

The influence of soccer playing surface on the loading response
to ankle (p)rehabilitation exercises

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Abstract

Context: Contemporary synthetic playing surfaces have been associated with an increased risk of ankle injury in the various types of football. Triaxial accelerometers facilitate in-vivo assessment of planar mechanical loading on the player. **Objective:** To quantify the influence of playing surface on the PlayerLoad elicited during footwork and plyometric drills focussed on the mechanism of ankle injury. **Design:** Repeated measures, field-based. **Setting:** Regulation soccer pitches. **Participants:** 15 amateur soccer players (22.1 ± 2.4 yrs), injury free with ≥ 6 yrs competitive experience. **Interventions:** Each player completed a test battery comprising three footwork drills (anterior, lateral, diagonal) and four plyometric drills (anterior hop, inversion hop, eversion hop, diagonal hop) on natural turf (NT), third generation artificial turf (3G) and astroturf (AT). GPS sensors were located at C7 and the mid-tibia of each leg to measure triaxial acceleration (100Hz). **Main Outcome Measures:** PlayerLoad in each axial plane was calculated for each drill on each surface, and at each GPS location. **Results:** ANOVA revealed a significant main effect for sensor location in all drills, with PlayerLoad higher at mid-tibia than at C7 in all movement planes. AT elicited significantly higher PlayerLoad in the mediolateral and anteroposterior planes, with typically no difference between NT and 3G. In isolated inversion and eversion hopping trials the 3G surface also elicited lower PlayerLoad than NT. **Conclusions:** PlayerLoad magnitude was sensitive to unit placement, advocating measurement with greater

anatomical relevance when using MEMS technology to monitor training or rehabilitation load. Astroturf elicited higher PlayerLoad across all planes and drills and should be avoided for rehabilitative purposes, whereas 3G elicited a similar mechanical response to NT.

Key Words: PlayerLoad, soccer, injury, playing surface

Soccer is traditionally played on natural turf (NT),¹ but synthetic or artificial turfs are increasingly used across different levels and types of football (soccer, American football, rugby league). The evolution of synthetic turfs enables less susceptibility to climatic variations and a more consistent playing surface, with reduced cost and greater ease of maintenance. However, whilst this might facilitate participation, there is a need to understand the influence of playing surface on the physical response to soccer-specific activity. Researchers have previously identified that there exist no differences between surface types and the associated total distances covered, distances covered at high intensities,² and the physical response to soccer-specific activity.^{3,4} However, it has been suggested that professional soccer players report greater perceptions of effort when completing soccer-specific exercise on artificial turf when compared to natural turf.² The observed increase in perceived effort may be related to an increased mechanical fatigue response (i.e. changes in movement efficiency) associated with artificial turf, with previous observations identifying an increased intensity of ballistic actions (i.e. sprinting and agility movements) when performed on artificial turf in comparison to natural turf.³ Literature therefore suggests that between surface differences may exist, but that they may only be identifiable during specific and/or isolated actions and movements. These observations therefore have potential implications for the design and delivery of discrete conditioning

and injury prevention drills and exercises. There is however a need to further assess the responses associated with isolated sport-specific actions performed on different playing surfaces, and a need for these actions to be informed by aetiological risk factors associated with soccer-match play.

When overall injury incidence is considered, literature reviews have typically reported no difference between natural and artificial playing surfaces.^{5,6} However, artificial surfaces are consistently associated with an increased risk of ankle injury.⁷⁻¹² Soccer presents a complex mechanical challenge, characterised by an irregular and multi-directional activity profile. Cutting movements reflect the common mechanism of ankle injury in soccer and have been shown to elicit increased ankle inversion and external rotation on artificial surfaces.¹³ American football also involves reactive cutting and is played on natural and synthetic turfs, with Mack et al. recently reporting that synthetic turf resulted in 16% more lower extremity injuries than on natural turf.¹⁴ That association became more pronounced as the authors focused on injuries located more distally,¹⁴ supporting epidemiological observations in soccer.⁷⁻¹²

Mack et al. concluded that artificial turf has a causal impact on lower extremity injury, attributed to a biomechanical mechanism associated with the shoe-surface interaction and based on biomechanical testing of football cleats on a variety of playing surfaces.^{15,16} Due to differences in methods used between studies, and the potential of contextual factors which may influence between surface comparisons, it is often difficult to develop a cause and effect relationship between surface usage and types of injury. The aetiological mechanisms associated with common injuries are however well known, thus allowing for these mechanisms to be assessed between surfaces and, in turn, allowing for changes in

mechanical capacity and performance to be compared. However, it is difficult to establish such a causal effect in the field given the complexity of lower extremity injury mechanics, and the relative lack of ecological validity in laboratory trials.

Contemporary developments in the micro electrical mechanical systems (MEMS) integrated within global positioning system (GPS) technology provide an in-vivo measure of external loading in soccer.^{17,18} Typically integrated within the GPS unit is a triaxial accelerometer, a micro inertial sensor that provides a higher sampling frequency than the GPS unit. This microtechnology is used to establish a mechanical loading metric termed PlayerLoad, based on the rate of change of acceleration, which can be quantified in each of the axial planes. The GPS unit is typically worn in a customised vest which positions the device at approximately C7, enhancing satellite reception for the analysis of distance covered and subsequent derivatives in velocity profiling. This restraint does not apply to the triaxial accelerometer, and loading magnitude is inevitably sensitive to unit placement. This facilitates the development of research paradigms more specifically aligned to injury location. The prevalence of lumbar (as opposed to cervical) injuries in cricket fast bowlers,¹⁹ and the efficacy in the progression of ankle rehabilitation drills²⁰ represent contemporary applications with a specific injury focus used to inform unit placement.

The loading metric can be calculated in each axial plane, in-vivo within the athletic context,¹⁷⁻²⁰ providing both richness of data and high ecological validity. Given the incidence of ankle injury in soccer, and the apparent increased risk of this injury on artificial turfs,⁷⁻¹² the aims of this study were twofold; Firstly, to quantify the influence of playing surface on the mechanical response to isolated actions (footwork and plyometric drills) that are specific to soccer conditioning and the reported mechanisms of ankle injuries. Secondly, to assess if

the location of the MEMS device influenced the observed response to the specific drills, and if this response was dependent upon playing surface. Three surfaces are considered to reflect the evolution of artificial turf surfaces, and to acknowledge that each variation of playing surface will have specific characteristics and mechanical properties and,²¹ in turn, specific mechanical responses and subsequent risk of injury.²² In addition to the traditional C7 placement of the MEMS devices, mechanical loading will also be quantified at the mid-tibia (in order to prevent restriction of ankle joint function during the tasks) of both lower limbs.

Methods

Design

The study was a repeated-measures design. To increase the ecological validity of our study, all analyses were conducted on regulation soccer pitches. Three experimental trials were completed in a randomized order, dictated by playing surface: natural turf (NT), 2nd generation ‘astro-turf’ (AT) comprising a sand-based surface with short synthetic grass, and FIFA 1 Star rated third-generation artificial turf (3G) comprising long synthetic grass with shock absorbent rubber crumb infill and graded silica sand, and in-situ shock pad. All surfaces are maintained by professional grounds staff. Players wore the same footwear in all trials, characterised by an outdoor soccer cleat with short, circular (not blades), moulded (non-replaceable) hard rubber studs evenly distributed across the entire outsole.

The test battery comprised drills designed to reflect the mechanism of ankle sprain injury and was consistent with the prehabilitation work regularly performed by the participants. This battery included drills defined as ‘footwork’ with a focus on agility and quickness, and ‘plyometrics’ including planar and multi-planar single leg hopping drills. The order of the drills was standardised between trials (to negate any potential accumulating fatigue effect),

so that the playing surface and the location of the GPS unit were the independent variables. The dependent variables were the total accumulated PlayerLoad (defined in procedures) in the anteroposterior, mediolateral and vertical planes, with each drill considered separately.

Participants

Fifteen amateur male soccer players (22.13 ± 2.36 years) participated in the current study. Inclusion criteria specified that in addition to weekly matches players had typical training volumes ≥ 3 sessions \cdot week⁻¹, had not suffered any lower limb injury in the 6 months prior to the commencement of the study, had no history of chronic ankle instability as determined using the Cumberland Ankle Instability Test (administered during familiarisation), and were outfield players with ≥ 6 years competitive experience. All players provided written consent, and the project was approved by the departmental research ethics committee, in accord with the Helsinki Declaration.

Procedures

Players completed three experimental trials, interspersed by a minimum of 72 hours. A familiarisation trial was completed with all players prior to testing, but the testing battery was also a regular feature of their injury prevention conditioning programme. Players were requested to refrain from vigorous exercise, alcohol and caffeine for 48 hours prior to the testing. All sessions were conducted at the same time of day to avoid any confounding interference from circadian rhythms, and specifically between 12:00 to 15:00 hrs to reflect competition practice of this cohort. Given the focus on playing surface, meteorological conditions were assessed during testing²³ to ensure the sessions occurred on dry days with minimal wind and consistent temperatures. The surfaces were dry prior to the sessions, with watering of the turfs occurring on the preceding day to the testing. Players completed a

standardised pre-test warm-up reflecting training practice. Prior to each drill the lead researcher provided a technical demonstration.

Each testing session comprised completion of the testing battery which consisted of seven drills. Drills 1-3 were designated as ‘footwork’ drills, shown schematically in Figure 1, and completed on a 10m agility ladder comprising 20 rungs, with 0.50m spacing between rungs. Drill 2, the lateral footwork drills was completed with a dominant and non-dominant leg lead. Drills 4-7 were designated as single-legged ‘plyometric’ drills, shown schematically in Figure 2. Drills 4-6 used the same 10m footwork ladder whilst Drill 7 used a 5m ladder reflecting the greater number of contacts between rungs. Each drill was completed as done habitually in a training context. All single legged plyometric drills were completed with the dominant and non-dominant leg.

** Insert Figure 1 near here **

** Insert Figure 2 near here **

During each testing session the player was fitted with three GPS devices (MinimaxX S4, Catapult, Scoresby, Australia) located at C7 and the posterior aspect of the mid-tibia of both limbs.¹⁷ The accelerometer (Kionix KX94, Kionix, Ithaca, New York, USA) embedded within the GPS unit collects uni-axial data at a sampling frequency of 100 Hz. Subsequently, the total accumulated PlayerLoad™ is calculated based on the rate of change in acceleration.²⁴ Rather than the single vector representation used in previous research²⁴ which negates an understanding of relative planar loading, in the current study PlayerLoad is calculated discretely in each of the mediolateral (ML), anteroposterior (AP) and vertical (V) planes of movement for each drill, and on each surface. For example, ML PlayerLoad

is calculated as the sum of instantaneous changes in mediolateral acceleration ($= \Sigma ((a_2 - a_1) / 100)$), where a represents planar acceleration calculated at a frequency of 100 Hz.

Statistical Analyses

A repeated-measures general linear model (GLM) was chosen as an appropriate parametric test to investigate main effects for playing surface (AT, NT, and 3G) and MEMS device location (C7, DL, and NDL) for measures of uni-axial PlayerLoad across a range of drills. The assumptions of normality associated with the general linear model were assessed using the Shapiro-Wilk test to ensure model adequacy, with none of the variables violating any of the assumptions. Where significant main effects or interactions were observed, post-hoc pairwise comparisons with a Bonferroni correction factor were applied. Main effects were supported with partial eta squared (η^2) calculated as a measure of effect size and classified as small (≤ 0.059), moderate ($0.060 - 0.137$), and large (≥ 0.138). All data are subsequently presented as mean \pm SD, with statistical significance accepted at $P \leq 0.05$. All statistical analysis was completed using PASW Statistics Editor 22.0 for Windows (SPSS Inc., Chicago, IL, USA).

Results

Footwork drills

Table 1 summarises the influence of playing surface and MEMS device location on uni-axial PlayerLoad during the footwork drills. For all PlayerLoad metrics, no surface by location interaction ($P \geq 0.388$, $\eta^2 \leq 0.033$) was identified across any of the footwork drills.

** Insert Table 1 near here **

Influence of playing surface

Irrespective of unit location, no significant main effect for playing surface was identified for the vertical PlayerLoad data recorded across all drills (Drill 1: $P = 0.346$, $\eta^2 = 0.017$; Drill 2: $P = 0.066$, $\eta^2 = 0.044$; Drill 3: $P = 0.071$, $\eta^2 = 0.042$).

There was however a significant main effect for playing surface identified for the AP PlayerLoad data recorded across all drills (Drill 1: $P = 0.030$, $\eta^2 = 0.056$; Drill 2: $P = 0.027$, $\eta^2 = 0.057$; Drill 3: $P = 0.007$, $\eta^2 = 0.079$). Post-hoc testing identified higher AP Playerload data on AT than on both 3G (Drill 1: $P = 0.004$; Drill 2: $P = 0.006$; Drill 3: $P = 0.001$) and NT (Drill 2: $P = 0.031$; Drill 3: $P = 0.008$).

A similar response was also observed for the ML Playerload data, with Drill 2 ($P = 0.022$, $\eta^2 = 0.060$) and Drill 3 ($P = 0.015$, $\eta^2 = 0.066$), but not Drill 1 ($P = 0.243$, $\eta^2 = 0.023$) eliciting higher responses on AT when compared to both 3G (Drill 2: $P = 0.003$; Drill 3: $P = 0.002$) and NT (Drill 2: $P = 0.048$; Drill 3: $P = 0.027$).

Influence of unit location

A significant main effect for unit location ($P < 0.001$) was however identified for all PlayerLoad metrics (ML: $\eta^2 \geq 0.577$; AP: $\eta^2 \geq 0.588$; V: $\eta^2 \geq 0.134$), with post-hoc testing identifying loading was significantly higher for all drills when recorded at mid-tibia than at C7 ($P \leq 0.001$). There were however no differences in the PlayerLoad response observed between the dominant and non-dominant limbs ($P \geq 0.369$).

Plyometric drills

Table 2 summarises the influence of playing surface and MEMS device location on uni-axial PlayerLoad during the plyometric drills. For all PlayerLoad metrics, no surface by

location interaction ($P \geq 0.087$, $\eta^2 \leq 0.071$) was identified across any of the plyometric drills.

** Insert Table 2 near here **

Influence of playing surface

The GLM identified a significant main effect for playing surface on the ML PlayerLoad recorded across all drills (Drill 4: $P = 0.015$, $\eta^2 = 0.066$; Drill 5: $P = 0.015$, $\eta^2 = 0.067$; Drill 6: $P < 0.001$, $\eta^2 = 0.126$; Drill 7: $P = 0.002$, $\eta^2 = 0.094$), with post hoc comparisons identifying higher ML PlayerLoad data recorded on AT when compared to 3G for all of the drills ($P \leq 0.002$), and when compared to NT for Drills 4, 6 and 7 ($P \leq 0.027$).

There was also a significant main effect for playing surface on AP PlayerLoad recorded in all drills (Drill 4: $P = 0.007$, $\eta^2 = 0.079$; Drill 5: $P = 0.003$, $\eta^2 = 0.090$; Drill 6: $P < 0.001$, $\eta^2 = 0.158$; Drill 7: $P < 0.001$, $\eta^2 = 0.123$), with post-hoc comparisons identifying higher AP PlayerLoad recorded on AT when compared to 3G for all drills ($P \leq 0.001$). AP PlayerLoad was also significantly higher on AT when compared to NT for Drills 4, 6 and 7 ($P \leq 0.031$), and greater on NT when compared to 3G for Drills 5 and 6 ($P \leq 0.034$).

There was also a significant main effect for playing surface for vertical PlayerLoad in Drill 6, the eversion hop ($P = 0.002$, $\eta^2 = 0.098$) and in Drill 7, the diagonal hop ($P = 0.012$, $\eta^2 = 0.069$), with post-hoc comparisons identifying that vertical PlayerLoad was greater on AT when compared to 3G ($P \leq 0.002$). Higher vertical PlayerLoad was also recorded on NT when compared to 3G for drill 6, eversion hop ($P \leq 0.005$). There was however no main

effect for surface identified for the other plyometric drills (Drill 4: $P = 0.071$, $\eta^2 = 0.042$; Drill 5: $P = 0.179$, $\eta^2 = 0.028$).

Influence of unit location

For all PlayerLoad metrics, the GLM identified a significant main effect for unit location ($P < 0.001$) across all drills (ML: $\eta^2 \geq 0.766$; AP: $\eta^2 \geq 0.746$; V: $\eta^2 \geq 0.648$). Post-hoc comparisons identified that for all drills, significantly higher PlayerLoad values recorded at the mid-tibia locations when compared to the C7 location ($P \leq 0.001$). However, for all of the plyometric drills, there was no significant differences observed between the dominant and non-dominant limbs ($P \geq 0.377$).

Discussion

The aims of this study were twofold; firstly, to quantify the influence of playing surface on the mechanical response to isolated actions (footwork and plyometric drills) that are specific to soccer conditioning and the reported mechanisms of ankle injuries. Secondly, to assess if the location of the MEMS device influenced the observed response to the specific drills, and if this response was dependent on playing surface. Epidemiological studies in soccer have observed an increased risk of ankle injury in soccer,⁷⁻¹² and Mack et al. recently suggested a causal influence of synthetic turfs on lower extremity injury in elite American Football.¹⁴ This causal link was attributed to a biomechanical hypothesis based on the shoe-surface interaction, based on laboratory testing of different surfaces under laboratory conditions. Contemporary developments in MEMS technology facilitates the measurement of PlayerLoad in the training or competitive environment.

The 'footwork' drills elicited a significantly greater anteroposterior and mediolateral PlayerLoad on AT than either the NT or 3G surface, which were themselves no different. This suggests that the completion of such 'footwork' drills should not be completed on 1st or 2nd generation synthetic surfaces, characterised by a short synthetic fibre and sand infill. Given the tendency to repeat such drills in greater volume in a session, and over a playing season, the findings of the current study are likely to be magnified with increased and prolonged exposure. However, third generation surfaces characterised by a long fibre and rubber crumb infill elicited a similar response to natural turf. The 3G surface was therefore at least as good as natural turf in terms of the PlayerLoad magnitude. Whilst we tried to standardise environmental conditions between trials, where climatic challenges are evident the 3G surface might be advantageous where a natural turf degrades in quality and consistency.

The 'plyometric' drills displayed a similar pattern, with the AT eliciting significantly greater anteroposterior and mediolateral PlayerLoad than either 3G or NT. Conditioning work, including that conducted during rehabilitation, should therefore avoid this type of surface where possible. In most cases the 3G and natural turf elicited a similar response. However, in the drills isolating inversion or eversion of the ankle there was evidence of additional benefit of 3G over natural turf. This might inform clinical choice of surface during rehabilitation for example, where the training objective might have a specific planar focus without generating excessive load. This might be a perceptual response by the player in reaction to the surface, as literature has suggested that the athlete will alter stiffness of the lower extremity whilst running and hopping on different surfaces.²⁸ The longer synthetic fibre on the third generation surface in combination with the shock absorption properties of the infill material, in this case rubber-crumbs, consistently produced lower PlayerLoad than the second generation turf. When performing more controlled and isolated movements like

an eversion hop the players perceived response to greater shock absorption and consistency in the 3G surface might enable the reduction in movements away from the medial direction of travel. Players' perceptions of an increased risk of injury when playing on artificial turf²⁶ have been attributed to a feeling that artificial surfaces are more physically demanding.^{27,28} However, the current study used isolated drills with a focus on movement quality, and therefore the perceptions might be quite different to those of match-play, tackling and high intensity running in particular.

When integrated within a GPS device the MEMS unit is typically located at C7, but in relation to the current study, it was identified that the PlayerLoad response at the mid-tibia was observed to be significantly higher than at C7 in all planes, and across all drills. This has implications for clinical reasoning and the monitoring of mechanical load during training or rehabilitation. This location-specific loading pattern supports previous applications in lumbar injuries in cricket¹⁹ and rehabilitative progressions specific to the mechanism of ankle sprain injury.²⁰ In the present study there was no surface \times location interaction, and therefore the clinical implications relate primarily to the magnitude of loading elicited at the mid-tibia. The PlayerLoad metric used in this study is based on the accumulation of rate of change in axial acceleration. The greater magnitude at mid-tibia is therefore indicative of greater magnitude and/or frequency of change in acceleration and reflects the nature of the drills where technical proficiency is enhanced by greater displacement of the support foot relative to the mass centre. A relatively consistent mass centre trajectory will enhance movement efficiency, with displacement of the support foot affecting the change in direction and speed. In addition to greater magnitude of PlayerLoad at the mid-tibia, there was also evidence of relative differences in the planar contributions to total (tri-axial) PlayerLoad. The ratio of AP:ML:V contributions to total PlayerLoad at C7 was 25:27:48 averaged across all drills and surfaces, whereas the ratio at mid-tibia was 34:33:34 (Figure 3). This highlights

an increase in the relative anteroposterior and mediolateral loading at mid-tibia, with a compensatory reduction in relative vertical loading.

** Insert Figure 3 near here **

The findings of the current study should not be generalised beyond the specific research design elements. We used amateur male soccer players who were injury free with no lower limb injury in the previous 6 months and no history of chronic ankle instability. The impact of previous injury and monitoring of subsequent rehabilitative loading on different surfaces warrants attention.²⁹ The current study utilised three different surfaces, reflecting the available choice to this cohort of players, and players wore a consistent boot in all studies. This short multi-moulded stud pattern is quite different to the longer stud worn on NT in certain environmental conditions, and to the nature of the cleats used in other football codes. The influence of the shoe-surface interaction is likely to be specific to the nature of the shoe and surface, and care should be taken when interpreting the results of our study. We also used isolated drills designed to reflect the mechanism of ankle sprain injury with a focus on plantar flexion and inversion of the ankle, and habitual to the players. In addition to the high level of habituation, all drills were prescriptive. The influence of playing surface might be altered when movements are reactive and performed at great speed. However, Strutzenberger et al. reported no kinematic difference between natural turf and a third generation synthetic turf during reactive cutting movements in soccer players.¹³ Whilst we considered an acute response to selected drills, the chronic exposure to artificial playing

turfs also warrants investigation with evidence of higher injury rates for clubs who play home games on artificial turf.³⁰

Clinical reasoning was shown to be dependent on unit placement, but this anatomical placement designed around injury foci offers potential in the management and monitoring of loading during training and rehabilitation. The present study used a location just proximal to the ankle joint but future research might consider bespoke solutions to sport-specific epidemiological issues.

Conclusions

Natural turf and 3G elicited similar loading magnitudes, indicative of consistencies in mechanical efficiency between these two surfaces, thus highlighting the interchangeability of these surfaces for the delivery of such drills. The similarity in the response observed between these surfaces may offer a useful consideration when climatic degradation of a grass surface might influence movement quality. Astro turf elicited the greatest loading across footwork and plyometric drills and, as such, practitioners should be aware of the reduction in mechanical efficiency associated with this surface, with this knowledge potentially informing the limited use of surface for susceptible athletes, or as a method to overload a specific (p)rehabilitation drill. Acknowledging the use of injury free players in the current study, the use of 3G during (p)rehabilitation specific to lower extremity injury might therefore be advocated, providing no greater load than natural turf, and potentially offering greater consistency in the shoe-surface interaction where movements are slower and prescriptive in contrast to match-play. Placement of the MEMS device was sensitive to the magnitude of PlayerLoad in all planes, and across all drills. The mid-tibia placement (used

to reflect the high incidence of lower extremity injury in soccer) elicited higher absolute loading than the typical C7 placement, with implications for clinical reasoning.

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Figures and Tables

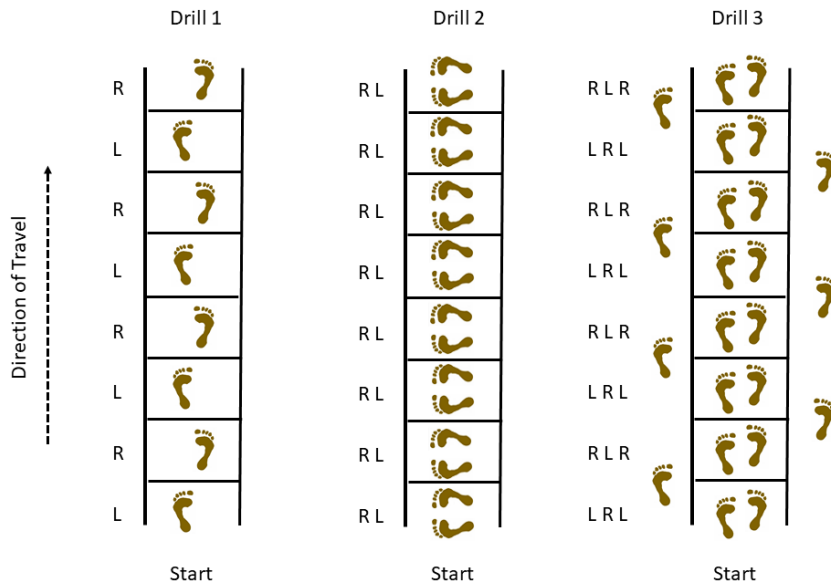


Figure 1. Schematic representation of the three footwork drills.

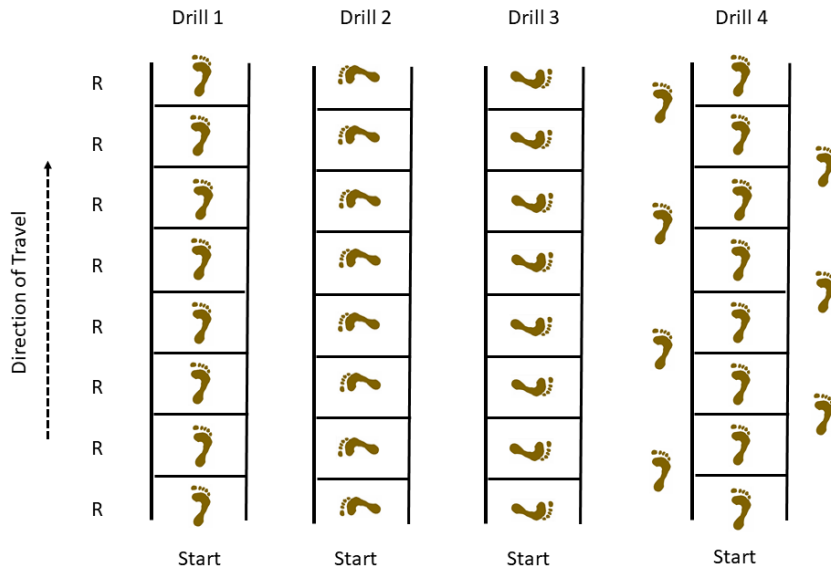


Figure 2. Schematic representation of the four single leg plyometric drills.

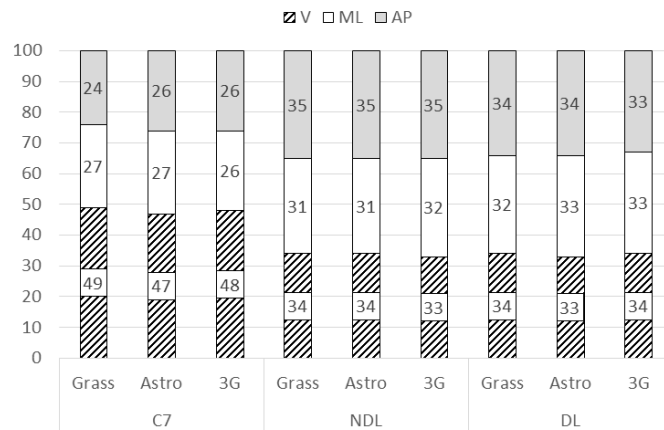


Figure 3. The influence of playing surface and MEMS device location on the relative planar contributions to PlayerLoad response.

Table 1. The influence of playing surface and GPS location on the planar PlayerLoad

response to footwork drills. * denotes significantly lower than Astro; ** denotes

significantly lower than NDL and DL across all drills and surfaces.

		PlayerLoad (arbitrary units)								
		Mediolateral			Anteroposterior			Vertical		
		C7 **	NDL	DL	C7 **	NDL	DL	C7 **	NDL	DL
Drill 1	Grass	0.48 ±	1.57 ±	1.49 ±	0.50 ±	1.55 ±	1.50 ±	1.19 ±	1.70 ±	1.65 ±
		0.14	0.49	0.43	0.12 *	0.45 *	0.51 *	0.45	0.59	0.58
	Astro	0.61 ±	1.60 ±	1.57 ±	0.58 ±	1.66 ±	1.70 ±	1.28 ±	1.81 ±	1.87 ±
		0.23	0.49	0.61	0.24	0.48	0.70	0.47	0.65	0.83
	3G	0.47 ±	1.40 ±	1.46 ±	0.47 ±	1.33 ±	1.43 ±	1.17 ±	1.53 ±	1.70 ±
		0.17	0.42	0.54	0.16 *	0.30 *	0.43 *	0.63	0.55	0.73
Drill 2	Grass	0.68 ±	2.78 ±	2.80 ±	0.69 ±	2.27 ±	2.24 ±	1.71 ±	2.66 ±	2.67 ±
		0.15 *	0.60 *	0.65 *	0.21 *	0.73 *	0.71 *	0.37	1.06	1.04
	Astro	0.93 ±	2.98 ±	3.08 ±	0.81 ±	2.57 ±	2.67 ±	1.91 ±	3.08 ±	3.09 ±
		0.43	0.88	0.88	0.42	0.84	0.83	0.65	1.12	1.12
	3G	0.71 ±	2.48 ±	2.73 ±	0.63 ±	2.13 ±	2.24 ±	1.70 ±	2.48 ±	2.67 ±
		0.24 *	0.51 *	0.66 *	0.21 *	0.67 *	0.76 *	0.43	0.79	0.94
Drill 3	Grass	0.81 ±	4.84 ±	4.98 ±	0.82 ±	4.13 ±	4.17 ±	1.81 ±	5.00 ±	4.82 ±
		0.17 *	1.38 *	1.42 *	0.28 *	1.08 *	1.24 *	0.74	1.47	1.63
	Astro	0.99 ±	5.48 ±	5.66 ±	0.90 ±	4.82 ±	5.07 ±	1.71 ±	5.55 ±	5.72 ±
		0.40	1.70	1.67	0.36	1.54	1.58	0.60	1.70	1.67
	3G	0.84 ±	4.42 ±	4.82 ±	0.76 ±	3.91 ±	4.17 ±	1.65 ±	4.54 ±	5.08 ±
		0.21 *	0.99 *	0.81 *	0.17 *	0.85 *	0.89 *	0.50	0.91	0.75

Table 2. The influence of playing surface and GPS location on the planar PlayerLoad response to single leg plyometric drills. * denotes significantly lower than Astro; ** denotes significantly lower than Astro and Grass; *** denotes significantly lower than NDl and DL across all drills and surfaces.

		PlayerLoad (arbitrary units)								
		Mediolateral			Anteroposterior			Vertical		
		C7***	NDL	DL	C7***	NDL	DL	C7***	NDL	DL
Drill 4	Grass	0.57 ±	3.08 ±	2.99 ±	0.68 ±	2.91 ±	2.91 ±	1.35 ±	3.66 ±	3.76 ±
		0.11 *	0.63 *	0.54 *	0.16 *	0.55 *	0.49 *	0.26	0.70	0.87
	Astro	0.71 ±	3.31 ±	3.15 ±	0.77 ±	3.37 ±	3.59 ±	1.41 ±	4.16 ±	4.27 ±
		0.25	0.90	0.67	0.31	0.98	0.95	0.37	1.37	1.26
	3G	0.58 ±	2.83 ±	2.92 ±	0.66 ±	2.57 ±	2.87 ±	1.32 ±	3.06 ±	3.56 ±
		0.11 *	0.62 *	0.45 *	0.22 *	0.48 *	0.46 *	0.27	0.51	0.61
Drill 5	Grass	0.61 ±	3.58 ±	3.65 ±	0.67 ±	2.71 ±	2.83 ±	1.26 ±	3.36 ±	3.54 ±
		0.10	0.77	0.77	0.15	0.68	0.56	0.17	0.91	0.91
	Astro	0.73 ±	4.03 ±	3.64 ±	0.76 ±	3.06 ±	2.89 ±	1.32 ±	3.68 ±	3.40 ±
		0.26	1.14	0.78	0.33	0.73	0.59	0.38	0.88	0.92
	3G	0.63 ±	3.10 ±	3.43 ±	0.65 ±	2.37 ±	2.59 ±	1.20 ±	3.29 ±	3.40 ±
		0.11 *	0.50 *	0.67 *	0.20 *	0.47**	0.43**	0.27	0.77	0.93
Drill 6	Grass	0.59 ±	4.11 ±	4.05 ±	0.71 ±	2.92 ±	3.03 ±	1.26 ±	3.75 ±	3.77 ±
		0.11 *	1.03 *	0.87 *	0.16 *	0.61 *	0.42 *	0.19	0.92	0.80
	Astro	0.70 ±	4.83 ±	4.43 ±	0.78 ±	3.38 ±	3.17 ±	1.26 ±	4.03 ±	3.84 ±
		0.23	1.27	1.27	0.31	0.82	0.71	0.37	0.99	0.97
	3G	0.59 ±	3.51 ±	3.70 ±	0.67 ±	2.51 ±	2.59 ±	1.18 ±	3.00 ±	3.31 ±
		0.14 *	0.59 *	0.51 *	0.23 *	0.47**	0.42**	0.25**	0.70**	0.90**
Drill 7	Grass	0.55 ±	3.72 ±	3.54 ±	0.64 ±	2.79 ±	2.82 ±	1.20 ±	3.45 ±	3.51 ±
		0.09 *	0.97 *	0.78 *	0.15 *	0.57 *	0.60 *	0.24	0.73	0.85

		0.67 ±	4.17 ±	4.11 ±	0.74 ±	3.24 ±	3.41 ±	1.26 ±	3.93 ±	4.05 ±
	Astro	0.23	1.11	1.13	0.32	0.83	0.90	0.41	1.04	1.20
		0.58 ±	3.33 ±	3.44 ±	0.63 ±	2.63 ±	2.76 ±	1.17 ±	3.21 ±	3.47 ±
	3G	0.14 *	0.52 *	0.48 *	0.21 *	0.48 *	0.41 *	0.25 *	0.70 *	0.78 *