Performance Characteristics of Sport Floors

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About ASET Services

- Founded in 2002
- 3rd party testing, inspection and engineering services
- Focused on sports surfaces and equipment
- FIBA test partner

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My Background

- Received degrees in Engineering from Purdue
- Involvement with sports surface performance started at Purdue in 1994
- Served as the Research and Design Engineer for Robbins
  - System Development, Installation Tools, Construction Methods, Portable Design and Manufacturing
- Licensed Engineer in Indiana and Ohio
- Developed and contributed to numerous sports surface standards (ASTM)

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Presentation Overview

- Review 3 impact standards commonly used in indoor sports facilities
  - **Force Reduction** (ASTM F2569, EN 14808??, DIN 180332-2, MFMA PUR)
  - **Vertical Deformation / Area Deflectio**n (ASTM F2569, EN 14808??, DIN 180332-2, MFMA PUR)
  - **HIC (Head Impact Criteria) (ASTM F355)** – Considering a new paradigm for hardwood indoor floors

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Presentation Overview

- For Each Impact Test
  - Summarize the physics of the test
  - Review biomechanical/other basis for each test
  - Review relationships between athlete safety/performance/comfort and each test

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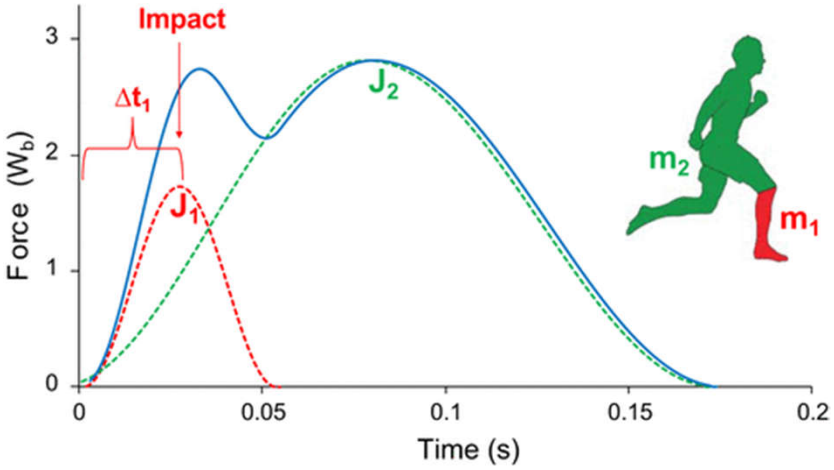
Running Gait – Biomechanical Basics

- This theory of Ground Reaction Forces dominated in the 1970's
  - Typical total ground reaction force in blue
  - Impact/Passive Forces in red (J1)
  - Propulsion/Active Forces in Green (J2)



Graphic Source: Udofa et al (2019)

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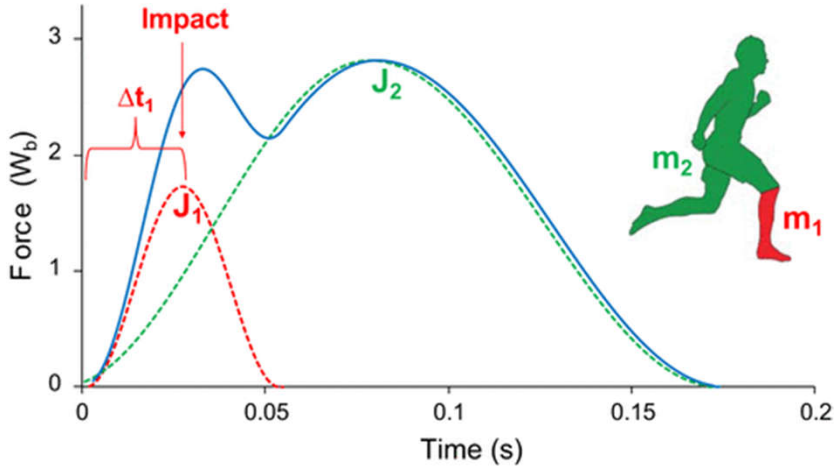
Running Gait – Biomechanical Basics

- This theory likely guided force reduction and vertical deflection test development



Graphic Source: Udofa et al (2019)

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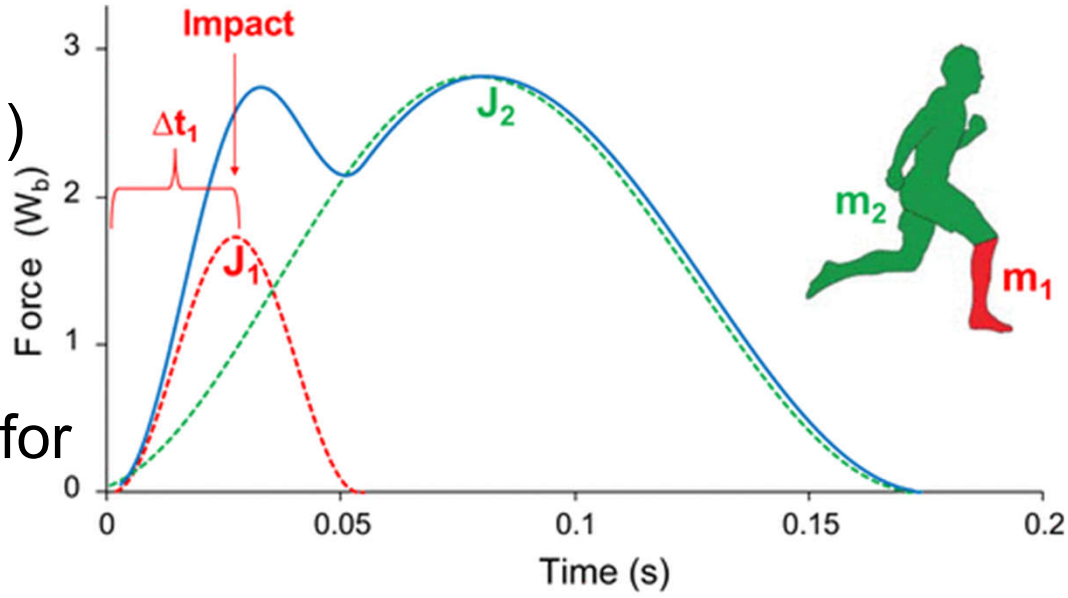
Running Gait – Biomechanical Basics

- While Force Reduction considered the ‘Passive/Impact’ phase (red)
- Vertical Def considers the ‘Active/Propulsion’ phase (Green)
- It is likely that the goal was for Force Reduction + Vertical Def to represent the entire GRF



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Force Reduction

- What are your thoughts on what Force Reduction means and how it relates to athlete
  - Safety
  - Comfort
  - Performance

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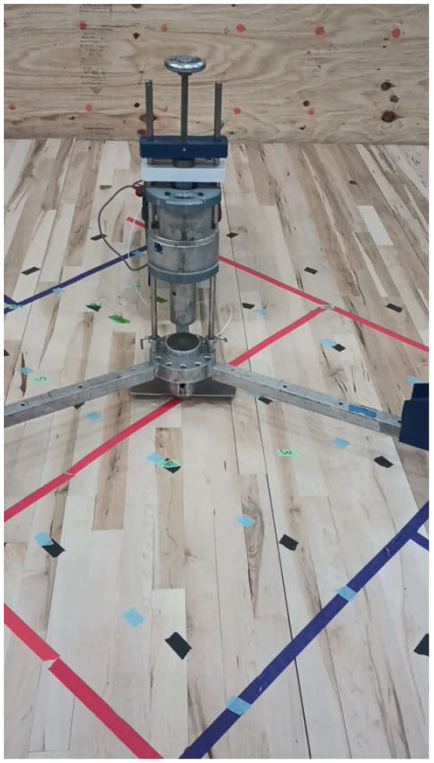
Force Reduction

- Basketball Biomechanics Video
- Force Reduction Test Video



Video Source: ASET Services, Inc

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Force Reduction

- One of the most common tests for sports surfaces
  - Specifications: ASTM F2772, EN 14904, FIBA, MFMA-PUR
- What force reduction means:
  - A force reduction of 25% means that the impact on a surface was 25% less than ‘concrete’
  - A force reduction of 50% means that the impact on a surface was 50% less than ‘concrete’

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Force Reduction

- Summary of Physics
  - Generates an impact energy of 95 in-lbs
    - About the same as dropping a basketball from 72”
  - Considers only an ‘instant’ in time where the maximum impact force is generated – does not evaluate the entire impact duration
  - Peak force is generated in about 0.02 seconds (20 milliseconds)
  - A 50% force reduction represents a 742 lbs impact (about 3.75 x body weight @ 200 lbs)
    - Which may have meaning, and it may not!
  - Indicates how the floor affects the athlete

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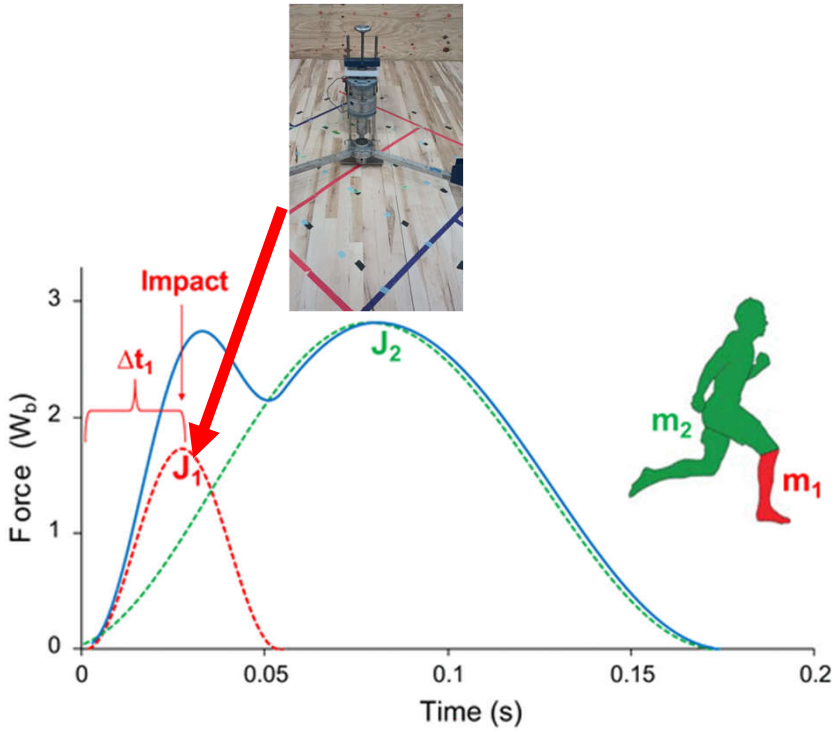
Force Reduction – Biomechanical Basis

- Back to basic GRF theory
- Force Reduction – May be related to the impact portion of GRF (red).
- Force Reduction – only represents the instant in time when the maximum value occurs



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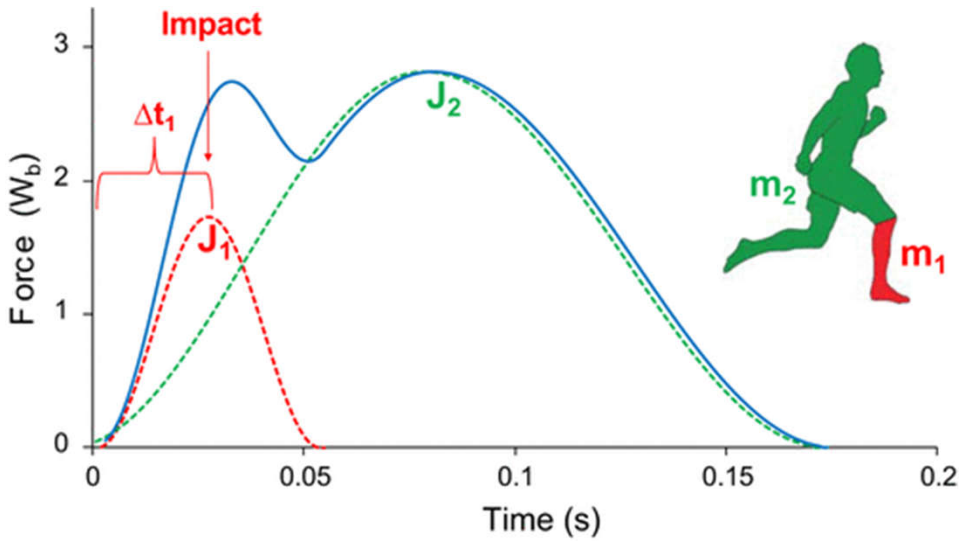
Force Reduction – Biomechanical Basis

- No data linking these Force Reduction to a reduction in injury severity or occurrence rate has been found



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Force Reduction – Biomechanical Basis

- Increased Force Reduction of the surface was thought to lower the magnitude of the GRF during passive/impact portion.
- List of scientific studies that link increasing force reduction (lower impact forces) with fewer or less sever injuries
  - The complete list is – no studies show this
- Biomechanical basis for force reduction test is weak
- Biomechanical basis for pass/fail, and class levels within common standards (ASTM, EN, DIN, FIBA) is nonexistent.

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Force Reduction – Biomechanical Basis

- Subjective case-studies where athletes report being in less pain after practices or games on softer floors are common, but poorly documented
- No data has linked force reduction test results to injuries
- It is my opinion that Force Reduction is an indication of ‘comfort’ but not related to safety

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Vertical Deformation and Area Deflection

- What are your thoughts on what Vertical Deformation means and how it relates to athlete
  - Safety
  - Comfort
  - Performance

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Vertical Deformation and Area Deflection

- What are your thoughts on what Area Deflection means and how it relates to athlete
  - Safety
  - Comfort
  - Performance

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Vertical Deformation and Area Deflection

- While Vertical Deformation and Area Deflection are measured during the same test/impact they are quite different
  - Considering Area Deflection even though ASET does not consider a test that provides insight into the athlete safety or performance

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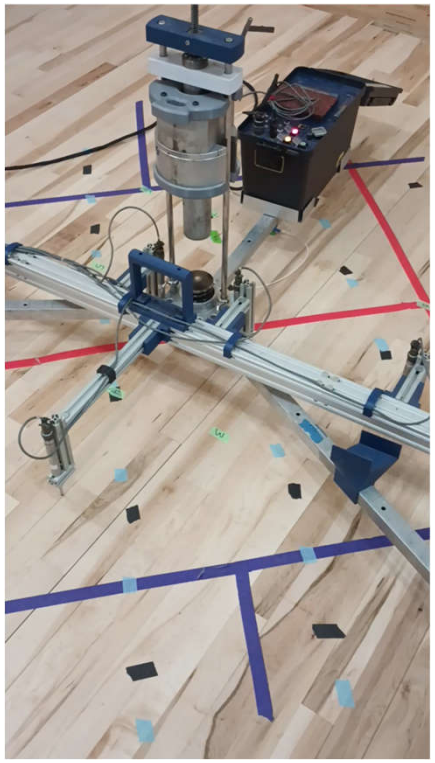
Vertical Deformation & Area Deflection

- Basketball Biomechanics Video
- Vertical Deformation Test Video



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Vertical Deformation and Area Deflection

- Summary Physics –
  - Creates an impact with 207 in-lbs of energy
  - The impact generates approximately 337 lbs on ***every*** surface regardless of surface hardness
- In my opinion Vertical Deformation is a reflection of how the floor is affected by the athlete during the impact rather than the floor affects the athlete

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Vertical Deformation and Area Deflection

- Summary Physics –
  - Like Force Reduction, Vertical Deformation and Area Deflection consider only ‘instants’ in time, the instant where maximum force and deflections are generated.

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Vertical Deformation

- Vertical Deformation is recognized in all standards that include Force Reduction
  - Example Specifications: ASTM F2772, EN 14904, FIBA, MFMA-PUR
- Summary of Physics
  - A 44 lb (20 kg) mass is dropped from 4.72” (120 mm) generating an impact of 207 in-lbs of energy

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Vertical Deformation

- Vertical Deformation is the measured deformation at impact normalized to a standard 1500 N (337 lbs) impact
    - So a Vert Def value of 2.3 mm means that the floor would be expected to move 2.3 mm under a 1500 N impact.

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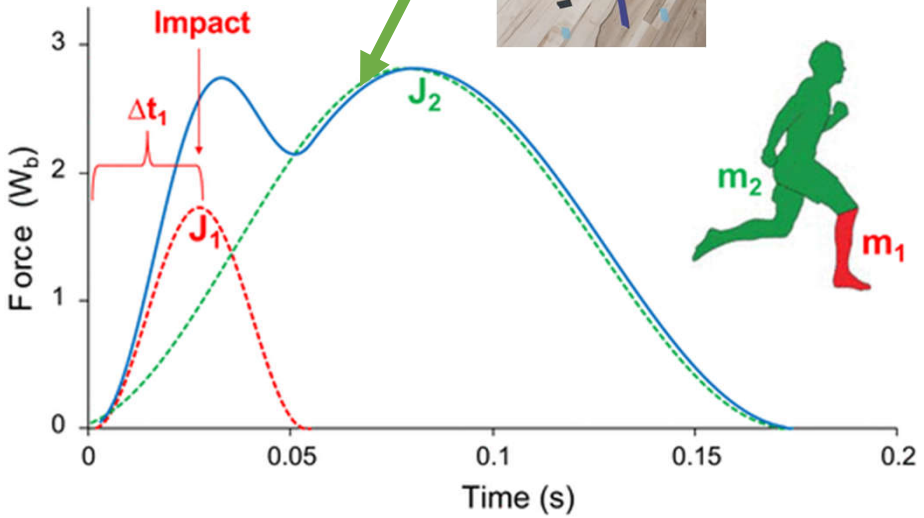
Vertical Deformation

- **Vertical Deformation Biomechanics**
  - Vertical Def considers the ‘Active/Propulsion’ phase (Green)
    - While Force Reduction considered the ‘Passive/Impact’ phase (red)



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Vertical Deformation Biomechanical Basis

- Vertical Deformation represents how much the floor moves beneath the foot during the impact
- There is no study linking vertical deformation to injury severity or rate
- The industry likely used ‘case-study’ data to guide the establishment of a 3.5 mm maximum allowable vertical deformation on point elastic floors
  - However no documentation has ever been found

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Vertical Deformation Biomechanical Basis

- The most plausible biomechanical basis that I've heard is that Vertical Deformation is related to foot stability and on synthetics foot blocking.
  - Since establishing a maximum Vert Def of 3.5 mm on synthetic floors, the industry seems to have mostly prevented knee and ankle injuries caused by early full-pour urethane systems
  - However, there is no scientific data supporting either notion or linking vertical deformation to a reduction in injury rate or severity

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Area Deflection

- Not universally recognized as a significant property
  - EN 14904 does not include it because they could not even agree that the test had meaning
- When recognized, no single level is universally accepted
  - DIN set limit at 15%, some countries allowed 25%, some did not measure.
- Area Deflection provides insight into how large areas of a floor move during an impact

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Area Deflection

- Area deflection of wood floors represents the vertical motion 500 mm (19.75”),def_{500}, from an impact compared to the vertical motion at the point of impact, def_{impact}
  - An area deflection of 15% means that the deflection 500 mm from the impact was 15% of the magnitude produced at impact

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Area Deflection Biomechanical Basis

- Simply put there isn't a link between area deflection and biomechanics.
  - Theory 1: Prevents one athlete from altering another athlete?
    – No data to support
    - Consider a floor with an AD of 10% and 2.3 mm VD-
      - The floor 500 mm away would be compressed 0.23 mm (0.009")
    - Consider a floor with an AD of 30% and 2.3 mm VD
      - The floor 500 mm away would be compressed 0.69 mm (0.027") less than 1/32"

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Area Deflection Biomechanical Basis

- Continued:
  - Theory 2: Moves less mass therefore better for lighter athlete? – No data to support
  - Theory 3: Prevents one athlete from altering the force reduction of an athlete landing nearby?
    - Recently heard an argument that it prevented the floor from moving ‘up’ toward the neighboring athlete during an impact – yet all measurements are downward
- Lastly – The differences are minute and likely contribute to the inability to link this property to safety
  - The difference between 10% and 15% AD is roughly 0.006” (less than 1/100th“)

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Area Deflection Biomechanical Basis

- While there is not a biotechnical basis some vague references exist to early tests on energy return.
- It is possible that this property was seen as related to something else that could not be measured with existing technology
  - Keep in mind the technology that these standards were developed with in the 1970's was limited.
  - Computing energy return would have been timely and laborious
  - It is possible that a 15% area deformation correlated with another property they were actually trying to measure but could not with the technology of the time

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Example of ‘Antique’ Technology Used In Standard Development

- This is a photo of data collection of head impacts during a football game (Aagaard & Dubois 1962).
  - Helmets had a radio transmitter
  - Receiver at the sideline
  - Recorded on tape reel
- You can see how we’d do things differently today.

Image Source: Aagaard & Dubois (1962)

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Force Reduction and Vertical Deformation Limitations

- In the real world athletes wear shoes – those shoes may provide greater force reduction and vertical deformation than the surfaces
- Athletes adapt their biomechanics to generate the impact forces they prefer – athletes may generate the same forces/deformation regardless of the surface they are on
- Consider only 1 impact energy may be significantly different for larger or smaller athletes

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Where did original limits in DIN 18032-2 come from?

- What about the limits in the original DIN 18032-2, where did those come from?
  - Example for wood (area elastic) – Force Reduction> 53%, Vertical Def > 2.3 mm, Area Def less than 15%
  - There is no biomechanical basis
    - Or to put another way: There is no link that surfaces that meet all 3 requirements are ‘safer’
  - It is likely these numbers came from significant product testing which presented barriers to entry into the German market from countries that utilized different materials and technology

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Summary So Far

- There is no known relationship between current tests (Force Reduction, Vertical Deformation, Area Deflection) and
  - Biomechanics
  - Injury Rate
  - Injury Severity
- At best there are case studies (i.e. user reports) where athletes report less pain and/or more comfort on more resilient systems
  - ASET considers all three properties to be indicators of comfort not safety

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Could There be a New Paradigm in Indoor Sports Impact Testing?

- What might that look like?
  - A test not based on lower extremity impacts consideration
  - A more holistic approach to athlete safety
  - A test that realizes that there are higher energy impacts
  - A test that has a foundation is actual safety
    - Recognized to be associated with injury rates and severity
  - A test that is already widely used in other sport and play surfaces in North America and Globally

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Why consider a new design/safety paradigm?

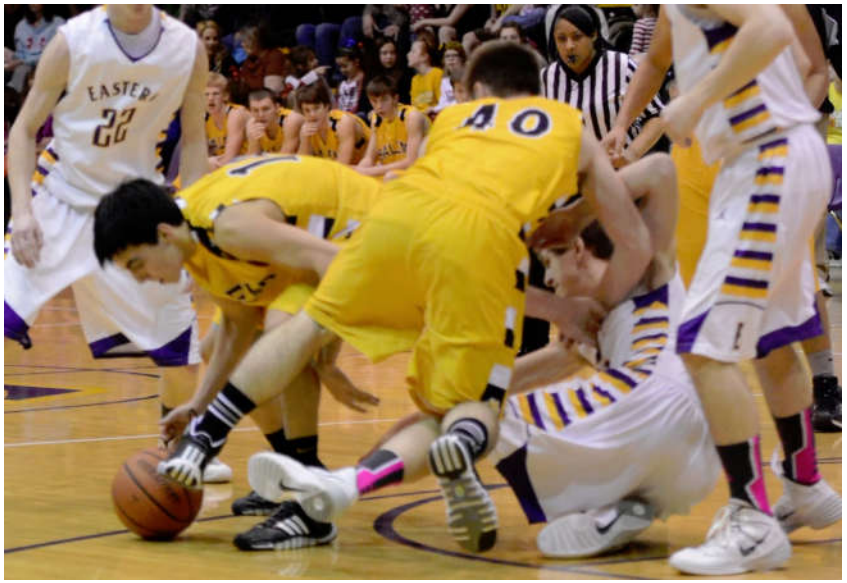

Image Source: ASET Services, Inc

- **The industry can and should adopt a holistic approach to athlete safety and comfort**
- Current low energy impacts ignore realities of the game
- We should protect athletes during all impacts

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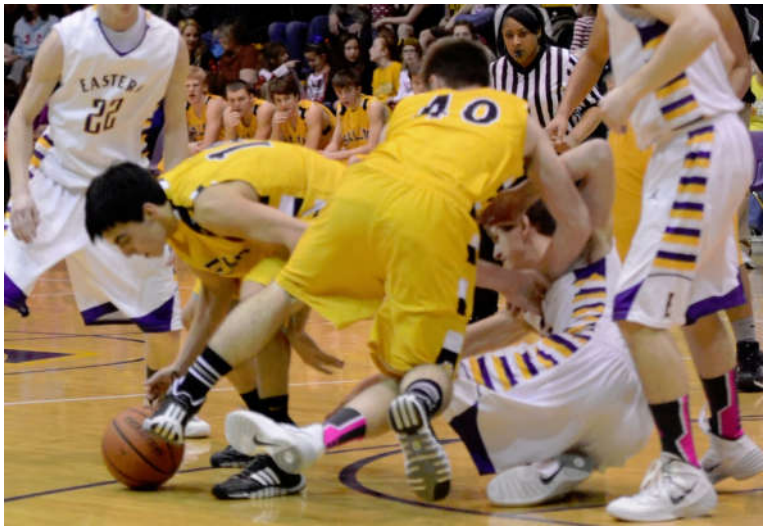
Is it time to consider HIC?



- **What is HIC?**
  - Commonly referred to as the ‘Head Injury Criteria’
  - Is an impact severity index
  - Provides an assessment of an impact with a given velocity, or energy
    - FR, and VD tests consider only 1 impact velocity/energy
  - Higher values indicate more severe impacts

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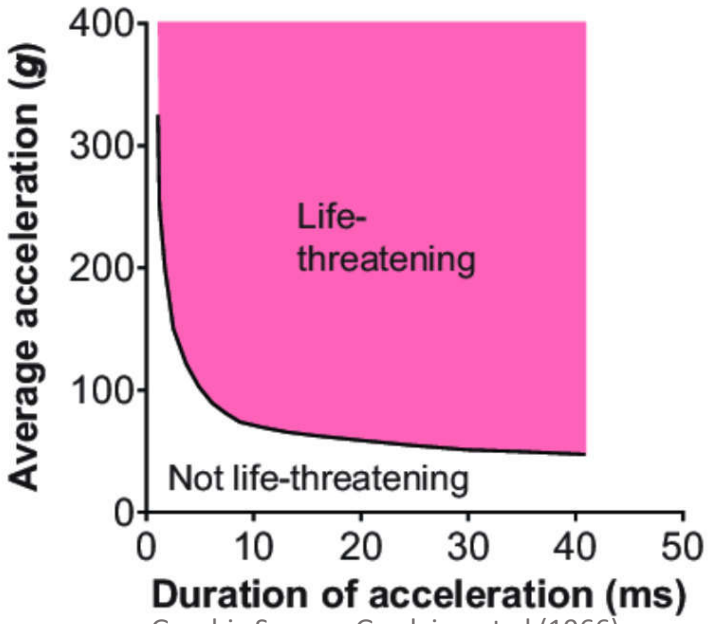
The safety background for HIC

- HIC - Based on data collected during cadaver testing at Wayne State
  - Research started in the 1940's
  - A Tolerance curve was developed by Gurdgian et al 1966)
  - This curve has been used to develop multiple severity indices – with HIC being the most widely accepted and used



Graphic Source: Gurdgian et al (1966)

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The safety background for HIC

- HIC Headform - Based research by Daniel (1968)
  - Daniel's research has been used in the design of automotive safety test dummies and equipment as well as multiple ASTM standards.
  - Left – Ed Milner with Early Synthetic Turf Test device

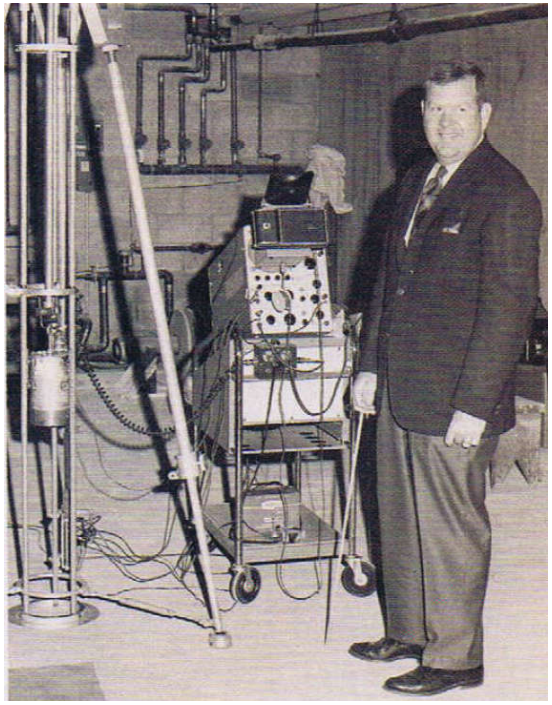

Image Source: Milner (1982)

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HIC-Injury Relationship

- National Highway and Transportation Agency (NHTSA, 2005) Developed Relationship Between AIS Injury Severity and HIC Impact Severity
- The Association for the Advancement of Automotive Safety developed and maintains the AIS Injury Scale

- AIS Injury Scale Examples
  - AIS 0 – No Injury
  - AIS 1 – Minor (headaches, dizziness)
  - AIS 2 – Moderate (closed skull fractures unconscious < 15 min)
  - AIS 3 –Serious (unconscious > 15 min)

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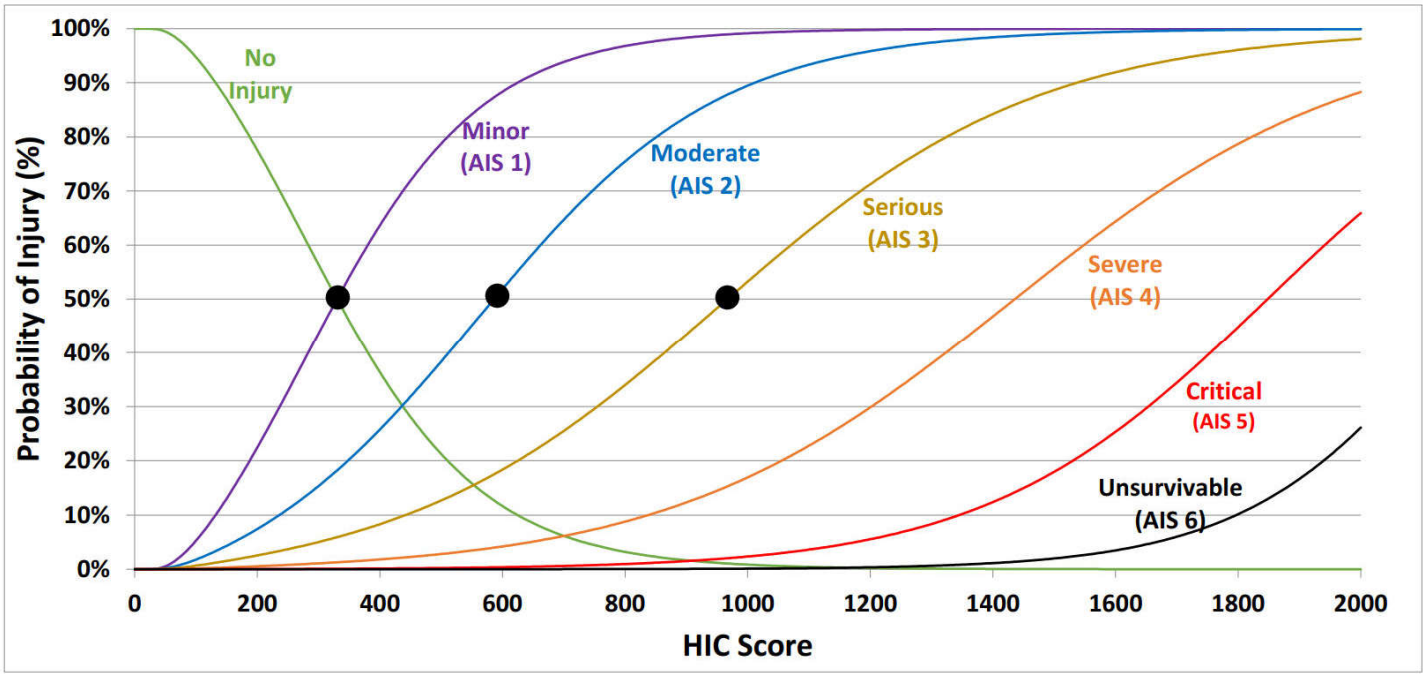
HIC-Injury Relationship



Graphic Developed from NHTSA (1997) and Prasad & Mertz (1985)

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HIC History in Sports Testing

- Current ASTM HIC Tests:
  - Playground Surfacing and Equipment - ASTM F1292
  - Indoor Wall Padding – ASTM F2440
  - Wrestling Mats - ASTM F1081
  - Rugby Turf – ASTM F3146
- Legacy Hardwood/Indoor Applicaton
  - BS 7044 – Artificial Sports Surface, Part 4 – Specification for Surfaces for Multi-Sports Use
    - Used a very similar device, and used Gmax in place of HIC but the concept was very similar. Floors were either rated ‘Impact Absorbing’, or ‘Unrated’

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Are Head Injuries Relevant in Sports?

- Floor impacts cause more than 1 in 4 basketball concussion (Daneshvar et al, 2011)
- 20% of all cheerleading injuries are concussions with 84% occurring in practice (Labela et al, 2012)
- Girls volleyball players have the 3rd highest rate of concussions in high school sports with 5% being due to impacts with the floor (UPMC Health, 2017)

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HIC Testing of A Hardwood Floor

- So what does HIC testing of area elastic floors look like?
- We performed drops at 4 ft, 5 ft, and 6 ft

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What might a HIC standard look like?

- We think it uses BS7044 as a general guideline with some modifications – ASET is currently developing a model standard and specification based on HIC results.
- Informative:
  - A 36 inch fall generates an impact energy of 360 in-lbs, or more nearly 75% more than Vertical Deformation testing, and 250% more than Force Reduction testing
  - A 4 ft drop would represent 480 in-lbs, and a 5 ft drop 600 in-lbs (6 times the impact energy generated during force reduction testing).

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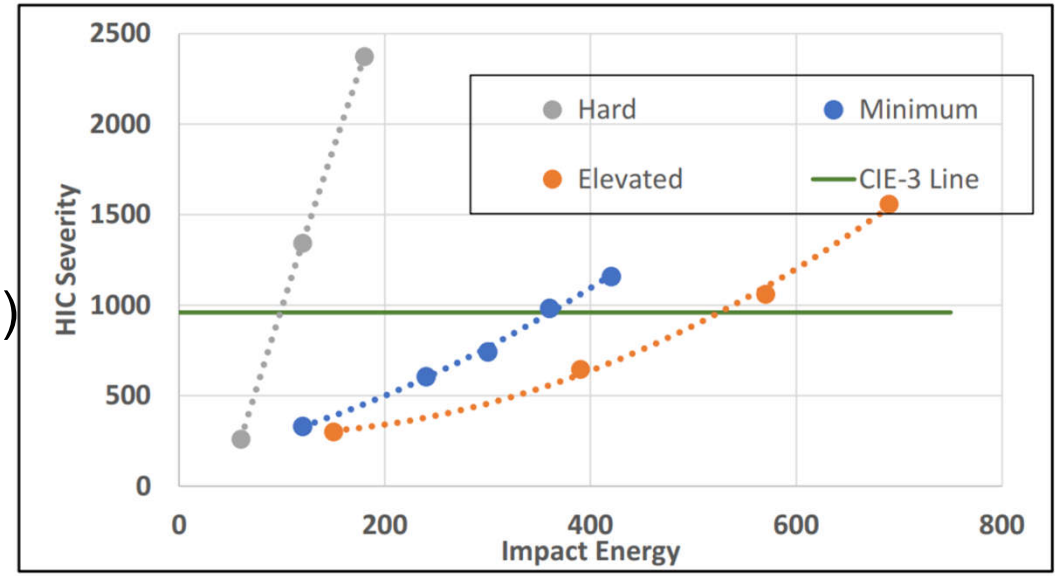
By Wood is Hard – Is there a difference?

- Here are 3 general floors
  - Hard floor (gray) would be unrated but produces a HIC of 960 at only 7”
  - The minimum ‘rated’ floor (blue) produces a HIC of 960 @ 36”
  - The elevated floor (orange) produces a HIC of 960 @ 54”



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By Wood is Hard – Is there a difference?

- Designers and Owners have to give up something to increase fall protection, or achieve higher fall heights, ball rebound

Floor	Height at HIC=960	Force Reduction	Ball Rebound
Hard	6.8”	10%	100%
Minimum	36”	60%	97%
Elevated	54”	63%	93%

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Hypothetical HIC Results at 4’ Drop

- Consider an AIS3- Injury
  - Skull fractures
  - Loss of consciousness
- Currently floor #1 is theoretical, but floor #2 exists as to floors 3 and 4
- This shows how lower HIC values are associated with lower injury probability rates

Floor	Measured HIC @ 4ft Drop	AIS 3 – Injury Probability
#1	450	10%
#2	650	22%
#3	852	39%
#4	960	50%

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Design Notes – HIC Related

- Point Elastic surfaces doubtful to meet BS 7044 would have been unrated
- Combination Systems could easily meet BS 7044
- Meeting BS7044 with 3/4” pads beneath a wood floor easier than with ½” pads
  - Part of that ‘holistic’ athlete approach – current tests fail to provide reasons why a thicker pad might be safer for the athlete

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Conclusion

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Force Reduction

- Summary of Physics - Continued
  - A 50% force reduction represents a 742 lbs impact (about 3.75 x body weight @ 200 lbs)
    - Which may have meaning, and it may not!
  - Surface hardness changes the impact forces generated during the test
    - It was assumed that these changes correlated into changes in forces generated by athletes and performers

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References

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