A Technical Report

Assessing Head Injury Risk in Sports Field Surfaces

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Assessing Head Injury Risk in a Sports Field Surface

Latest Research:

- An extensive neurological study published in January 2018 found that head impact injuries, independent of concussive signs, can induce traumatic brain injury as well as pathologies and functional consequences associated with chronic traumatic encephalopathy (CTE). [1]
- The phenomenon of sub-concussive hits to the head resulting in Chronic Traumatic Encephalopathy (CTE) is much more prevalent than previously believed. [2]
- To reduce the risk of brain injury, the frequency and severity of hits to the head must be limited to the greatest degree possible. [3]
- Head-to-ground hits are frequent and can be extremely severe, producing linear impact forces more than 2x greater than head-to-head collisions [4]
- At least 1 in 5 sports-related concussions is a result of a head-to-surface impact. [5]
- As compared to traditional artificial turf, natural turf grass produces comparatively lower impact forces. [6]

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Measuring Head Injury Risk

> The published research shows that impact is strongly implicated in the etiology of traumatic head injury, that sports surfaces present an opportunity for impacts to occur, and that different kinds of surfaces present different relative risks of injury. Therefore, it is important to assess how different surface designs and material properties can influence head injury risk. "

- Shorten M.R. & Himmelsbach, J.A. (2003)
Sports surfaces and the risk of traumatic brain injury. pp 49-69 in Sports Surfaces
(Eds. B.M. Nigg, G.K. Cole, D.J. Stefanyshyn) Calgary, University of Calgary

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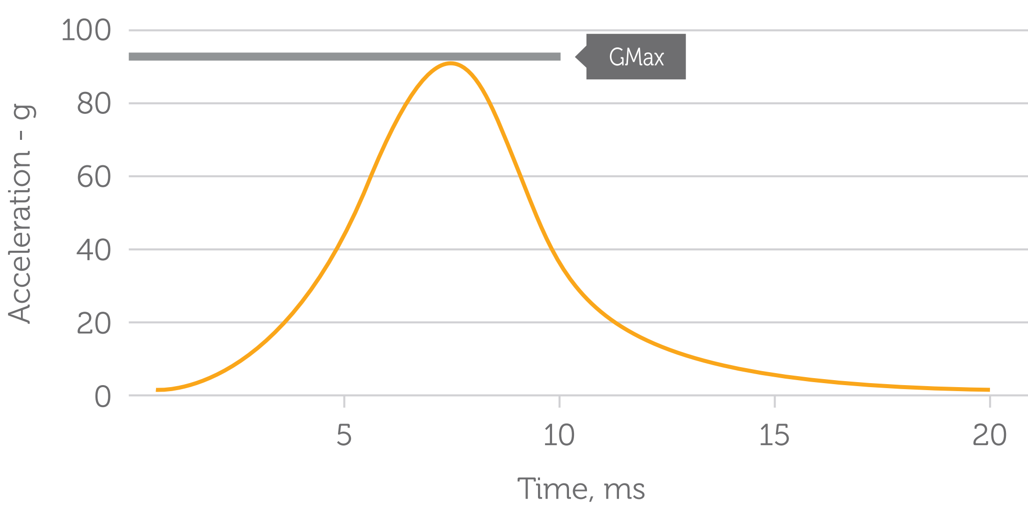
G-Max Defined

The most common test value used in the United States to characterize the "hardness" of a playing surface is the maximum deceleration rate during an impact event, which is proportional to the maximum impact force on the head or body. The linear deceleration rate of an impact is measured in multiples of *g*, which is the Earth's standard gravitational acceleration rate (1 $g \approx 9.8$ m/s^2). "G-max" is defined as the peak deceleration experienced in an impact event. The maximum force on the head during an impact event is G-max times the mass (weight) of the player's head. G-max during the impact on a playing field is an indicator of the surface's "hardness". The higher the G-max value, the harder the surface.

The head (and body) can withstand significant forces, but for very short durations. For example, a force produced by 80 *g* for an extended period of time will result in death, whereas the head may incur an instantaneous blow of 150 *g* and survive. The duration of head impacts in sports are <15 milliseconds, which is very short. The calculation of G-max does not consider the duration of the impact or the total energy absorbed by the head during the impact event and therefore is not as useful in determining the likelihood or severity of brain trauma as metrics that consider both acceleration and duration.



Example of impact curve on sports field surface

Head Injury Criterion (HIC) Defined

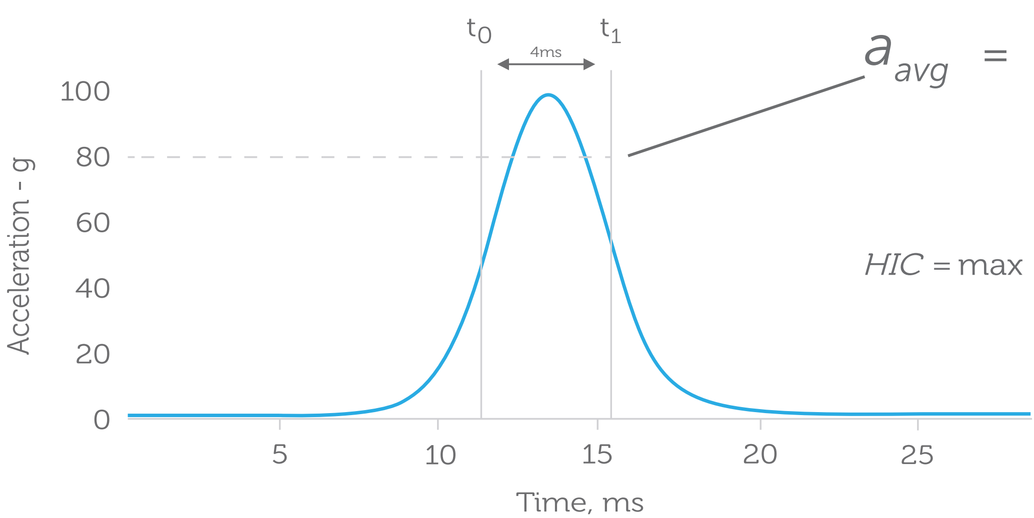
Head Injury Criterion (HIC) is a different impact test value that includes the effects of both head deceleration rate and duration during the most critical time period of the impact event, not just the peak deceleration rate. Data originating from human cadaver and animal studies has shown that the HIC is a more accurate prediction of severe head injuries as compared to peak deceleration (G-max).[7]

HIC is defined as:

$$HIC = \max \left((t_1 - t_0) \left[\frac{1}{(t_1 - t_0)} \int_{t_0}^{t_1} a(t)\, dt \right]^{2.5} \right)$$

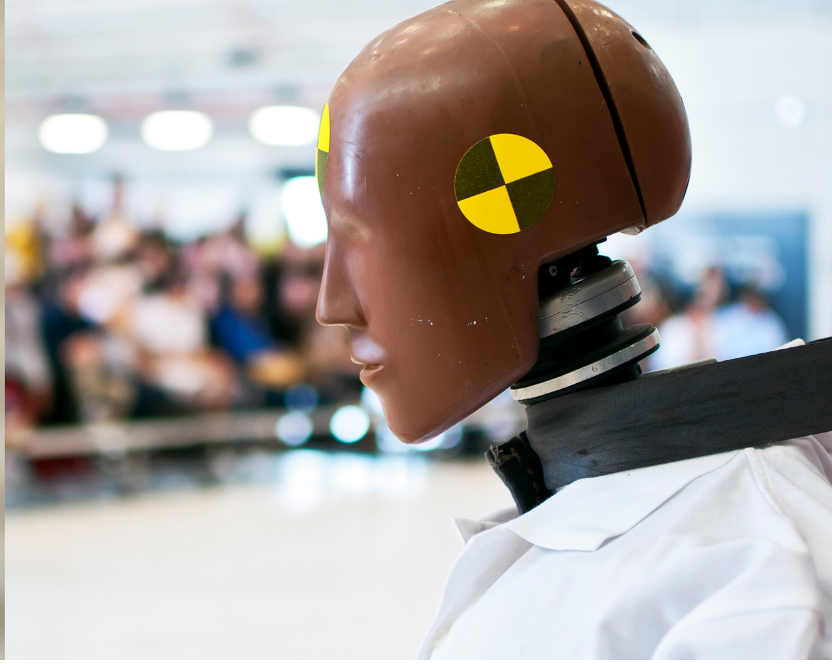
...where t_0 and t_1 are the initial and final times (in seconds) of the interval over which the HIC score is calculated, and acceleration, $a(t)$, is measured in multiples of g (Earth's standard gravitational acceleration).

The chart below shows acceleration vs. time data captured during a HIC test. The vertical lines show the time interval (4 milliseconds) that happens to maximize the HIC score for this particular impact event. The acceleration vs. time data must be analyzed iteratively to find the time interval (t_0 to t_1) that maximizes the value of the expression shown in the HIC formula above, and this maximum value is reported as the HIC score. For sports-related impacts, the HIC interval, $t_1 - t_0$, typically falls within the range of 3 to 15 ms. Impacts on sports surfaces rarely exceed 15 ms in duration.



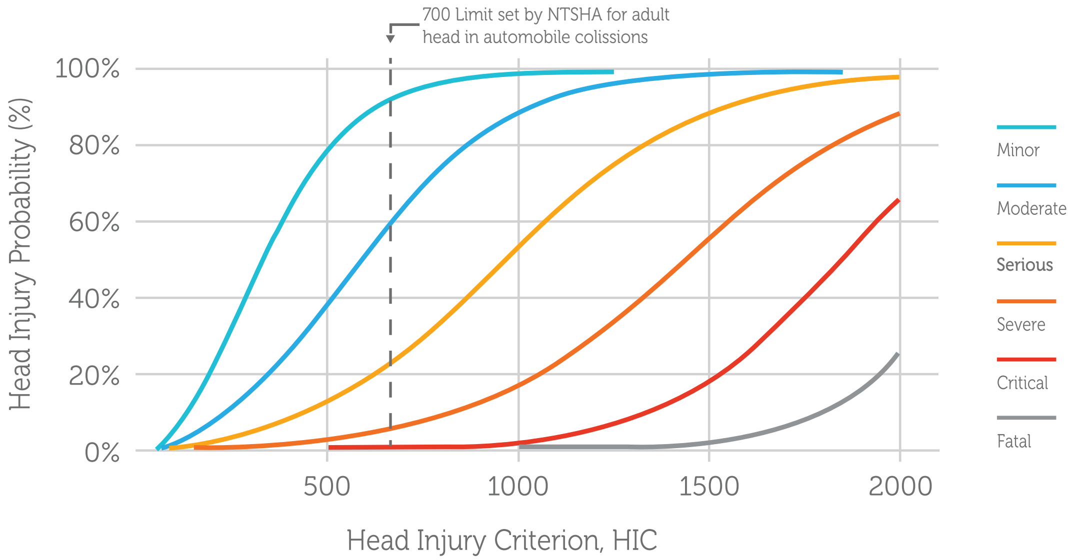
$$a_{avg} = \frac{1}{(t_1 - t_0)} \int_{t_0}^{t_1} a(t)dt$$

$$HIC = \max \left((t_1 - t_0) \left[a_{avg} \right]^{2.5} \right)$$



Applying HIC to Impact Safety Standards

For many decades the automotive industry has applied its vast resources to the study of passenger safety during impact events. Crash testing has enabled significant improvements in vehicle safety and the establishment of acceptable safety thresholds for the human head and body. The National Highway Traffic Safety Administration (NHTSA) has used HIC to assess head injury risk during automobile crashes since the early 1970's. The relationship between HIC scores and the probability of head injuries is illustrated in the expanded Prasad-Mertz Head Injury Criterion curves shown below.



The symptoms and consequences associated with the head injury severity levels shown in the figure above ("Severe", "Critical", etc.) are described by the Head Abbreviated Injury Scale (AIS), which classifies head injuries according to a series of characteristics of ascending severity.

INJURY/SYMPTOM	ABBREVIATED INJURY SCALE DEGREE					
	1 Minor	2 Moderate	3 Serious	4 Severe	5 Critical	6 Fatal
Risk of Fatality		0.1% - 0.4%	0.8% - 2.1%	7.9% - 10.6%	53.1% - 58.4%	
Headache/Dizziness						
Loss of Consciousness						
Skull Fracture						
Neurological Damage						
Hemorrhage						
Brainstem Damage						
Brain Tissue Disruption						

According to the Prasad-Mertz curves, at HIC 1,000 there is >0% risk of a Critical Head Injury (AIS 5). A Critical Head Injury is characterized by loss of consciousness, skull fracture, neurological damage and brain hemorrhage, with a >50% chance of a fatality. Based on the requirement that a possible impact must not produce "Critical" head injuries (AIS 5), playground and certain international sports standards currently specify HIC 1,000 as the "Critical" threshold. A simulated head impact from a fall that produces a HIC score >1,000 is considered beyond the "Critical Fall Height."

Based on the requirement that a simulated automotive collision should not produce "Severe" head injuries (AIS 4), the NHTSA has set their HIC threshold at 700 for persons 6 years old or older. At HIC 700 the risk of a Critical head injury (AIS 5) is zero and the risk of a Severe head injury (AIS 4) is 5% - statistically considered "improbable".

The table below identifes the HIC limits of the NHTSA.The limit is HIC 700 for an individual six years old and older for vehicles manufactured or sold in the United States after the year 2000.

DUMMY TYPE	Large Adult Male	Mid-Sized Male	Small Female	6-Year-Old Child	3-Year-Old Child	1-Year-Old Child
HIC_{15} LIMIT	700	700	700	700	570	390

Many of the research findings from the automotive industry can be adapted and applied to playing field surfaces to improve player safety. The adoption of new impact test methods, HIC, and meaningful safety thresholds can lead to developments in artificial turf systems as important as the airbag was for vehicle passenger safety.

The research from the automotive industry and the HIC limits set by the NHTSA lead to the question posed in 2014 by the ASTM Standard Technical Paper 1552 – The Mechanism of Concussion in Sports:

"Impact Attenuation Values and Prevention of Head Injuries on Sports Fields: Do Athletes Deserve Protection the Same as or Better Than in an Automobile Crash?"

Field Testing: G-Max and HIC

The purpose of testing the impact attenuation properties of a sports surface is to estimate the probability that an impact on the surface will cause an injury. The impact response of a playing field is measured by dropping a "missile" onto the surface. An accelerometer, an electronic device mounted within the missile, enables the measurement of acceleration over the duration of an impact. The acceleration vs. time data collected by the device can be analyzed to determine the desired result (e.g., G-Max or HIC). The higher the drop height for any given missile, the greater the velocity and resulting impact energy.

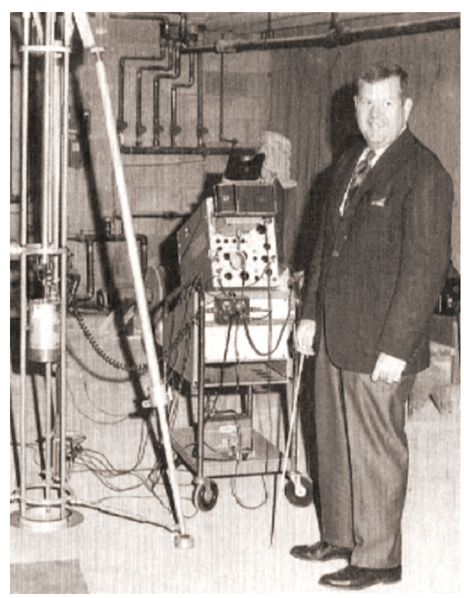
In order to have value as an estimator of an injury risk, an impact test must simulate the event that presents that risk. Despite significant advances over the past decade in sports field assessment by multiple international governing bodies, artificial turf playing fields in North America are still today most often tested using the ASTM F355-A method, commonly referred to as the "G-max test".

The origins of this test date back to the 1960's and 70's. In the test, a 20 lb, 20 sq. in. flat-faced cylindrical "A" missile is dropped from a 24" fall height, producing 54.5 J of energy. This flat-faced missile does not penetrate surfaces the way a body or human head would.

Consequently, it introduces bias in test results for thin, soft surfaces that would otherwise "bottom out" prior to effectively absorbing the impact during a test with a missile shaped more like a human head. With minimum surface penetration, this test method significantly distorts the relative injury risks imposed by artificial turf systems as compared to natural turf.

ASTM F355-A G-Max Testing Device

Ed Milner with equipment used to measure the impact-attenuation characteristics of artificial turf.



Extensive research has demonstrated that an impact test with a missile having geometry and inertial properties that differ significantly from those of the human head is not applicable to the prediction of head injury outcomes. Impact tests that use missiles with a geometry and mass approximating those of a human head are strongly preferred when attempting to assess the head injury risk of sports surfaces. Multiple studies have demonstrated that the impact results from flat faced missiles have no correlation to results obtained with surrogate head form missiles. [7-9] The "A" missile test is therefore not to be considered a test for head injury risk assessment, but simply a measure of resilience.

The ASTM F355-E head form missile can be used to simulate a head impact with the surface. The test method involves dropping a 10.1 lb hemispherical missile with a geometry and mass approximating that of the human head (similar to the mid-adult Hybrid III, a crash test dummy head form). A recent study compared the E missile to the Hybrid III by performing impact tests on a variety of playing field surfaces. The study found a strong correlation between the two devices ($R^2 \sim 0.90$) for HIC scores up to 700 and peak accelerations up to ~140 *g*.[9]

Therefore, the E missile has been shown to be a reasonably accurate and repeatable test apparatus to assess severe head injury risk on playing fields, particularly for values up to HIC 700. For many years, the E missile method has been the basis for head injury risk assessment in playgrounds and for sports fields by multiple sports governing bodies.

ASTM F355-E head form missile

Triax 2015 Tripod with ASTM F355-E head form missile

Mid-adult Hybrid III

"The Farm" research center for the University of Tennessee - TurfGrass Science Department - Test plots of both natural and artificial turf allow the researchers to study the effects of weather and simulated game play in a large-scale, realistic environment.

Natural Grass: The Benchmark for Artificial Turf

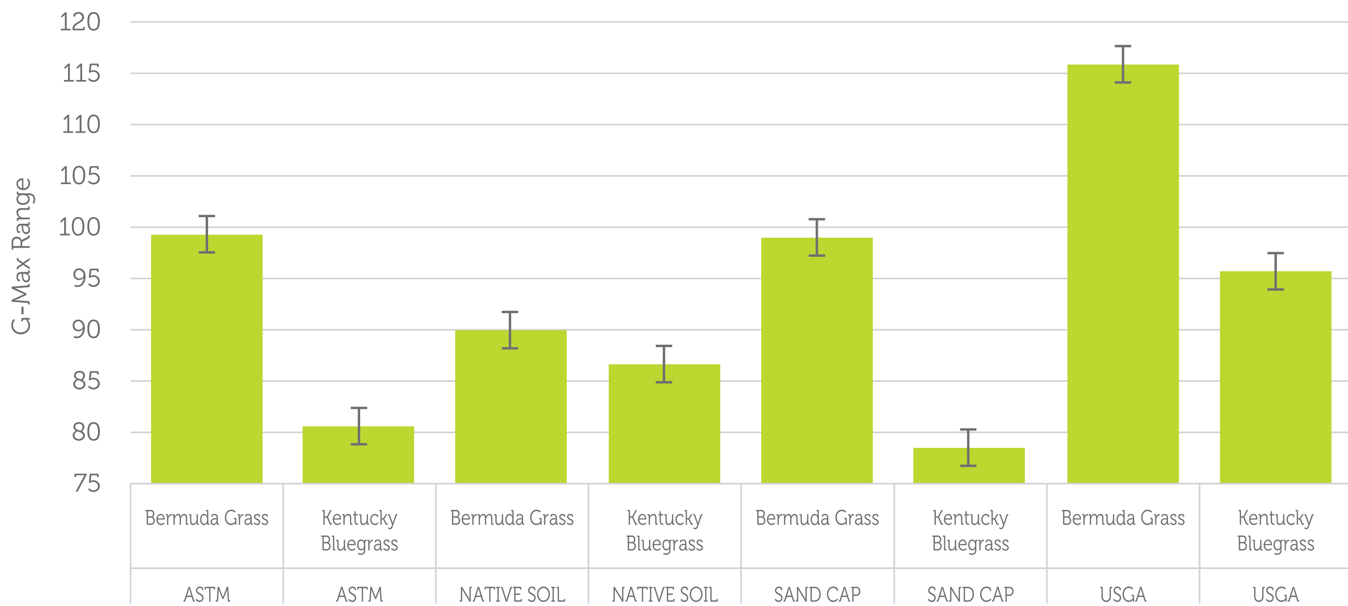
The objective for a quality playing field is to produce the lowest possible impact forces while simultaneously providing a sufficiently firm running surface. When comparing two sports surfaces, the surface with the higher critical fall height will result in lower impact forces than the other surface at any given fall height. This is important when considering both sub-concussive and concussive hits to the head have been shown to cause brain injury. Concurrently, the playing field must provide sufficient under-foot firmness and stability to reduce fatigue and help prevent lower extremity injuries.

Well-groomed natural turf grass provides a logical benchmark for artificial turf. Natural turf is overwhelmingly the preferred playing field surface of athletes and, although firm under foot, has been shown to produce significantly lower overall impact values as compared to traditional artificial turf.

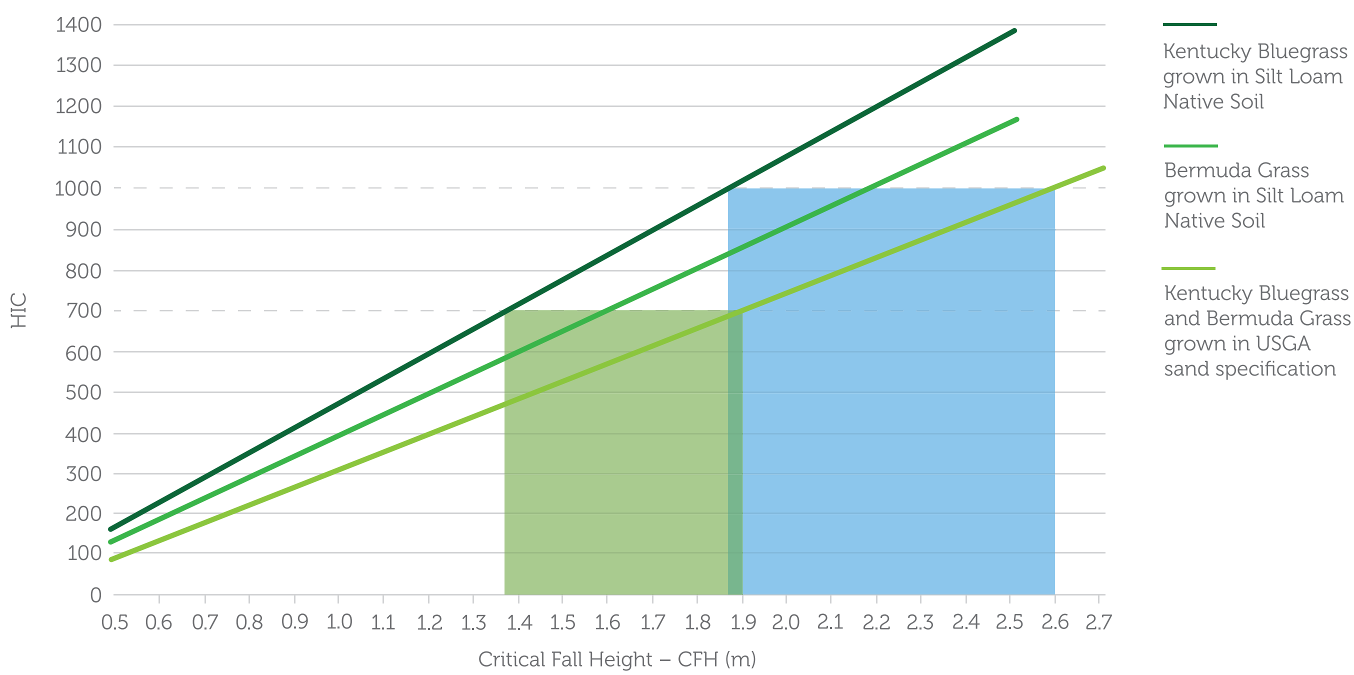
Multiple independent studies have shown well-groomed natural turf grass to produce the following impact values:

- ASTM F355-E HIC result of <700 from no less than a 1.3 m drop height and up to 1.8 m
- ASTM F355-E HIC result of <1,000 from no less than a 1.8 m drop height and up to 2.6 m
- ASTM F355-A G-max result of between 70-105 *g*
- ASTM F3189-17 Vertical Deformation result of between 6-11 mm
  (a measure of surface firmness for the running athlete)

Research conducted by the University of Tennessee Center for Athletic Field Safety measured G-Max on different species of natural sports grass over different base types. The specimens were all representative of a well groomed natural grass field. The range of G-max values for the different configurations was 78-115 *g*, with most systems producing results below 100 *g*.



The same test plots were also used to determine critical fall height. For a HIC threshold of 1000, the critical fall height for natural sports turf ranged from 1.8 m (5′ 11″) up to 2.6 m (8′ 6″).



HIC 700 Range = 1.37 - 1.9 m, HIC 1000 Range = 1.86 - 2.59 m

Facts to Consider for Player Welfare

Head impacts, independent of concussive signs, can induce traumatic brain injury.

Head-to-ground hits are frequent and can be extremely severe, producing linear impact forces more than 2x greater than head-to-head collisions.

The objective for player welfare on a playing field is to produce the lowest possible impact forces while simultaneously providing a sufficiently firm, playable surface.

When comparing two sports surfaces, the surface with the higher critical fall height will result in lower impact forces than the other surface at any given fall height.

The ASTM F355-E head form missile can be used to measure the results of a simulated head to surface impact.

Surveys show athletes overwhelmingly prefer natural turf as a playing surface to artificial turf.

Results from impact tests on well-groomed natural turf can be used as benchmarks for artificial turf surfaces to ensure a comparable level of risk.

ASTM F3189-17 (Advanced Artificial Athlete) can be used concurrently to measure vertical deformation under the simulated load of a running athlete to ensure sufficient surface firmness.

Reference ASTM Standards

The American Society for Testing and Materials develops and publishes voluntary standards, including those selected here below, with explanations that relate to athletic field testing:

ASTM F355-2016:
Standard Test Method for Impact Attenuation of Playing Surface Systems.
This test method defines three missiles for use in playing surface impact tests, including the hemispherical head form E missile and the flat-faced A missile. The procedure section of this standard states that, "The user is to select the appropriate missile as called for in the surface specification". This may be an ASTM specification, a facility designer specification, a field owner specification, or a sports governing body specification.

ASTM F1936-10 :
Standard Specification for Impact Attenuation of Turf Playing Systems as Measured in the Field.
This specification based on the A missile method currently requires that the average Gmax of the second and third drops at a single test point on the field is not to exceed 200 *g*. However, a result of 200 *g* is not only far above the maximum value measured on natural turf, but the specification itself states:

> *"This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use."*

"Nothing in this specification is intended to keep an owner, architect, engineer or other specifier from establishing more stringent performance requirements for a turf playing system."

ASTM F3189-2017:
Standard Test Method for Measuring Force Reduction, Vertical Deformation, and Energy Restitution of Synthetic Turf Systems Using the Advanced Artificial Athlete.
This standard defines a method for the measurement of vertical deformation, a determination of surface firmness under the simulated foot impact of an running adult athlete.

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(1) Tagge, Chad A; Fisher, Andrew M., et al. – Concussion, microvascular injury, and early tauopathy in young athletes after impact head injury and an impact concussion mouse model – Brain, A Journal of Neurology 2018

(2) Mez J, Daneshvar DH, et al. – Clinicopathological Evaluation of Chronic Traumatic Encephalopathy in Players of American Football – Journal of the American Medical Association 2017

(3) Cantu M.D., Robert – Boston University School of Medicine – Department of Neurology 2016

(4) Athletic Surfaces & Concussion Research in the NFL – ASTM F08.65 Synthetic Turf Playing Systems and Surfaces 2017

(5) Nowinski Ph.D., Chris, et al. – The Role of Synthetic Turf in Concussion – Concussion Legacy Foundation 2015

(6) Dickson, K.H., W. Strunk, and J. Sorochan. 2018. Head impact criteria of natural grass athletic fields is affected by soil type and volumetric water content. Proceedings. 2:270

(7) Ashare A, Ziejewski, M. – The Mechanism of Concussion in Sports ASTM STP1552-EB 2014

(8) Shorten Ph.D., M.R. & Himmelsbach, J.A. (2003) Sports surfaces and the risk of traumatic brain injury. pp 49-69 in Sports Surfaces (Eds. B.M. Nigg, G.K. Cole, D.J. Stefanyshyn) Calgary, University of Calgary

(9) Biokinetics – Head to Turf Impact – ASTM F08.65.13 Task Group 2015

(10) Sorochan Ph. D., John, et al. – University of Tennessee Center for Athletic Safety – Measuring Athlete to Surface Interactions – ASTM F08.65.13 Task Group 2016

For more information:

All studies are available upon request. For any questions or to learn more about the science of field design and safety testing, please contact us.

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