traction surfaces, during the agility and vcut drills, required increased foot torsion and ankle inversion to maintain similar upper body orientation. Previous studies have shown foot and ankle kinematics to be altered with changes in surface [23], with an increase in the frontal plane ankle angle associated with high-traction surfaces [11]. One possible interpretation of this finding is that a flatter foot orientation combined with increased ankle inversion may influence how joint moments are distributed across planes during cutting movements. While no significant changes in the peak sagittal plane ankle moment occurred, on average, the ankle moment was decreased by ~5% during the vcut on the high-traction surface. This reduction may reflect changes in sagittal plane ankle joint moment demands rather than a reduction in force-producing capability. Concurrent increases in frontal plane ankle moments observed during the vcut and agility drills on the high-traction surfaces suggest altered joint loading patterns across planes.

A similar result was seen during the cone drill in terms of ankle joint kinematics and kinetics. While there were no differences in foot orientations, an increase in the peak ankle eversion angle did occur on the high-traction surfaces (Control, Shockpad). This change in ankle orientation was accompanied by a reduction in the peak ankle plantarflexion moment on the high-traction surface (Shockpad) and a corresponding increase in the peak ankle frontal plane moment.

At the knee joint, kinetic changes were movement-dependent, with an increase in the peak transverse and sagittal plane moments on the high-traction surfaces occurring during the agility and cone drill, with no change during the vcut. Previous studies have highlighted an increase in both ankle and knee joint loading on surfaces with increased rotational traction [11,24,25]. Peak joint moments are commonly used as biomechanical indicators of joint loading [26–30] and have been associated with loading mechanisms in prior injury biomechanical research studies. However, the present study did not assess injury outcomes. As such, these findings should be interpreted as differences in biomechanical loading patterns rather than direct indicators of injury. However, those previous studies did not quantify or measure athlete performance. It would be assumed that a corresponding increase in ankle and knee joint moments would be associated with an increase in athlete performance. It is unclear from those previous studies as to what the changes in performance of the participants were. From the current and associated study, athletic performance increased on the high-traction surfaces. Therefore, a certain amount of increased joint loading may be required for increased athletic performance, while also potentially increasing lower-extremity joint loading magnitudes that have been examined in prior injury-related biomechanical studies.

Comparing the two high-traction surfaces (Shockpad, Control), in which performance was not statistically different [20], the Control surface had greater available rotational traction and a corresponding increase in the frontal plane knee joint loads for all three movements. When comparing the two high-traction surfaces (Shockpad and Control), performance outcomes were similar, while differences in knee joint loading were observed. From a biomechanical standpoint, these findings suggest that surfaces with comparable performance characteristics may nevertheless differ in how load is distributed in the knee. As performance was similar between conditions, from an injury reduction perspective, the Shockpad surface had similar performance and reduced knee joint loading. However, a recently published cohort study indicated that the addition of a Shockpad under an artificial turf surface increases injury rates in high school football players [27]. It should be noted that the mechanical properties, specifically the traction and stiffness of the padded and non-padded surfaces in the epidemiological study, are unknown. Therefore, it is difficult to attain any inferences from the previous data. When compared to a surface that has greater stiffness and similar rotational traction (Control), no substantial biomechanical differences are present to indicate an increased injury risk when a pad was added under the surface. However, the associated influence of the Shockpad on performance and injury should be further investigated with proper documentation of the pad's structural properties.

Overall, athletes were able to utilize greater peak traction from Control and Shockpad surfaces to improve their performance relative to the Low FW surface. Alterations in foot and ankle orientations were present, with a more foot-flat orientation on the Control and Shockpad surfaces.

https://doi.org/10.3390/app16052423

4.2. Position Effect

Changes in kinematics and kinetics were also present based on whether the athlete was classified as a speed player (running backs, defensive backs, etc.) or a power player (offensive or defensive linemen). For all movements, differences in the utilized traction were present with speed players utilizing a greater amount of traction than power players. The increased utilized traction for the speed players was due to them being able to generate a greater relative horizontal ground reaction force compared to the heavier linemen. Therefore, positionally, speed players require a minimum translational traction coefficient of 1.61 at takeoff, while power players require a minimum translational traction coefficient of 1.49 at takeoff to maximally perform rapid changes in direction movements. It should be noted that differences in body mass and movement speed are intrinsic to positional roles and were therefore not considered as confounding variables. Positional findings should be interpreted as reflecting integrated movement profiles rather than isolated effects.

As the speed players were generally faster than the power players, joint angular velocities were also increased for the speed players. During the agility drill and vcut, speed players increased their forefoot inversion velocity and their ankle dorsiflexion angular velocity, while during the cone drill, increases in the rearfoot, forefoot and ankle eversion velocity were also present. Additionally, ranges of motion were also increased for speed players, with speed players achieving greater peak foot and ankle angles compared to power players. Interestingly, despite increased ankle and knee sagittal plane moments for the power players, no differences were present for non-sagittal plane joint loading between the participants.

While there is a lack of positional biomechanical data in American football to compare to, this data indicates that the movement patterns of speed and power players substantially differ. Speed players generate greater horizontal forces, have higher joint angular velocities and go through a higher range of motion when compared to power players. While the overall positional goal of the different player types is substantially different, when performing the same tasks, these player types may have different footwear and surface requirements. This is supported by the previous study, which reported a position effect in terms of the preferred surface, with the power players preferring the low traction (Low FW) surface more than speed players. It is currently unknown why power players preferred the low-traction surface, and this topic may be the focus of future research. In a study of high school football athletes, linemen (offensive and defensive) had the lowest one season risk of injury and the lowest rate of lower extremity game injury of all player positions [21], aside from quarterbacks and kickers, which may be associated with their lower utilized traction, joint angular velocities, joint angular range of motions or lower relative horizontal forces. It should be noted that references to positional injury studies are intended to provide contextual background rather than direct inference from the present biomechanical data.

4.3. Limitations

It should be noted that the artificial turf surfaces were installed in a laboratory setting using modular trays to facilitate controlled biomechanical measurements. While this approach allowed for standardized comparison between the different surfaces, it may not fully replicate the structure, boundary conditions or environmental exposure of permanent outdoor playing surfaces.

5. Conclusions

These findings provide biomechanical insight into how surface traction properties influence movement strategies and joint loading during football-specific cutting tasks, which may inform future research examining performance–loading tradeoffs across different playing surfaces. In summary, when on a high-traction surface, football players have a flatter foot orientation, which may increase cleat engagement and allow players to generate a greater utilized traction at takeoff. Players additionally increase their foot torsion and ankle version to maintain upper body orientation while increasing shoe–surface interaction. Positionally, speed players generate greater horizontal forces and utilized traction, have higher joint angular velocities, and go through a higher range of motion when compared to power players, indicating that player positions may have different footwear and surface requirements and preferences. The observed positional differences in utilized traction and lower-extremity biomechanics suggest that surface and footwear traction requirements may differ between speed and power position players. While further work is needed, these findings provide biomechanical context that may inform considerations related to footwear design. These findings provide biomechanical context for understanding surface-dependent movement strategies during cutting tasks with implications that should be considered within the scope of the measured outcomes.

Author Contributions: Conceptualization, J.W.W., D.S., E.M.S. and C.M.O.; methodology, J.W.W. and D.S.; formal analysis, J.W.W. and D.S.; investigation, S.K. and E.S.-B.; writing—original draft preparation, J.W.W.; writing—review and editing, J.W.W., D.S., P.A., E.M.S., C.M.O. and G.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Football League.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Ethics Committee) of the University of Calgary (REB16-1133, 20 October 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: The authors gratefully acknowledge the generous donation from Nike for the football cleats provided to the study's athlete population, as well as Darren Gill (Senior Vice-President, FieldTurf) who supplied the synthetic surfaces utilized in the study. The research presented in this paper was made possible by a grant from the National Football League and the National Football League Players Association. The views expressed are solely those of the authors and do not represent those of the NFLPA, the NFL, or any of its affiliates.

Conflicts of Interest: Edward Meade Spratley, Philipe Aldahir, Cody M. O'Cain, and Gwansik Park are employed by Biomechanics Consulting and Research (Biocore), LLC and are paid consultants of the National Football League. Darren John Stefanyshyn and John William Wannop are paid consultants to Biomechanics Consulting and Research LLC. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. This study received funding from National Football League. The funder was not involved in the study design, collection, analysis, interpretation of data, the writing of this article, or the decision to submit it for publication.

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