Impact Deceleration Differences on Natural Grass Versus Synthetic Turf High School Football Fields

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Abstract

American football has the highest rate of concussions in United States high school sports. Within American football, impact against the playing surface is the second-most common mechanism of injury. The objective of this study was to determine if there is a difference in impact deceleration between natural grass and synthetic turf high school football fields. A Century Body Opponent Bag (BOB) manikin was equipped with a Riddell football helmet and 3 accelerometers were placed on the forehead, apex of the head, and right ear. The manikin was dropped from a stationary position onto its front, back, and left side onto natural grass (n = 10) and synthetic turf (n = 9) outdoor football fields owned and maintained by public and private institutions on O‘ahu, Hawai‘i. Data was collected on 1,710 total drops. All accelerometers in forward and backward falls, and 1 accelerometer in side falls showed significantly greater impact deceleration on synthetic turf compared to the natural grass surfaces ($P < .05$). The results of this study provide evidence-based rationale to inform youth sports policies, particularly those aimed at injury prevention through safer playing environments and equipment.

Keywords

Sports, football, concussions, biomechanics, prevention, high school, pediatrics

Introduction

American football accounts for the majority of concussions in US high school sports.[1-3] Head contact with the playing surface accounts for up to 10.2% of concussions, making it the second-most common mechanism of concussion following player-to-player head contact.[1–3] The risk of injury due to head-to-surface contact is exacerbated at the youth level, where up to 21% of concussions in children aged 5-9 from 1990 to 2009 occurred from surface impacts during play.[4] This has been attributed to the "bobblehead" effect, where disproportionately large head size and relatively underdeveloped neck musculature limits young athletes' ability to brace their head in a fall. Concussions in young, developing athletes have been shown to be more damaging than in the adult brains, with significant negative impacts on attention and concentration and negative associations with academic performance.[5] Field surface hardness directly affects how much force is transferred to the brain and may be correlated to concussion incidence and severity.

While synthetic turf fields are increasing in popularity due to low maintenance costs, durability, and multi-use potential, synthetic turf has been causally linked to more ankle and knee injuries, with inconclusive data on concussions.[6-18] One proposed cause of these higher rates of injury is that turf exhibits increased grip and traction during changes in position while natural grass fields would break apart and reduce ligamentous strain.[6] Well-maintained synthetic turf fields can perform similarly to natural grass fields, but a multitude of factors such as weather and infill compaction with use can cause deterioration of their protective effects.[19,20] These factors may be exacerbated in high school sports, where field maintenance resources may be less available or of lower quality than those of professional sports stadiums. It has been suggested by research on athletes of many levels, from high school to professional American football, that these differential injury rates may result from differential surface hardness.[14-16] Previous studies have been observational, examining differences in injury rates or testing field materials at collegiate or national level competition. To the authors' knowledge, there has been limited reporting on the differences of playing surfaces at the high-school level where there is often a higher degree of variability in field conditions and maintenance. The objective of this study was to determine if there is a difference in impact deceleration between natural grass and synthetic turf high school football fields.

Methods

This experiment was conducted at 10 natural grass and 9 synthetic turf high school football fields on O‘ahu, Hawai‘i (**Table 1**). Field testing for each individual field was completed within a single day. Testing was conducted in dry conditions. ADXL326 - 5V ready triaxial accelerometers (Analog Devices, Inc., Norwood, MA) were placed on the forehead, apex of the head, and right ear of a Century Body Opponent Bag (BOB®) manikin (Century, LLC, Oklahoma City, OK). A previously used and unmodified Riddell 2012 Victor Youth XL football helmet (Riddell, Rosemont, IL) was secured onto the head of the manikin over the accelerometers. The head and torso manikin was a martial arts and boxing manikin that mounts onto a weighted base via a hollow plastic tube (**Figure 1**). The weighted base was disconnected from the manikin and it was not included in the manikin drops.

The 1.13-meter-tall manikin weighing 10 kg was dropped from a stationary position from the edge of a folding table at a height of 60 cm onto its front, back, and left side. Each of these drops was conducted 10 times at the hashmarks of the 40-yard line, 20-yard line, and endzone to account for the effect of unequal use of certain field areas (90 total drops at each field). Falls that did not result in the intended impact as ascertained visually and through outlier sensor data were redone.

The primary measure of this experiment was impact deceleration, where a high impact deceleration indicates low impact attenuation and a harder surface. From this point forward, surface hardness or impact force will be used interchangeably with impact deceleration, where high impact deceleration is equivalent to a harder surface or higher impact force and low impact deceleration is equivalent to a softer surface and lower impact force. Each accelerometer recorded linear acceleration (in g units, 1 g = 9.8 meters/second^2) experienced by the manikin in x, y, and z vectors. Continuous data from each accelerometer was recorded onto a high-speed micro secure digital card (SD card) at a rate of 300 readings per second. This data was transferred to a Microsoft Excel Version 16.0 spreadsheet (Microsoft Corporation, Redmond, WA) in which a macro was written to identify the point of maximum impact force and graph the data points prior to and following this point. The net deceleration on impact for each accelerometer was calculated as a net vector from the maximal change in x, y, and z vectors which coincided with the moment of impact.

Results were expressed in mean values with 95% confidence intervals [95% CI] for each accelerometer and drop type, calculated using Microsoft Excel. Significant differences with

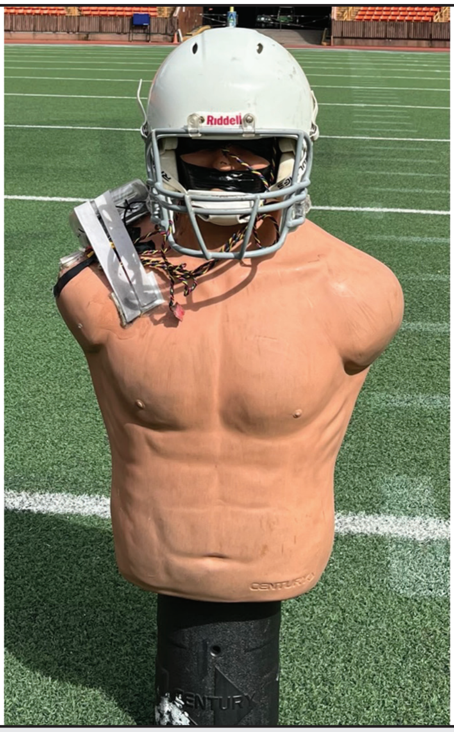

Figure 1. Image of Manikin Used in the Study

Accelerometer chips were attached to the manikin's head with a football helmet over the accelerometers. A plastic box on the manikin's right shoulder contains a pair of digital acquisition cards onto which data from the accelerometer chips is recorded.

Table 1. Summary of Sampled Football Field Characteristics

Synthetic Turf Field	Month Tested	Football Offseason	Temperature (˚C)	Year of installation
1	July	Yes	27.8	2017
2	August	No	29.4	2016
3	October	No	29.4	2012
4	October	No	28.3	2019
5	October	No	28.3	2016
6	November	No	27.8	2016
7	November	No	26.7	2013
8	December	No	26.7	Unknown
9	December	No	26.7	Unknown
Natural Grass Field	**Month Tested**	**Football Offseason**	**Temperature (˚C)**	**Length of Grass (cm)**
1	May	Yes	26.7	2.5
2	May	Yes	26.1	1.0
3	June	Yes	30.0	2.5
4	August	No	30.0	6.4
5	August	No	30.6	2.5
6	August	No	29.4	1.0
7	August	No	28.3	1.5
8	September	No	29.4	1.0
9	September	No	28.9	1.0
10	September	No	28.3	1.5

corresponding *P*-values were calculated using an unpaired *t*-test. Comparison of field position and correlation with other field characteristics were performed by ANOVA analysis and Pearson's correlate, respectively, using IBM SPSS Statistics, Version 29 (IBM, Inc., Armonk, NY).

Results

Data was collected on 10 natural grass and 9 synthetic fields which culminated in a total of 1710 total drops. Average daily temperature of testing was 27.9 °C and 28.8 °C for synthetic turf and natural grass respectively. Most tests occurred during the football season; 1 out of 9 synthetic turf fields and 3 out of 10 natural grass fields were tested in the football offseason.

ANOVA analysis between field position groups demonstrated no significant differences for each sensor and fall type at the 40-yard line, 20-yard line, and endzone with exception of the ear sensor during side falls only (**Supplemental Table 1**). Field position largely had no influence on the deceleration force, therefore, data was aggregated by accelerometer and drop type only. Results are summarized in **Figure 2** with means measured in g's and 95% CI shown as error bars. Forward drops between grass vs. synthetic fields showed higher decelerations on synthetic fields in all sensors; forehead, apex, and side (mean [95% CI] measured in g's 117 [114.2-119.8] vs. 129 [126.5-131.5] *P*=.001, 56 [55.4-55.6] vs 61 [60.5-62.5] *P*=.001, 78 [76.4-80.3] vs 82.7 [80.7-84.8] *P*=.002). Backwards drops also demonstrated this pattern in forehead, apex, and side sensors (139 [136.7-140.5] vs 148 [146.1-150.2] *P*=<.001, 135 [131.9.5-137.9] vs 144 [141.5-147.0] *P*=<.001, 130 [126.9-133.1] vs 139 [137.1-141.3] *P*=<.001). Falling on the side demonstrated significant differences in the apex sensor only (133 [130.4-135.9] vs 157 [153.7-159.4] *P*=<.001) **(Table 2)**.

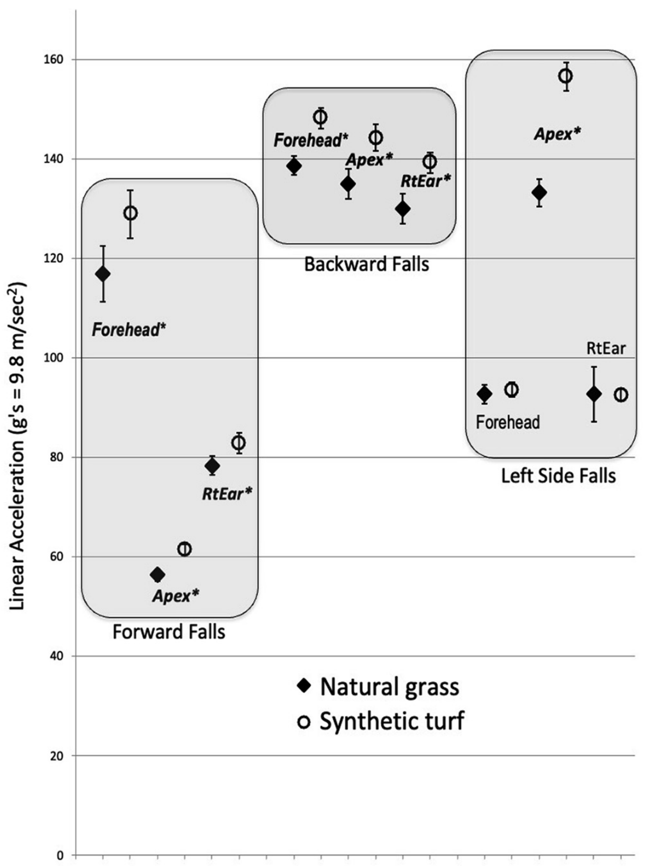

Figure 2. Comparison of Impact Deceleration on Natural Grass and Synthetic Turf

Natural grass (solid diamond) and synthetic turf (open circle) fields aggregated by fall types (Forward, Backward, Left Side) and sensor locations (Forehead, Apex, RtEar) displayed in mean in g's and 95% CI. An asterisk (*) indicates statistically significant differences (*P*<.05).

Supplemental Table 1. ANOVA Comparison of Impacts Among 40-Yard, 20-Yard, and Endzone Field Positions

	Sensor	Sum of Squares[a]	Mean Square	F-value	Significance
Front Drops	Forehead	9733.2	4866.6	2.5	P =.083
	Apex	217.6	108.8	1.1	P =.34
	Right Ear	1669.2	834.6	2.9	P =.057
Backwards Drops	Forehead	154.9	77.5	0.1	P =.90
	Apex	1545	772.5	1	P =.35
	Right Ear	130.7	65.3	0.1	P =.92
Side Drops	Forehead	425.6	212.8	0.2	P =.82
	Apex	502.4	251.2	0.4	P =.65
	Right Ear	22632.2	11316.1	6.3	P =.002

[a] Sum of squares measured in g's (9.8m/s^2)

Table 2. Student's T-test Comparison of All Falls for Each Sensor and Drop Type Across All Grass and Synthetic Turf Fields

	Sensor	Natural Grass Mean in g's [95%CI][a]	Synthetic Turf Mean in g's [95%CI][a]	Significance
Forward Drops	Forehead	117.9 [114.2-119.8]	128.8 [126.5-131.5]	P =.001
	Apex	56.4 [55.4-55.6]	61.5 [60.5-62.5]	P <.001
	Right Ear	78.3 [76.4-80.2]	82.8 [80.7-84.8]	P =.002
Backwards Drops	Forehead	138.6 [136.7-140.5]	148.2 [146.1-150.2]	P <.001
	Apex	134.9 [131.9-137.9]	144.3 [141.5-146.9]	P <.001
	Right Ear	130.0 [126.9-133.1]	139.2 [137.1-141.3]	P <.001
Side Drops	Forehead	92.7 [90.8-94.6]	93.6 [92.1-95.1]	P =.46
	Apex	133.2 [130.4-136.0]	156.5 [153.7-159.4]	P <.001
	Right Ear	92.7 [87.1-98.2]	92.5 [91.3-93.7]	P =.95

[a] Means and standard error measured in g's ($9.8m/s^2$)

Supplemental Table 2. Pearson's Correlation for Additional Field Characteristics

		Temperature (Celsius)[a]		Turf age (years)[b]		Grass length (cm)[c]	
	Sensor	Correlate[d]	*P*-value	Correlate[d]	*P*-value	Correlate[d]	*P*-value
Front Drops	Forehead	-.229 (545)	<.001	0.075 (208)	.276	-.230 (275)	<.001
	Apex	-.193 (557)	<.001	.166 (208)	.016	-0.032 (287)	.591
	Right Ear	-.193 (551)	<.001	.145 (208)	.036	-.213 (281)	<.001
Side Drops	Forehead	-.250 (557)	<.001	-0.059 (208)	.395	-.135 (287)	.021
	Apex	-.154 (558)	<.001	0.023 (208)	.736	-0.043 (288)	.467
	Right Ear	-.091 (549)	.032	-0.108 (208)	.117	0.069 (279)	.246
Backwards Drops	Forehead	.413 (557)	<.001	.187 (208)	.007	-0.064 (287)	.275
	Apex	-0.067 (554)	.113	0.032 (208)	.641	-.124 (284)	.036
	Right Ear	.333 (568)	<.001	-0.063 (208)	.366	-0.069 (298)	.233

[a] Temperature correlation was performed for all fields due to information availability.
[b] Turf age correlation was performed on 7 of the 9 synthetic fields due to information availability.
[c] Grass length correlation was only performed on natural grass fields.
[d] Correlates are reported as r(degrees of freedom), *P*-values are 2-tail significance.

Additional analyses on field characteristics were performed using Pearson's correlation (**Supplemental Table 2**). Grass length was found to be weakly inversely correlated with acceleration although this finding was not observed across all sensors. The age of the synthetic turf was observed to have minimal to no association on decelerating force. Temperature demonstrated weak inverse correlation with acceleration force that was observed across nearly all drop type and sensors. Sample size was not sufficient for meaningful analysis of impact forces with month of testing or football offseason testing.

Discussion

The results of this study demonstrate that natural grass fields are a softer playing surface compared to synthetic turf fields. Prior literature has quantified the differential surface hardness between various field types, as well as the correlation between field surface type and injury risk. To the authors' knowledge, there has been limited reporting on playing surface hardness at the high-school level that may exhibit a higher degree of variability in field conditions. Additionally, studies examining playing surface hardness have typically used devices such as a Clegg hammer, which measures impact attenuation in a single dimension in a highly uniform manner. The use of a manikin with 3 triaxial accelerometers and the simulation of multiple impact types may better capture the variance between impacts and between different anatomical locations within a single impact. The consistency of higher impact forces on synthetic turf across the majority of accelerometers and drop types strengthens the validity of this finding. One prior study compared natural grass fields to different types of synthetic turf installations, including stitched, hybrid, and woven turf systems, measuring different field areas similarly to the current study. In that article, it was determined that natural grass provided greater impact attenuation than any synthetic turf, consistent with the results of this study.[21] It has been suggested that harder synthetic turf correlates with a higher rate of injuries, particularly lower extremity injuries, though data on concussions is inconclusive.[6,7,11,13] A study representing 17 549 high school and collegiate football players reported a higher rate of severe concussions occurring on synthetic turf rather than natural grass.[22] In contrast, several publications have shown fewer concussions on artificial turf or higher post-concussive symptom severity due to contact with natural grass.[13,23] This variability in head injury risk and outcomes can likely be attributed to the multifactorial nature of head injuries, such as force magnitude and direction, helmet characteristics, and level of competition.[18] While the present study does not provide a definitive answer to the question of whether concussions are more likely on natural grass versus synthetic turf fields, it aims to add to the literature providing a biomechanical rationale for differential rates of concussions caused by head-to-surface impact.

The results of this study provide a baseline biomechanical comparison between impact forces on natural grass versus synthetic turf football fields. In high school American football players, concussions occur when head impacts approach 95 g.[24] A study of 124 youth American football players aged 9-14 determined that 62.4 ± 29.7 g was the threshold for concussions.[25] Because most of the fields tested in this study are used for both youth and high school football, it was important to capture this wide range of forces. The impacts generated in this study encompass and exceed this range of forces in various accelerometers and drop types, with the lowest impacts observed on natural grass in the apex accelerometer in front drops (56.4 g) and highest impacts observed on synthetic turf in the apex accelerometer in side drops (156.5 g). As previously stated, the lower threshold for concussions in younger players is most likely a function of physiological development. Youths' heads grow to over 90% of their full size by the age of 5 and reach adult size between the ages of 10 and 16.[26] In contrast, body development lags behind, resulting in an increased head-to-body ratio for youths relative to adults. In addition, children have reduced neck strength and musculature, limiting their ability to brace against rapid head acceleration and deceleration.[27] Young athletes may be more susceptible to even small differences in force, further amplifying the need to minimize surface hardness in small increments.

A multitude of factors can impact field hardness, including field maintenance, weather, and compaction due to use.[19] There is a misconception that one of the benefits of synthetic turf over natural grass is that synthetic turf is maintenance free. Routine maintenance practices such as raising matted-down fibers, infill restoration, and paint and debris removal, may be required even weekly depending on field usage. Twomey et al reported a higher risk of injury on field surfaces that had unacceptably low hardness as well as unacceptably high hardness, emphasizing the importance of field maintenance for natural grass fields.[16] The composition, turf thickness, and material underlying the synthetic turf layer can also have significant effects on its hardness.[20] The infill used to mimic soil in synthetic turf installations, often referred to as crumb rubber, alter the impact of falling onto the turf. One study identified decreased infill density as a risk factor for football injuries.[28] A greater density of infill logically softens the impact, but these beads can degrade or be depleted over time, making maintenance crucial. Natural grass fields have traditionally required more frequent maintenance, as grass length and soil compaction change quickly over time and can alter impact force. The type of grass can also affect the field hardness. Some natural grass fields are installed using "sod," which is grass grown elsewhere, removed from the site of growth, transported to the field site, and rolled out onto the new playing surface. Other fields are grown naturally from seed. The significance of these different growing types is that playing surface hardness may be influenced by the method in which a field is grown. The aeration from the upheaval of the sod may influence how compact the surface is. Although this effect has not been well studied it does pose a potential confounder in analyzing natural grass fields. One strength of the present study is the number of fields that were tested to account for these variables that can affect playing surfaces.

The increased awareness of brain injury detection and long-term effects of brain injuries on children and adolescents must be met with a proportionate investment into examining all aspects of injury prevention. The results of the current study provide a basis for one aspect of sports safety policy in terms of equipment and environment modification. National and state-level sports organizations and governing bodies should establish data collection protocols to better understand the context in which injuries happen, such as field characteristics, equipment usage, or level of play. Analyses of these results may contribute to a more complete understanding of the circumstances that influence injury rates and therefore improve injury prevention efforts. In the state of Hawai‘i, guidelines established by the National Federation of State High School Association (NFHS) and Act 197 in Hawai‘i state legislature form the basis of concussion management.[29] These guidelines place an emphasis on symptomatology and diagnosis by enforcing initial symptom assessment, evaluation by a healthcare provider, gradual return to activity, and reporting of diagnoses to the ImPACT database. The utility of such guidelines and the reporting database could be strengthened for the purposes of further research by encouraging the reporting of variables such as field characteristics and conditions. Although this study was not designed to demonstrate a causative relationship between surface hardness and concussion rates, the results do demonstrate a significant difference in surface hardness between natural grass and synthetic turf fields. Therefore, further research and data collection is needed to incorporate these findings into sports safety policy.

One limitation of the current study was the simulated representation of an adolescent football player and impact against the ground. Although the manikin is representative of a human adolescent in size, neither weight nor composition were modified to complete accuracy. Future testing may feature more accurate representations of human anatomy or utilize sensors on live players. Additionally, some field testing was conducted during the football offseason, when fields may not have been adequately maintained to playing standards. Another limitation was that testing on a particular field was conducted over a single day. As previously stated, maintenance and weather conditions may have a significant effect on field hardness. Despite the findings of the current study, it is possible for a new, well-built, and well-maintained synthetic turf field to provide more impact attenuation than a poorly maintained natural grass field. Finally, detailed records of field maintenance, synthetic turf brand, or natural grass type were not able to be obtained. Future studies may include a longer testing period to determine the effect of climate and play usage on field hardness.

Conclusion

This study demonstrates a greater impact deceleration of a helmeted manikin on synthetic turf than on natural grass football fields. More data is needed to determine how a difference in impact deceleration translates to increased risk for concussions or other injuries. This study identifies a potential area of safety improvement for field sports of all levels, which can inform decision-making by sports organizations and governing bodies.

Conflict of Interest

None of the authors identify any conflicts of interest.

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